PNNL-13598

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Test Plan for the Demonstration of Geophysical Techniques for Single-Shell Tank Leak Detection at the Hanford Mock Tank Site—Fiscal Year 2001

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Summary

This report describes part of the testing for the Leak Detection, Monitoring and Mitigation program conducted by CH2M HILL Hanford Group, Inc. at the Mock Tank 105-A during FY 2001. The tests are being conducted to assess the applicability of these methods (electrical resistance tomography, high resolution resistivity, cross-borehole seismography, cross-borehole radar, and cross-borehole electromagnetic induction) to the detection and measurement of single-shell tank leaks into the vadose zone during planned saltcake dissolution operations. The testing in FY 2001 will result in the selection of up to two methods for further testing in FY 2002.

The Mock Tank is located in the 200 East Area of the Hanford Site and was used in 1995 and 1996 for early deployment of the electrical resistance tomography methods. Much of the infrastructure (primarily the tank, leak simulation system, and surrounding wells) from those tests will be used for testing in FY 2001. Six new wells (PVC and steel-cased, and sealed from the formation) will be drilled for insertion of geophysical instrumentation at specific locations around the perimeter of the tank. Baseline monitoring to establish background conditions and assess noise will be conducted during July 2001. Following the baselining period, 4,000 gal of a solution of sodium thiosulfate pentahydrate, an environmentally benign surrogate for single-shell tank wastes, will be released according to a specific schedule over a period of 2 weeks. The solution release rates, volumes, location, and timing of releases are planned so as to optimize the quantity and quality of information gathered to determine the capabilities of the methods for leak detection. Of primary importance in the testing is the determination of minimum time for a method to detect a leak, the method's capability to quantify leak volumes, the capability of the method to detect staged leaks (superimposed leaks), and an estimated cost of an operational system in a tank farm. Deployment of multiple methods will also provide an opportunity for comparison of results from independent data sets.

In parallel with the geophysical tests, a Partitioning Interwell Tracer Test study will be conducted simultaneously at the Mock Tank to assess the effectiveness of this technology in detecting and quantifying tank leaks in the vadose zone. Preparatory and background work using cone penetrometer methods will be conducted at the Mock Tank site and an adjacent test area to derive soil properties for groundtruthing purposes for all methods.

Acknowledgments

The authors extend their appreciation and recognition to the principal researchers whose knowledge and experience is at the heart of the testing represented by this plan. The researchers include Dr. William Daily and Dr. Abe Ramirez (Lawrence Livermore National Laboratory), Dr. Ernest Major and Dr. Michael Hoverston (Lawrence Berkeley National Laboratory), and Dr. James Fink (HydroGEOPHYSICS, Inc.). Appreciation is also extended to Mr. Jerry Cammann, CH2M HILL Hanford Group, for his unflagging project support and Dr. Wes Bratton, Dr. Joe Maresca, and Mr. Phil Ohl, Vista Engineering Technologies, L.L.C., for their special contributions and insight in technical specifications for the project. Sincere thanks are also extended to Mr. Michael Johnson, Pacific Northwest National Laboratory, for providing peer review, and Dr. Susan Narbutovskih, Pacific Northwest National Laboratory, for providing peer review and timely consultation.

Acronyms

bgs	below ground surface
BHI	Bechtel Hanford, Inc.
CEMI	Cross-Borehole Electromagnetic Induction
CHG	CH2M HILL Hanford Group
CPT	cone penetrometer techniques
DC	direct current
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office
EM-50	DOE Office of Science and Technology
EMSP	Environmental Management and Sciences Program
EPA	U.S. Environmental Protection Agency
ERT	Electrical Resistivity Tomography
FY	fiscal year
GW/VZ	Groundwater/Vadose Zone
HRR	High-Resolution Resistivity
I.D.	inside diameter
ILAW	Immobilized Low Activity Waste
LDMM	Leak Detection, Monitoring and Mitigation
Mock Tank	Mock Tank 105-A
PITT	Partitioning Interwell Tracer Test
PNNL	Pacific Northwest National Laboratory
PVC	
QA	Quality Assurance
RPE	Retrieval Performance Evaluation
RPP	River Protection Project
SBMS	Standards-Based Management System
SST	single-shell tank

TLDD	Tank Leak Detection Demonstration
VEA	vertical electrode array
VZTFS	Vadose-Zone Transport Field Study
WHC	Westinghouse Hanford Company
XBR	Cross-Borehole Radar
XBS	Cross-Borehole Seismic Tomography

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1.0 Introduction

In accordance with the M-45 series of milestones under the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement; Ecology et al. 1998), CH2M Hill Hanford Group, Inc. (CHG) will remove wastes from single-shell tanks (SSTs) and other miscellaneous underground tanks for storage in the double-shell tank system. Under the Tri-Party Agreement, CHG will demonstrate several retrieval methods as alternatives to past practice sluicing that use very little, if any, liquid to dislodge, mobilize, and remove the wastes. These retrieval methods include (1) low-volume density gradient saltcake dissolution, (2) robotic crawler-based confined sluicing, and (3) power fluidics, and pulsating mixing and pumping. Under the auspices of the U.S. Department of Energy (DOE) Office of Science and Technology (EM-50), efforts are also underway to develop and demonstrate dry methods for retrieval of wastes from potentially leaking tanks.

Because of the age of the SSTs, CHG is employing routine surveys and inspections to evaluate tank structural integrity, and has instituted administrative controls to protect tank structures from external disturbance (e.g., such as imposing load limits over tank domes). Additionally, CHG is performing interim stabilization activities and corrective measures to minimize the potential of waste leakage from the SSTs, and avoid mobilization of any potential contamination in the vadose zone. These activities include the removal of pumpable liquids from the SSTs (for transfer to the double-shell tanks), installation of run-on control barriers, and cutting and capping of raw water lines that cross the tank farms.

As additional assurance of protection of the vadose zone beneath the SSTs, tank wastes and tank conditions will be aggressively monitored during retrieval operations. Hence, significant effort is aimed at detecting, monitoring, and devising mitigation techniques for tank leakage. Identification of potential tank leaks may be made through in-tank methods (e.g., precise measurements of changes in tank volumes) or ex-tank monitoring by invasive or non-invasive methods. Thus far, in-tank measurement techniques may only be capable of reliably detecting leaks exceeding several thousand gallons, and operational ex-tank methods are currently limited to borehole logging techniques with extremely limited monitoring range (i.e., within tens of centimeters of the borehole).

Accordingly, CHG and their subcontractors have been evaluating a variety of potential ex-tank technologies in support of the development of a Leak Detection, Monitoring and Mitigation (LDMM) system for use during waste-retrieval operations. The LDMM strategy includes the use of a graded approach to apply increasing degrees of refinement to potential LDMM technologies, with the ultimate goal of applying these technologies to tanks whose integrity is more suspect and/or contain higher-risk chemical and radioactive constituents. Under the Tri-Party Agreement, LDMM provisions will be fully integrated with retrieval system designs. In support of this requirement, Retrieval Performance Evaluation (RPE) methodology was developed to guide risk-based decisions on both waste retrieval and LDMM system designs. The RPE methodology establishes retrieval-release criteria and target leak detection rates that will depend on the inventory of contaminants in the subsurface from past tank leaks, the potential for leakage/loss during retrieval, and inventories of wastes residuals in the SSTs after retrieval operations.

The ex-tank technologies are being evaluated in phases, beginning with small field-scale tests during fiscal year (FY) 2001 to demonstrate "proof-of-concept" under vadose-zone conditions approaching those actually found beneath an SST farm site. Hence, the phase described in this test plan will take place at Mock Tank 105-A (Mock Tank), a facility constructed to simulate an SST setting. Conceptual proof involves primary levels of experimentation with deployment of the chosen technologies within the Mock Tank environment. This early stage of testing is aimed at determining the bounds of operating parameters for the technologies, including whether a technology is at all viable in a simulated SST environment (see Objectives in Section 1.1). At this level of scrutiny, the desired, engineered applications of the technologies determine the ultimate direction of testing, but do not constrain testing parameters to a degree that would limit a complete appraisal of a technology's range of capabilities. Subsequent phases of testing will require more cognizance of engineered forms and operational considerations.

If the proof-of-concept phase is deemed successful, then additional Mock Tank site demonstrations may be conducted in FY 2002 for one or more of the most promising leak-detection techniques. This will be followed by testing to determine the range(s) of sensitivity of the technology(ies) in support of possible consideration in the retrieval technology demonstration (including LDMM design) for Tri-Party Agreement milestone series M-45 in May 2003, and for the design phase of a full-scale waste retrieval demonstration planned for FY 2005.

The Tank Leak Detection Demonstration (TLDD) described herein has been designed to provide data to determine the lower limits of sensitivity, including both minimum detectable effluent volume and time-to-detection, of five specific subsurface geophysical methods described below. The TLDD will also be helpful in assessing the interference of infrastructural features (e.g., transfer lines, pipes, electrical noise, etc.) with detection capabilities and identifying solute-retardation mechanisms likely to be present in SST environments.

The contribution of the TLDD will be maximized through integration with information from other ongoing site projects such as the Vadose-Zone Transport Field Study (VZTFS) (Ward and Gee 2000, 2001) and the Partitioning Interwell Tracer Test (PITT) (Gauglitz et al. 2001). Integration will lead to data sharing and subsequent cost reductions through coordination of these monitoring/characterization efforts. The PITT technology will be tested at the Mock Tank in coordination with the FY 2001 TLDD described in this test plan. A recent Environmental Management and Science Program (EMSP) workshop held in Richland in November 2000, affirmed the concept of integrating vadose-zone research activities that focus on processes controlling transport beneath Hanford waste sites. This information is needed not only to evaluate the risks from accelerated transport, but also to support the adoption of measures for minimizing the migration of contaminants to the groundwater and surrounding environments. The TLDD addresses these issues in the context of a tank environment involving either a gradual or sudden release of fluid.

1.1 Objectives and Scope

The principal objective of the test plan is to describe work to be performed by Pacific Northwest National Laboratory (PNNL), with the assistance of other investigators, for field-scale demonstrations of five geophysical techniques for leak detection at the existing Mock Tank site in the 200 East Area of the

Hanford Site. The five techniques selected for demonstration include (1) Electrical Resistivity Tomography (ERT), (2) Cross-Borehole Electromagnetic Induction (CEMI), (3) High-Resolution Resistivity (HRR), (4) Cross-Borehole Radar (XBR), and (5) Cross-Borehole Seismic Tomography (XBS). These geophysical techniques will be conducted to demonstrate "proof-of-concept" under conditions similar to those actually found in an SST farm setting. This work constitutes an experimental, initial phase of method evaluation. Specific objectives for this phase include:

- Acquiring a better understanding of each leak-detection technology's sensitivity to leaks (on a total-volume basis)
- Determining minimum response time for leak detection by each method
- Estimating a rough, "order-of-magnitude" cost of deployment for deploying an operating system around an SST
- Determining an optimum system configuration for best performance (borehole placement, electrode placement)
- Selecting the method(s) that offers most promise for eventual deployment in a tank farm.

While FY 2001 leak quantification efforts will focus on a "total volume" determination, subsequent work on down-selected geophysical methods will require determination of leak *rates* to fully support RPE criteria. The follow-on work in FY 2002 and beyond will involve quantification of leak rates.

The test plan also describes the planning and method-selection criteria, site preparation and construction, deployment and operating schedule, and all required documentation for proper conduct for the observance of safety, and the protection of human health and environmental resources. In parallel with this test plan, specifications for the performance of the solution-release portion of the testing and overall program objectives have been described by Vista Engineering Technologies, L.L.C. (2001). The key applicable aspects of these specifications are presented in Appendix D. The Engineering Evaluation Plan (in preparation by Vista Engineering Technologies, L.L.C.) will address out-year planning for down-selecting geophysical methods and strategies for further testing of the selected methods.

Although a separate project, the PITT testing in FY 2001, which is planned concurrently at the Mock Tank site, will be coordinated with the geophysical testing described here. Elements of the coordination between these simultaneous efforts are described in Section 4.7.

1.2 Method Selection and Evaluation Criteria

Although the phase of testing described in this plan is experimental in character, the eventual goal of the LDMM program is to derive an engineered application of an external (outside of a tank) leak-detection technology that is appropriate and cost-efficient for SST farm deployment. Hence, testing in FY 2001 will focus on elements of performance that eliminate some methods from further consideration and establish more refined testing protocols for methods that show greater potential for SST deployment.

Criteria for method performance are concerned with adaptability of the method to the physical environment of a tank farm, the cost of system deployment, and the overall reliability of the technique in comparison to alternative detection and monitoring methods. More specific criteria that will be considered in the ultimate selection of methods for further development include:

- *Accuracy*: Is a solution release (leak) detectable by the method; if so, how does the (test) volume released compare with the volume indicated by the method?

- *Precision (reliability)*: Can the method consistently detect a leak with acceptable probabilities of false detection?

- *Engineered Practicality*: What are the logistical and practical constraints to deploying a system derived from the method within a SST farm (e.g., can existing infrastructure and wells be used successfully, or are more invasive procedures needed to install an effective system)?

- *Status of Development*: What level of effort will be required to develop the method into an effective monitoring system?

- *Versatility*: What scenarios of tank leakage will the method be likely to successfully address (e.g., will the engineered system be capable of detecting multiple leak points or recurrent leaks superimposed over previous leaks in the soil, or operate with variable levels of noise)?

These criteria will be considered, as feasible, at each stage of the testing and in the data-interpretation period following the FY 2001 tests, although it is unlikely that they can be fully addressed at the current experimental stage. It is assumed that a weighted matrix of performance under these criteria, or an expanded set of criteria, will be used to assign relative values of preference to each method.

Of the criteria listed above, perhaps the most important is the method's ability to avert false alarms. False alarms would have detrimental implications for waste retrieval operations and other tank-related activities, and, as such, must be avoided. The precedent for deriving probabilities for false alarm, using U.S. Environmental Protection Agency (EPA) methodology, has been presented by Vista Engineering Technologies, L.L.C. (2001), but those tests may not be readily applicable to the tank-external LDMM work, particularly in the FY 2001 testing. However, the strategic goal for method precision to satisfy LDMM requirements is to establish a 95% probability of leak detection, with no greater than a 5% false alarm rate. Part of the continuing evaluation of methods will include the identification of feasible approaches to deriving false alarm probabilities.

Because ERT is considered a more highly developed technology for the purposes of tank leak detection, the expectations for this method are somewhat greater in terms of defining the minimum leak detectable and estimating the volume of the leak. Although ERT was deployed at the Mock Tank in 1995 and 1996, some system improvements have been added, and additional value will be realized in the FY 2001 testing through comparison with other methods.

1.3 Project Linkage and Integration

The Hanford Groundwater/Vadose Zone (GW/VZ) Integration Project was established to integrate Hanford's entire groundwater and vadose-zone activities. The detailed test plan of Ward and Gee (2001) outlines important project linkages between the VZTFS, and other site activities, including the River Protection Project (RPP) characterization work, the 200 Area Soil Remediation Project, the Immobilized Low Activity Waste (ILAW) project, and specific EMSP activities that are focused on Hanford. These projects add critical information and guidance to the project described below (see Section 2.4.2).

2.0 Test Site Description

The TLDD will be conducted at the Mock Tank 105-A ("Mock Tank) in the 200 East Area of the Hanford Site (Figures 2.1 and 2.2). The Mock Tank was constructed in 1994–1995 for the purpose of testing the applicability and effectiveness of an array of electrical resistivity sensors in providing tomographic imaging of simulated fluid leaks beneath the tank. This section describes the existing conditions and infrastructure at the Mock Tank.

2.1 Soils and Vegetation

The soil at the Mock Tank is dominantly blow sand and disturbed Hanford formation sand and gravel. Disturbance from the access road and tank construction has partially denuded the vegetative cover at the site. In relatively undisturbed portions of the site, the dominant plants are Sandberg's bluegrass, cheatgrass, and gray rabbitbrush (see Appendix B).

2.2 Stratigraphy and Hydrogeology

The details of the stratigraphy and hydrogeology of the 200 East Area have been described by numerous authors over the years of Hanford Site operations, with the most recent and authoritative including Reidel et al. (1992), Lindsey et al. (1992), and Williams et al. (2000). Stratigraphy and lithologic descriptions specific to the Mock Tank were provided in an informal report by K. A. Lindsey in 1995[1] as support for ERT at the DOE Hanford Site (Narbutovskih et al. 1996a).

Surficial sediments at the Mock Tank consist of a thin veneer of dune sand up to 1 m (3 ft) thick. Fluvial (catastrophic floods) sand and gravel of the Pleistocene Hanford formation extend from about 1-m (3.3-ft) below ground surface (bgs) to greater than 120-m (400-ft) bgs. Lindsey described some of this section as Pliocene/Miocene Ringold Formation sand and gravel, but Williams et al. (2000) interpret this area to be scoured by Pleistocene flood events, and thus, the entire section to be underlain by the less-consolidated Hanford formation sediments. The sediments, in turn, overlie the basalt flows of the Miocene Columbia River Basalt Group.

The only detailed lithologic records of the subsurface at the Mock Tank are those of Lindsey's unpublished report that were derived from borehole drilling for the ERT investigation by Narbutovskih et al. (1996b). These borings each extended to approximately 55-m (180-ft) bgs, with the nearest (B2469) located approximately 24 m (80 ft) from the eastern edge of the Mock Tank. The visual descriptions and interpretations by Lindsey were also supported by neutron and natural gamma logging. Figure 2.3 illustrates the lithologies encountered in this borehole, which may be regarded as representative of conditions beneath the Mock Tank.

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[1] K. A. Lindsey. 1995. "Geologic Setting of the Electrical Resistivity Tomography and Seismic Tomography Test Stie, 200 East Area," unpublished data.

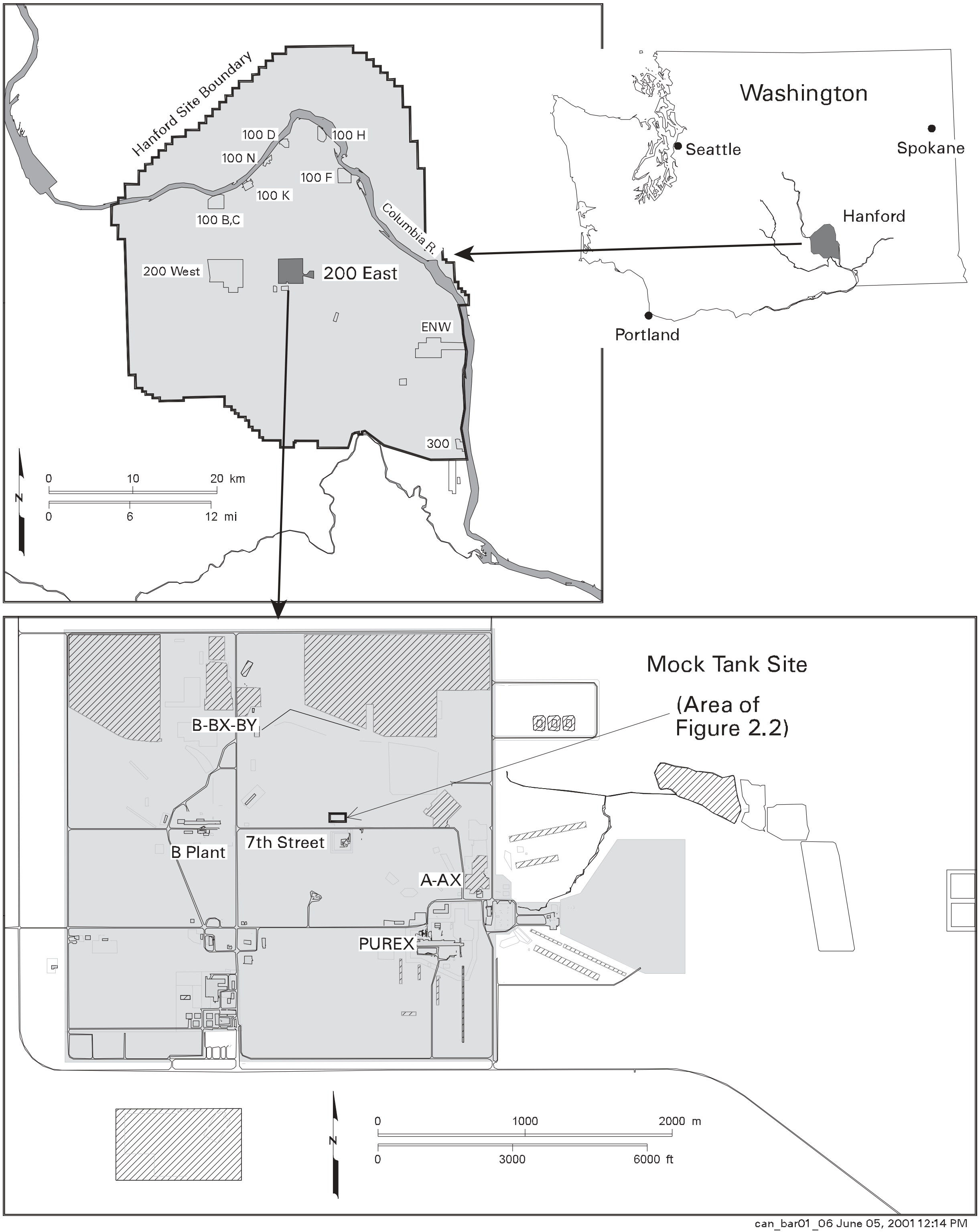

Figure 2.1. Location of the Mock Tank 105-A Site

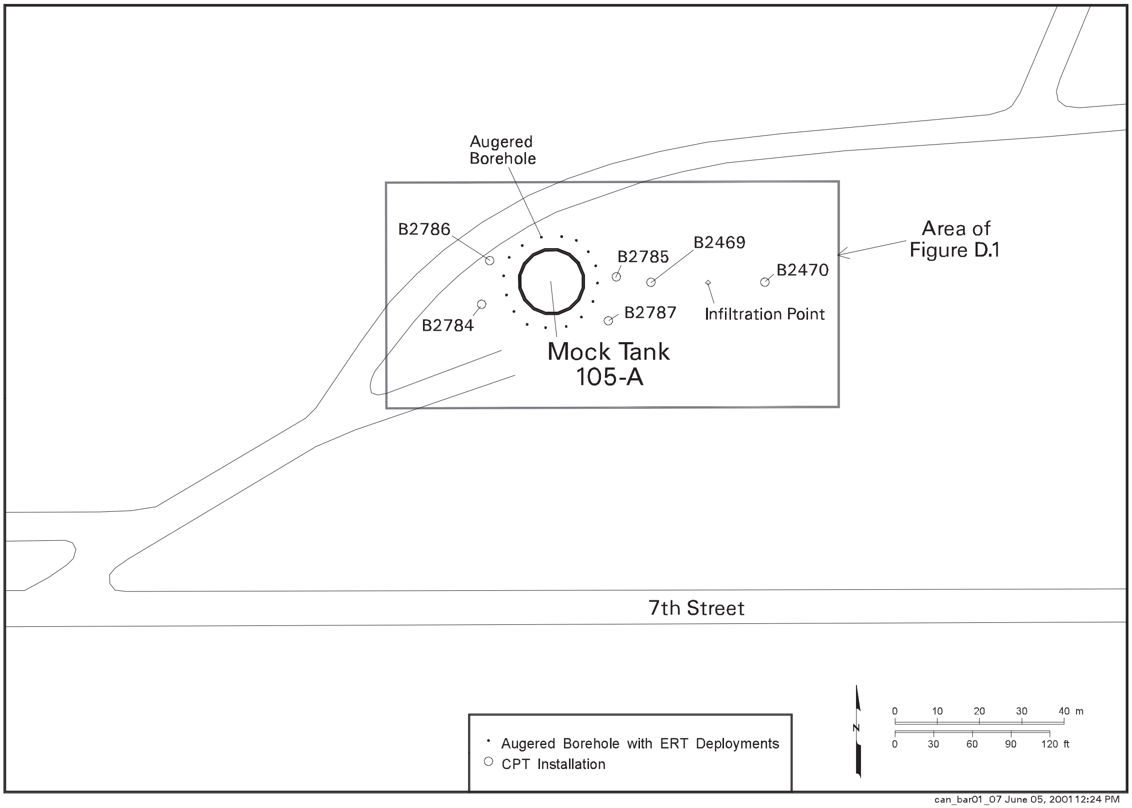

Figure 2.2. Location and Configuration of the Mock Tank Site, Showing Existing Boreholes and Infrastructure

Although the lithologic log of the zone represented in Figure 2.3 is divided into 10 layers for descriptive purposes, the sediments are dominated by medium sand throughout, with variable amounts of gravel. This zone is occasionally punctuated by thin horizons of silt and clay or calcareous silt (e.g., at 50 m [164 ft]). These thin, fine-grained, or indurated layers may have a retarding effect on downward movement of groundwater or applied solution.

The water table occurs at approximately 88-m (290-ft) bgs beneath the Mock Tank. This estimate is derived from well 299-E24-8, which is the nearest well with routine water-level data, located approximately 2 km (1.24 mi) west of the Mock Tank. The base of the unconfined aquifer in this area occurs at approximately 120-m (394-ft) bgs at the basalt-sediment contact (Williams et al. 2000). The water table in this area has fallen approximately 3.5 m (10 ft) in the last 10 years (through CY 2000), as a result of the discontinuation of effluent discharges to the ground in the 200 East Area.

2.3 Existing Infrastructure

Since the Mock Tank was used for extensive testing from 1994–1996, much of the infrastructure created for those tests has been left in place. Boreholes and ERT installations put in place in 1995 are still

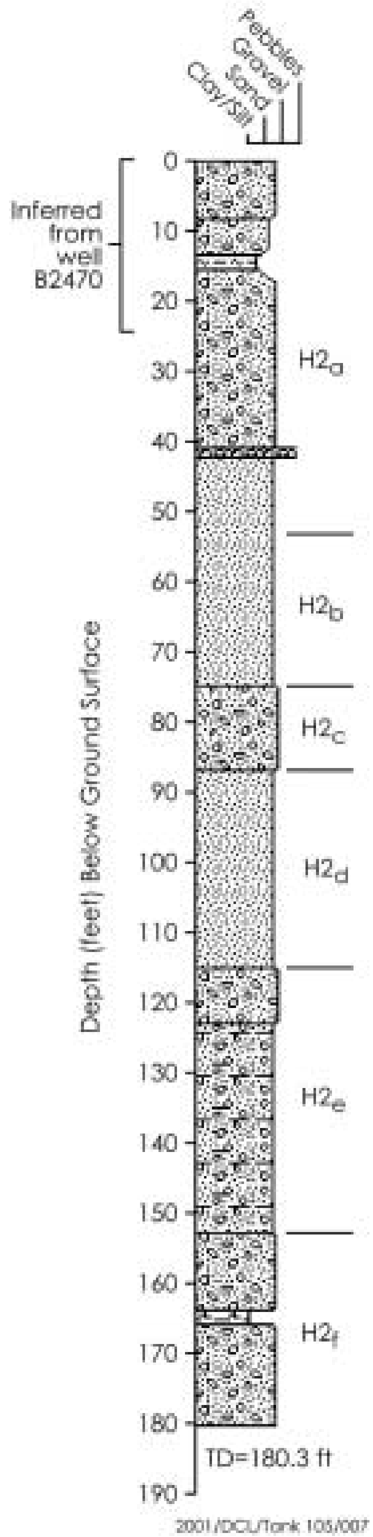

Figure 2.3. Representative Stratigraphy of the Mock Tank Site Based on Lithologic Logs of Wells B2469 and B2470 (see Figure 2.2 for location)

serviceable and are planned for use during the 2001 TLDD. This section describes the existing features of the site that will have continuing importance to the FY 2001 study.

2.3.1 Construction Details of the 105-A Mock Tank

Primary design features of the Mock Tank are illustrated schematically in Figure 2.4. Figure 2.5 is an oblique aerial view of the site, showing the ERT array installed in 1995. The primary function of the

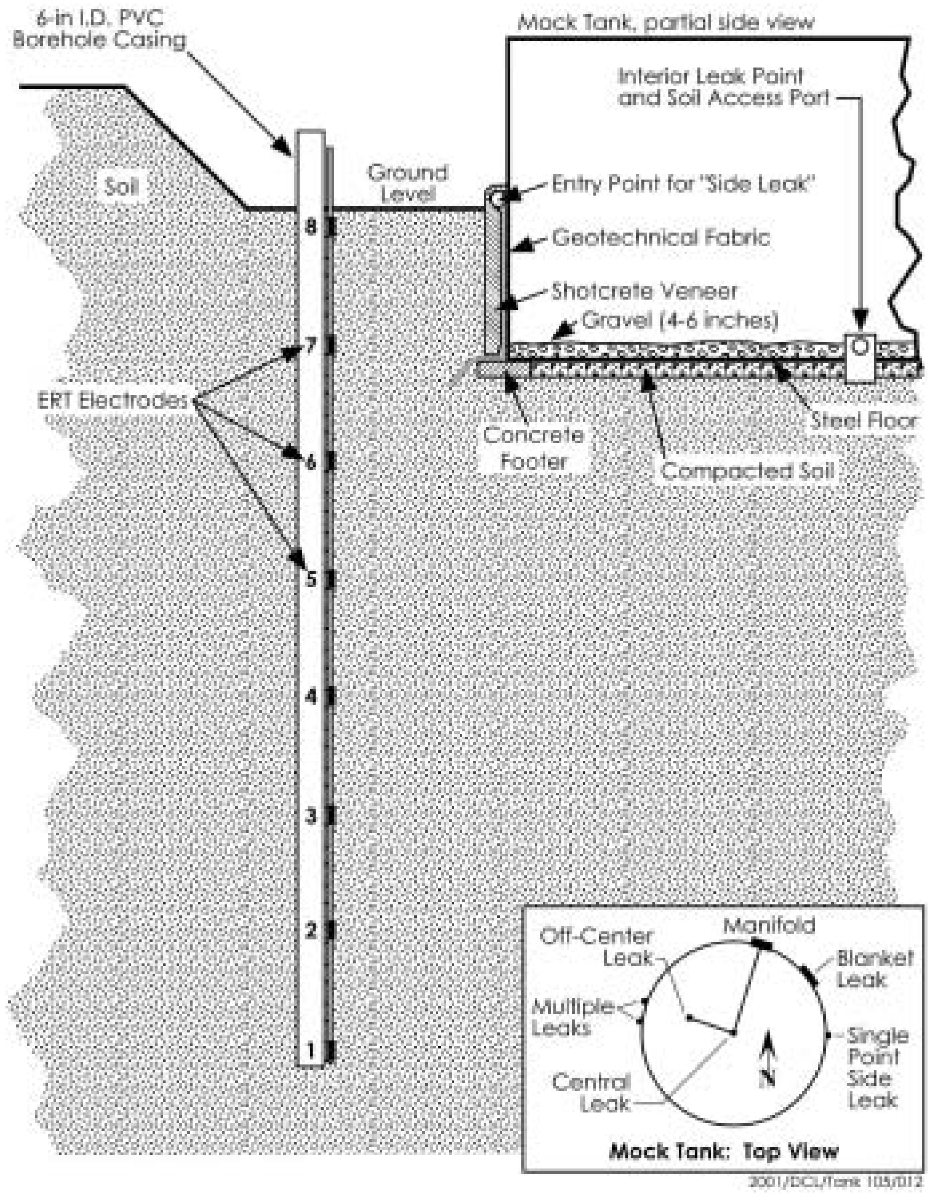

Figure 2.4. Principal Design Features of the Mock Tank, Showing One of the Sixteen ERT Installations Surrounding the Tank. The tank is outfitted with multiple leak points to simulate several tank-leak scenarios.

Figure 2.5. Oblique Aerial View of the Mock Tank Site Showing the 1995 ERT Array and Related Infrastructure

Mock Tank was to simulate leaks at various points around an SST. As such, it was constructed with a distribution manifold of pipes that directed water or solutions to five separate, simulated leak points.

The 0.32-cm (0.125-in.) steel wall of the tank is 15.24 m (50 ft) in diameter and rests on a 15.24-cm (6-in.) thick, 45.72-cm (18-in.) wide concrete footer located approximately 1.5 m (5 ft) below grade. A layer of shotcrete and geofabric coats the lower portion of the tank wall and contains piping for the exterior leak points.

Because the ERT method was the first to be considered for leak detection at the Mock Tank, many of the tank's features were designed with that technology in mind. Most notably, the 0.32-cm (0.125-in.) steel floor of the tank was tack welded together to provide electrical continuity, and a 10-to-15-cm (4-to-6-in.) gravel layer was spread over the steel bottom to ensure contact with the compacted soil underneath. Also, a leveled, backfilled surface was provided around the periphery of the tank to allow installation of the 16 ERT electrode arrays. The presence of the conductive tank embedded in the relatively resistive soils results in a contrast in resistivity of 10 orders of magnitude (Ramirez et al. 1995), resulting in a pronounced shunting of current through the tank. Experimental work with scale models of buried tanks (Daily et al. 1995) indicated that ERT methods would still be able to detect fluid leakage in the presence of these contrasting materials, and, in part, helped guide the construction details of the tank.

2.3.2 Comparison of the Mock Tank with SSTs

Although the Mock Tank was constructed to simulate the electrical profile of an actual SST, some differences are especially noteworthy. The “100”-Series SSTs are 22 m (75 ft) in diameter and are from 10 to 13 m (30 to 40 ft) in height (profile). The steel interiors of the tanks are encased in concrete—a condition that could enhance the detectability of a leak by electrical methods. The SSTs are covered by concrete domes and are completely buried beneath 2 to 3 m (6 to 10 ft) of fill soil (WHC 1992). In contrast, the steel walls of the Mock Tank are exposed to the soil and are almost completely above ground level. Also, the SSTs contain varying amounts of waste, and in other respects (proximity to adjacent tanks, infrastructural details of the farms, etc.) are each unique structures that will probably represent unique monitoring challenges for geophysical technologies.

Hence, while the primary difference between actual SSTs and the Mock Tank may be that of scale where the responses of geophysical methods are concerned, other differences are at present non-quantifiable and may require modeling and/or further testing in more realistic settings. In general, the larger size of the SSTs, the greater depth of leak detection required because of the subsurface locations of the tanks, and the complex infrastructure within a tank farm (including adjacent tanks) may create greater challenges for most methods compared with the Mock Tank.

Two 2,500-gal, above-ground tanks (see Figure 2.5) were provided to hold the water, or other solution, that could be used as a leak simulant. The tanks were positioned within 30.5 m (100 ft) of the tank at a height of approximately 1.2 m (4 ft) above the leak-point manifold on the north side of the tank. Flexible hose connected the supply tanks with the manifold via quick release and screw-on connectors. The two supply tanks were connected by piping that allowed transfer of solutions between tanks and mixing within one of the tanks (west position tank).

2.3.3 Existing Boreholes and Instrumentation

The ERT array installed in 1995 consists of 16 boreholes, each completed with 15.24-cm- (6-in.-) inside-diameter (I.D.) polyvinyl chloride (PVC) casings to a depth of 10.7 m (35 ft). The casings were sealed at the bottom so as to be isolated from the soil environment. To the outside of the 15.24-cm (6-in.) casings were strapped a smaller tube upon which were mounted eight electrodes (see Figure 2.4). This array is still in place and appears to be in serviceable condition. A continuity check of the wiring at the surface of two of these boreholes indicates that the installations are still usable for future tests.

Four ERT installations emplaced by the cone penetrometer technique (CPT) lie immediately outside the 16-hole array east and west of the Mock Tank (see Figure 2.2). Approximately 25 m (82 ft) east of the Mock Tank are a set of two CPT-installed boreholes with a central infiltration well, termed the “RCRA Wells Site.” The installations (B2469 and B2470 in Figure 2.2) were emplaced in 1996 and consist of a vertical electrode array (VEA) in each well to a depth of approximately 49 m (160 ft).

2.4 Summary of Previous Work

2.4.1 Previous Work at Mock Tank Site

Leak-detection studies at the Mock Tank site were conducted from 1994 through 1996 (Ramirez et al. 1995; Ramirez et al. 1996; Narbutovski et al. 1996a, 1996b). In 1994 and 1995, VEAs installed in sixteen boreholes around the Mock Tank (see Figures 2.2 and 2.5) were used to evaluate the performance of ERT as a leak detection method using injections of saline solution through the tank leak points (see discussion in Appendix D). An example of one of these sixteen arrays in relation to the Mock Tank is shown in Figure 2.4.

Both the 1995 and 1996 studies consisted of releases of 0.08 molar saline (NaCl) solutions at different leak points within the Mock Tank.

In the 1995 study (Ramirez et al. 1995), three release/monitoring events were staged. The first consisted of 3,800 L (1,004 gal) of solution released at a rate of 26 L/h (9.5 gal/h) at the side leak location at the northeast portion of the tank (see inset Figure 2.4). The second release of 1900 L (502 gal) was conducted at the center release point at a rate of 3.2 L/h (0.85 gal/h). A third release was discharged at the off-center leak location, but was aborted because of difficulties with the release system. The leaks were imaged using the 16 auger-hole ERT array shown in Figure 2.2.

An additional two wells drilled to 49 m (160 ft) were emplaced east and west of a central infiltration point in an area immediately east of the Mock Tank (wells B2469 and B2470 of Figures 2.2 and D.1). These were completed with a 9.65 cm (3.8 in.) PVC casing and fitted with an array of electrodes at intervals of 3 m (10 ft). This testing was aimed at determining the effectiveness of ERT in mapping vadose-zone plume-migration monitoring apart from tank-leak scenarios. Some success was achieved in imaging the downward migration of a saline plume with ERT at this site, but an attempt to deploy a cross-hole seismic system in these wells failed because of compromised well seals.

During 1996, additional VEA installations were emplaced near the Mock Tank using CPTs in the configuration shown in Figure 2.2. These were used to not only perform additional ERT evaluation, but also as a technology transfer using the CPT as an installation method. As a preliminary phase of the work in 1996, two sealed boreholes were installed immediately east of the Mock Tank (wells B2469 and B2470; see Figure 2.2) for testing the CPT VEA installation process.

Later in 1996, an additional four VEAs were installed east and west of the tank (wells B2784 through B2787 in Figure 2.2) outside of the original 16 installations. These arrays were installed to a depth of 30.5 m (100 ft), and have eight electrodes equally spaced on each array (Narbutovskih et al. 1996b).

The blanket leak point on the northeast portion of the tank (see Figure 2.4) was used in the 1996 study (Narbutovskih et al. 1996a) to receive 11,500 L (3,000 gal) over a period of 12 days at rates between 30 to 40 L/h (8 to 10 gal/h). For this study, the four CPT-emplaced electrode arrays (wells B-2784 through B2787 in Figure 2.2) were used for generating two-dimensional tomographic images of the leak.

2.4.2 Related Work at the VZTFS Site

Recent and ongoing experimentation with several subsurface vadose-zone plume-detection techniques, including the geophysical methods considered in this plan, is the subject of work at the VZTFS site (Sisson and Lu site). The VZTFS site is approximately 1,200 m (3,937 ft) south of the Mock Tank site in the 200 East Area (Figure 2.6).

This work began in FY 2000 and continues at present (June 2001). The prime focus of this study is to evaluate mass balance and migration characteristics of a simulated tank leak in the subsurface for vadose-zone transport modeling purposes. A secondary objective is to evaluate emerging measurement techniques for non-invasive or semi-invasive vadose-zone characterization (Ward and Gee 2000; Ward and Gee 2001). These techniques include isotopic tracers, neutron probe, advanced tensiometers, core sampling, and the five geophysical techniques (ERT, XBR, XBS, CEMI, and HRR). Although mutually supporting, objectives of the work at this site differ from testing at the Mock Tank site in that it seeks to identify dominant transport mechanisms on a detailed scale in typical Hanford soils and hydrogeologic

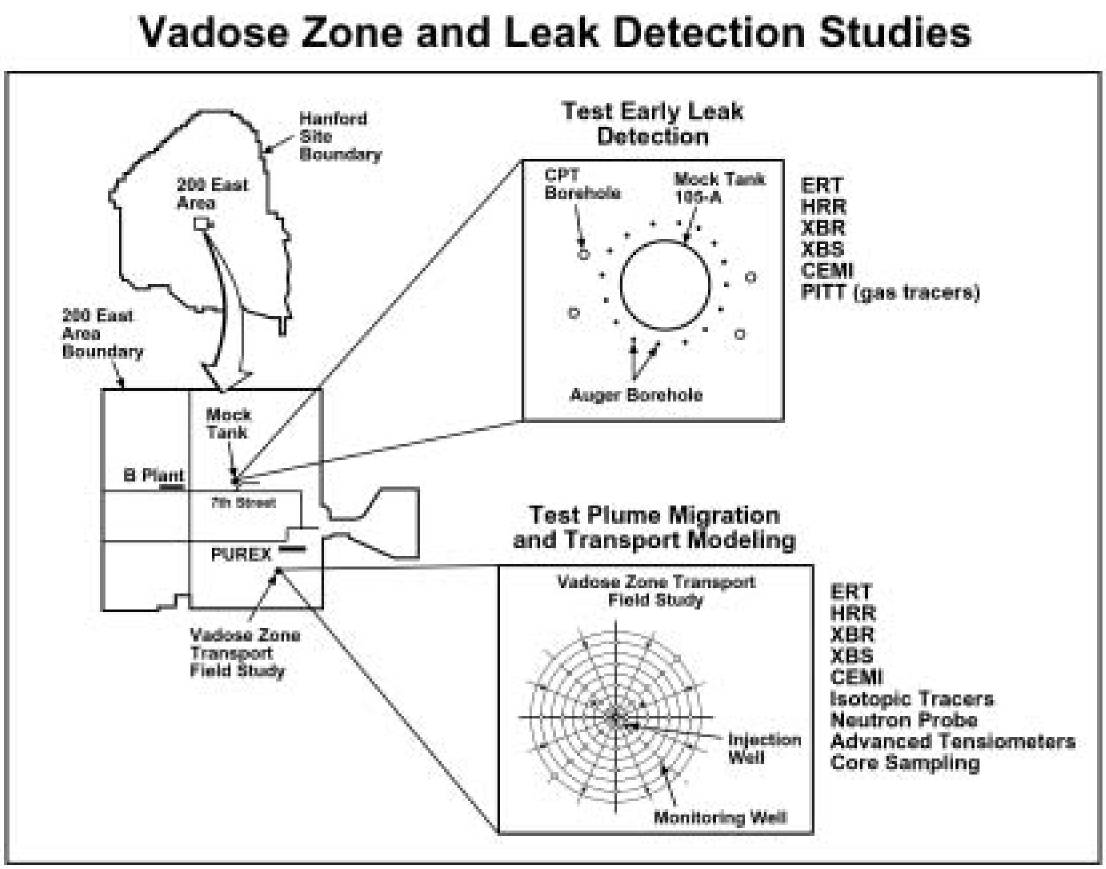

Figure 2.6. Relative Locations on the Hanford Site and General Layouts of the VZTFS and Mock Tank Sites, Listing Experimental Methods Used at Both Sites

conditions. Identifying these mechanisms will reduce uncertainty in conceptual models and allow development of a detailed and accurate database of flow and transport parameters for numerical model validation.

The physical layout of the site is most recently described by Ward and Gee (2001) and consists mainly of a circular array (approximately 17 m [56 ft] in diameter) of 32 steel-cased wells, numerous instrumentation boreholes for the methods noted above, and infiltration points for plume introduction. Several split-spoon and CPT wireline cores have also been taken of the site, thus providing overall the most exhaustively characterized section of *in situ* vadose-zone materials on the Hanford Site.

Although data analyses for the geophysical methods are as yet incomplete, results thus far from the FY 2000 and FY 2001 VZTFS site show that subsurface features (bedding planes and horizontal layers of fine-textured sediments) control the flow and cause significant lateral spreading of the plume. Deep penetration (below 12 m [39 ft]) did not occur in FY 2000 after more than 18,930 L (5,000 gal) of Columbia River water was injected into the subsurface. No deep penetration was observed in FY 2001 until about 30,000 L (8,000 gal) of fluid of 36 weight percent sodium thiosulfate solution, followed by 11,360 L [3,000 gal] of Columbia River water) were injected. Penetration of the dense thiosulfate solution to a depth of 18 m (59 ft) is attributed to the unique properties of the fluid. However, the exact cause of observed fingering, seen as localized penetration of fluid, is still being investigated. The geophysical methods (ERT, HRR, and XBR) tested in FY 2001 were all shown to be capable of detecting the salt injection. Resolution varied according to the method used. Details of the results will be presented in a PNNL report scheduled for distribution in September 2001.

3.0 Geophysical Monitoring Technologies

The methods selected for testing are based on proven technologies that have been used, in one form or another, for many years and within many industries. These methods also have recent application history at the Hanford Site (e.g., Ward and Gee 2001). Adaptations of these technologies have produced specific approaches that offer even greater promise for detecting leaks, potentially of very limited volumes and within short time frames. The Vadose Zone Advanced Characterization Workshop held in January 2000 addressed numerous potential methods for external tank-leak detection, including the geophysical methods discussed below (see http://webdev.pnl.gov/vadose/workshops.asp). Partially as a product of this meeting, along with their favorable historical application to problems identical with, or similar to, tank-leak detection, these methods have been selected for further demonstration at the Mock Tank Site in FY 2001.

Electrical and electromagnetic geophysical methods have long been used as mineral and groundwater exploration techniques, being deployed in both boreholes and as large surface arrays or moving surveys to define ore bodies or aquifer characteristics. Similarly, numerous seismic methods have been used for decades in defining subsurface conditions. Advances in data processing/computing capabilities and electronics have allowed refinements of these methods. More recent methods involve deployment in conjunction with vertical borehole arrays around specific targets of more limited size (such as underground tanks) and tomographic processing and display of results. These developments allow three-dimensional, volume-integrating representations of subsurface features, specifically, contaminant plumes in the case of tank leaks. When applied over time intervals, the methods allow depiction of transient features, such as developing and migrating contaminant plumes. The essential characteristics of these advanced methods are described below.

The process of selecting and eliminating geophysical monitoring technologies with application to problems at Hanford is described by Ward and Gee (2000). Those technologies and methods determined to be appropriate for further evaluation are described below. Elements of quality control, such as signal-to-noise analysis and method-performance criteria, are discussed in Appendix D for each method. By deploying multiple methods during the testing at the Mock Tank, it is expected that inter-method comparisons will be made to provide independent verification of results.

The summary descriptions of the techniques discussed below are adapted from Ward and Gee (2000), Ward and Gee (2001), and descriptions provided by the geophysical researchers (see Acknowledgments). Table 3.1 summarizes the applicability, measured properties, sources of error, and spatial resolution of the techniques.

3.1 Electrical Resistivity Tomography

Ramirez and his colleagues described the method of ERT data collection and processing in detail (e.g., Ramirez et al. 1993). LaBrecque et al. (1996) described the forward and inverse modeling codes The forward solution is implemented using the finite-difference technique with Newman boundary

Table 3.1. Characterization and Monitoring Technologies Selected for FY 2000 Field Tests

Method	Application	Properties Measured/Derived	Resolution	Status	Sources of Noise or Error
Electrical Resistivity Tomography	Monitor changes in bulk resistivity	DC electrical resistivity	≥1 m	Continuous monitoring of resistivity in either a plane or a volume. Requires the installation of a series of electrodes in at least two monitoring wells. Now commercially available.	Electrical signal associated with HRR or motor generators, utilities, etc.
Cross-Borehole Radar	Moisture distribution, lithology, soil disturbances, buried materials	Dielectric permittivity	5–60 cm depending on frequency	Depth of penetration may be quite limited (<30 cm) if formation is electrically conductive; it can be as high as 9 m in nonconductive formations. Measures continuous vertical profile. Interpretation may be difficult in complex situations.	Metallic objects in imaged medium may interfere with interpretation; will not penetrate steel casing. Zones of low resolution near bottom and top of tomograms.
Cross-Borehole Seismic Tomography	Porosity, mechanical rock properties, lithology	Compressional and shear travel times, fracture estimation	≤15 cm	Most systems require fluid-filled borehole. All require either open hole, or good contact between casing and formation.	Potential limited range. Effective transducer coupling may require water columns of 76 m or more. Borehole compensated.
Cross-Borehole Electromagnetic Induction	Moisture distribution, identification of shallow contaminant plumes, lithology through steel casing	Electrical conductivity, Dielectric permittivity	1.5–>4.5 m	Measurements can be made rapidly. Depth of investigation is 1–60 m. Can measure continuous profiles.	Sensitive to signal interference from transmission lines, radio frequency sources if not identified. Cannot operate with ERT and HRR.
High-Resolution Resistivity	Moisture, lithology, geologic structure, buried materials, identification of shallow contaminant plumes	DC electrical resistivity	>1 m	Rapid measurements. Can measure continuous profiles to a depth of -60 m. Improved data acquisition and incorporation of topography into volume calculations.	Sensitive to signal interference from transmission lines. Electrodes require sufficient contact with formation. Positional control is crucial.

conditions at the ground air interface and Dirichlet boundary conditions along the other faces of the cube. The inverse solution employs an objective function, which aims to minimize data misfit and model roughness. The minimization of the objective function is done iteratively.

ERT has been demonstrated to be a useful characterization tool, providing details of the lithostratigraphy between wells (e.g., Newmark et al. 1994), subsurface processes such as fluid infiltration (Daily et al. 1992), and steam injection and ohmic heating (Ramirez et al. 1993) by mapping the spatial and temporal changes in soil resistivity resulting from changes in liquid saturation and temperature. Because tank wastes at Hanford are generally rich in high-ionic-strength electrolytes, resistivity should be an ideal surrogate for locating difficult-to-detect contaminants. In general, ERT has been conducted using a cross-borehole geometry, using multiple electrically-isolated electrodes placed in vertical arrays. This geometry has the potential to produce relatively high-quality, high-resolution images when the aspect ratio of vertical to horizontal spacing is equal to or greater than 1.5:1.0. Typical electrode installations involve multiple electrodes strung on nonconductive casing (e.g., plastic or fiberglass) in conventionally installed boreholes, or as instrumentation strings installed using cone penetrometers. Both designs have been effective in shallow to moderate depths (most recently >395 m [1,296 ft]), but deeper installations require significant and more costly modifications.

The capability to obtain ERT images using existing conventional steel casings would increase the applicability of the technique and make it particularly useful for deployment in tank farms. Recent simulations of ERT with vertical casings as electrodes show that there is a distinct signature indicative of the changing resistivity across the field, which is well above the noise level in the simulations. However, vertical resolution may be limited (Newmark et al. 1994).

3.2 Cross-Borehole Radar

Cross-Borehole Radar (XBR) measurements provide information about the porous medium (sediments) between two boreholes. Radar is analogous to the seismic reflection technique, except that radar (microwaves) is used rather than acoustic waves. The primary information obtained is the variation of dielectric properties of the subsurface. Because of the large contrast in the dielectric constant between water (κ = 80) and most earth materials (κ = 3 to 5), volumetric water contents can be easily inferred from radar data (Hubbard et al. 1997). Also inferred is the lithology and distribution of different soil types. Media with strong discontinuities (e.g., fracture zones) delay pulse arrival times and attenuate the transmitted radar pulse. The late arrivals and reduced-pulse amplitudes are measured and analyzed using tomographic processing. Even later arrivals from reflectors are also analyzed. The velocity and amplitude of the data are recorded as a function of time, resulting in a series of data in the time domain. However, the data are often reduced to the frequency domain to infer attributes of the data indicative of various subsurface properties. Normally, numerous rays are measured, and the data are usually collected in a tomographic mode, which is then inverted to provide a tomogram of either velocity or attenuation properties. The data can also be collected in a more rapid fashion in a limited crosshole configuration. The data can also be processed to give reflection images in stratigraphic sequences.

3.3 Cross-Borehole Seismic Tomography

Cross-Borehole Seismic Tomography (XBS) involves measuring the travel time of seismic energy transmitted between two or more boreholes to derive information on the dynamic elastic properties of the intervening porous medium (Majer et al. 1997). Such data can then infer lithology, bed geometry and continuity, fracture and fault properties, porosity, and in some cases, the fluid distribution. The Mock Tank tests will use a transmitter in one hole and either single or multiple receivers in an adjacent hole or holes. Energy is transmitted at multiple positions in the transmitter well and received in the receiver well(s) with sensors. In practice, a three-component wall-locking geophone and a directional downhole seismic source are initially lowered to the bottom of two boreholes. The two probes are then moved together in intervals of 30 to 60 cm (12 to 24 in.) so that a near horizontal ray path is maintained between them. Average shear (S) and compressional (P) wave velocity values are obtained by calculating wave travel times between the source and receiver boreholes. The accuracy of the data requires that the boreholes be installed as vertically as possible and be cased with steel or PVC. The technique requires that the boreholes be sealed at the bottom so they can be filled with water. At the Mock Tank site, PVC-cased boreholes are already in place, but their verticality is unknown. The bottoms of these wells are sealed. In the case of existing steel wells at tank farms, inflatable packers that can be removed after the test could be used to seal the boreholes. A deviation survey will first be run to determine the verticality of the boreholes. Measurements will be made of background conditions before solution release at the mock tank site, at intervals during the releases, and at the end of the periods of release.

3.4 Cross-Borehole Electromagnetic Induction

Cross-Borehole Electromagnetic Induction (CEMI) uses the principle of induction to measure the electrical conductivity of the subsurface between two boreholes. The technique can provide high-resolution images of the subsurface between existing wells up to 1,000 m (3,280 ft) apart. The CEMI system consists of a transmitter deployed in one well and a receiver deployed in a second well. The transmitter uses a vertical-axis coil wrapped with 100 to 300 turns of wire tuned to emit a single low-frequency sinusoidal signal that induces currents to flow in the surrounding soil. The optimum operating frequency depends on borehole separation and background resistivity, but generally the frequency ranges between 40 to 100 kHz. A frequency that is too low limits the resolution, while one too high limits the range of the measurement. At the receiver borehole, a custom-designed coil detects the total magnetic field, consisting of the magnetic field from the induced currents in the medium as well as the primary magnetic field generated by the transmitter. The receiver section consists of a magnetic field sensor and a commercial lock-in amplifier located at the surface. The lock-in amplifier operates like a radio by measuring only those signals that are coherent with the transmitted signal while rejecting incoherent background noise. By positioning both the transmitter and receiver tools at various levels above, below, and within the zone of interest, images of the resistivity distribution between the wells can be generated. The data are interpreted by inverse modeling to produce a tomogram.

The Mock Tank field study will explore the ranges and sensitivity of CEMI to a tank-leak simulation of limited size. The operation frequency of the antennas are from 100 to 200,000 Hz. The PVC wells will allow the highest frequencies to be collected while the steel-cased wells will admit, at most, 1000 Hz.

3.5 High-Resolution Resistivity Tomography

Electrical surveys undertaken by a direct current (DC) resistivity device involve placement of electrodes in the ground. There are various geometries for the electrode layout, but most have all four electrodes in line. The Wenner and Schlumberger arrangements are the most popular. The two outer electrodes are the current source and sink; self-contained batteries drive current. The two inner potential electrodes sense the electrical potential at the surface while current is flowing between the outer electrodes. The potential measured varies with electrode spacing in a predictable way and also changes as the strata and contained fluids vary laterally and vertically. HRR is an evolutionary development in DC electrical resistivity differing from conventional, industry-standard approaches by modification of the field-data acquisition procedures (Fink 1980, 1994) and subsequent data processing (Fink 2000). Determining the volume under investigation gives a physical basis for the manner in which the data are presented. HRR has proven itself in extremely rugged terrain by incorporating the topography into the volume calculations. HRR is particularly useful in mapping the distribution and time-dependent changes of moisture in the subsurface. HRR is optimally based on the pole-pole electrode geometry, but may be derived from any array of electrical sensors, including steel well casings.

In general, two modes of operation are common: (1) depth sounding and (2) profiling. In the depth-sounding mode, all four electrodes are placed in the ground initially with very short spacing between adjacent electrodes. A reading is taken, and then the array is reset with an incremental increase in spacing. Another reading is taken, and the array is, in turn, progressively expanded in this manner until the maximum depth to be investigated is reached. The current and potential sense progressively deeper layers as the array is expanded. In the profiling mode, a constant electrode spacing is selected that senses the subsurface geology to the depth of interest, and this constant array is “leap frogged” along a profile line to measure lateral variations that have geologic meaning. Adaptations of these configurations will be applied at the Mock Tank site using existing ERT installations, surface electrodes, and newly installed steel-cased wells. A detailed description of HRR configuration and deployment is described Section 4.6 and Appendix D.

4.0 Description of FY 2001 Testing

Tests to be conducted at the Mock Tank during FY 2001 will evaluate several aspects of a tank-leak scenario by using six separate techniques on a controlled leak from a central leak point in the tank. The five geophysical methods, described in Section 3.0 (and Appendix D) will be deployed around the tank site during July and August 2001. The first phase (~July 9–30) will consist of instrument installation/preparation, calibration, testing, and a baseline measurement of soil and background noise conditions. The second phase (~August 1–30) will involve semi-continuous monitoring of the subsurface beneath the tank with the five methods during the release of the sodium thiosulfate solution. As many as five separate releases, totaling up to 15,000 L (4,000 gal) each, will occur over a 2-week period during August 2001. The five geophysical methods will be applied to monitor one or more of these leaks to establish the sensitivity and usefulness of the methods in this setting.

As the research proceeds, the scale at which one needs to understand and characterize the vadose zone may also change, which would imply that the resolution of the geophysics must change (either up or down). Testing will identify the scale at which characterization must be done to characterize tank leaks at the waste-site scale and the sensitivity of each method. Analysis of the experimental data to determine parameters and properties and their spatial representation will follow techniques previously specified by the investigators and documented in previous reports (see Appendix D.3) and instrument manuals, where appropriate. The analysis of field tests will be completed for inclusion in draft reports due in the fall of 2001.

4.1 Rationale for Testing Strategy

The Mock Tank site was constructed to represent, as nearly as feasible, the subsurface environment surrounding an actual SST at the Hanford Site (see Section 2.3) and to simulate a leaking tank. Capabilities for early detection of leaks will support environmentally responsible management of potential leakage losses during waste-retrieval operations and minimize potential risks to human health and the environment. Quantification of the leak volume will enable informed decisions regarding appropriate leak-mitigation response actions.

The five geophysical methods selected for testing in 2001 are a subset of a larger field of tests that have been evaluated by field testing at Hanford or elsewhere. The evaluations determined that these five methods are most acceptable for immediate testing because of several factors, including ease of deployment, compatibility with realistic tank-farm environments, past successes in producing reliable results, non-invasiveness, and cost efficiency. At the Hanford Site, general selection criteria for the geophysical methods were based on performance of these technologies at the VZTFS (Ward and Gee 2000; Ward and Gee 2001) and encouraging results for ERT in the early Mock Tank tests (Ramirez et al. 1996; Narbutovskih et al. 1996b).

The strategy of combining the testing of these methods and the PITT method will allow cross-comparison of results and maximum utilization of resources. General aspects of the PITT Technology and elements of coordination with this project are discussed in Section 4.7 and Appendix D.5.

4.2 Drilling and Borehole Construction

Preparation of the Mock Tank site for FY 2001 activities will require the construction of up to 12 boreholes to depths of 9 to 15 m (35 to 50 ft). Three of the boreholes will be completed with sealed carbon steel casings. These will be paired with three PVC-cased boreholes that will also be sealed so as to contain water without leakage, as necessary for seismic testing. The six remaining boreholes will be drilled for use by the PITT technology demonstration at the Mock Tank and will be completed with screens to allow airflow through the vadose zone beneath the tank (see summary of PITT technology in Appendix D.5). A detailed description of borehole drilling and completion specifications is presented in Appendix D.1.

4.3 Pre-Deployment Testing

CPT methods will be used to test soil conditions before deploying the geophysical and PITT technologies. The tests will evaluate the lithologic, electrical, and hydrologic properties of the soils for comparison with, and calibration of, as appropriate, the PITT and geophysical test results. Specific test parameters are described in Appendix D.2.

4.4 Baseline Measurements

Baseline measurements will occur in the 2 weeks before the planned solution release to establish noise levels and general background characteristics of the Mock Tank environment. Investigators will be encouraged to establish baseline during a period when potential interference of noise is alternately at a maximum and minimum, thus accounting for the widest range of noise. The schedule for baseline measurements is described in Section 8.0.

4.5 Fluid Injections and Post-Injection Monitoring

The FY 2001 experiment at the Mock Tank site will simulate four independent leaks at the center of the tank. The schedule for the simulated leaks will be refined further (see Section 8.0), but will consist of up to five releases with a total volume of up to 15,140 L (4,000 gal) and will require up to 15 days. Waiting periods of 1 day are anticipated between the end of a release and the beginning of the next. The first and last release events will be partially blind in that the actual amounts of solution released during these periods will be unknown to the investigators. Following the blind release events, each method will be asked to provide an estimate, if possible, of leak volume. Also, release rates will be varied to determine the sensitivity of methods to this variable. Methods such as HRR and ERT may alternate on a multi-hour schedule during the early stages of the first release to prevent interference between methods.

The fluid selected for injection in the FY 2001 tests is concentrated (36% by atomic weight) sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5\ H_2O$). Important properties of the sodium thiosulfate solution are as follow:

- Atomic weight percent: 36.0
- Solution weight percent: 56.51
- Specific gravity: 1.3406
- Concentration (g/L): 481.8
- Relative Viscosity: 4.350
- Conductivity (umhos/cm): 128

The tabulated data and experience garnered from the Sisson and Lu site (Ward and Gee 2001) suggest that concentrated sodium thiosulfate is a good surrogate for tank waste in terms of density, viscosity, and electrical properties, and specifically so since tank-leak fluids have similar characteristics. This is substantiated by actual study of waste characteristics from process information (e.g., WHC 1992). Although most salt wastes are various metals complexed with nitrate ligands, sodium thiosulfate is selected as a reasonable surrogate with virtually no risk to the environment and human health or safety.

Sodium thiosulfate ($Na_2S_2O_3 \cdot 5\ H_2O$), when prepared as a concentrated solution (at 36% atomic weight), has a specific gravity of 1.34. When such a dense solution is applied to unsaturated Hanford sediments, the solution moves at rates different from that of water. Preliminary bench-scale tests, including permeameter and capillary-rise experiments, were conducted to evaluate the movement of saturated sodium thiosulfate in Hanford sediments (Ward and Gee 2001). Actual field use of the solution in March 2001 at the Sisson and Lu site indicated that a 40% thiosulfate solution would crystallize if the solution temperature fell below 10°C. For this reason, the concentration was reduced to 36% for the purposes of the Mock Tank simulations (although temperatures are not expected to be below 10°C during the height of summer on the Hanford Site). Ambient and solution temperatures will be monitored with a thermocouple array on and near the solution storage tank.

4.6 Deployment of Geophysical Methods

All geophysical methods will be deployed so as to maximize the opportunities for satisfying the objectives described in Section 1.1. This will require configuring the instrumentation (sensors and recorders) to optimize data-gathering capabilities while working in a complex environment (other methods operating simultaneously, noise, infrastructure).

All methods will require a “baselining” period of data collection before solution release to determine background-noise conditions. Operational considerations must also include the potential for interference between methods (e.g., ERT and HRR).

With the exception of CEMI, all methods will collect data at or near the start of solution release, during one or more intermediate release periods, and at the conclusion of the solution releases (see Section 8.0). Because of the expected sensitivities of the method, the CEMI system may conduct one extended measurement to begin during later stages of the first release and extending into subsequent releases. Below are described the general elements of system deployment and data collection for each geophysical method. Basic specifications for instrumentation, expected sensitivities, aspects of data analysis, and error sources are listed in Appendix D.3. One of the objectives of the testing is to more completely define these limitations for each method.

4.6.1 Electrical Resistivity Tomography

The 16-well ERT array emplaced by auger around the tank in 1995 will be used for the FY 2001 work (see Figures 2.2 and D.1). The arrays have been spot-checked for continuity and appear to be in satisfactory working order. Vertical and horizontal control for the sensor arrays is approximately ±30.5 cm (±1 ft).

Data collection will begin during a baseline period just before the first release of the surrogate solution (see Section 8.0) and continue immediately after the beginning of the release to determine the minimum time (and volume) to detection of the leak. A complete ERT measurement will require 3 to 4 h of continuous monitoring. Three to five complete measurements will be made during a solution-release period. Multiple measurements will be made during the solution release period and following the final release to depict plume movement.

Each measurement period will require coordination with other methods, particularly HRR. Hence, ERT and HRR will alternate on a 3- to 4-h basis during the first release, and any subsequent release where both methods are operating.

A leak will be detected via ERT data by differencing data from background resistance with post-leak resistance. This will be displayed as a three-dimensional *resistivity* tomograph consisting of sets of "voxels" (3-D pixels) representing an equivalent media volume of approximately 453 L (16 ft^3). Archie's equation (relating porosity, fluid conductivity, and bulk-media resistivity) is used to relate resistivity changes to volume of fluid detected.

4.6.2 Cross-Borehole Radar and Cross-Borehole Seismic Tomography

Many similarities exist between the configuration of the XBR deployment and that of the XBS. The XBR method will be deployed in existing (ERT) boreholes and new PVC wells located around the Mock Tank. Both steel and PVC-cased boreholes will be used for the XBS system deployment during the FY 2001 testing, but radar will function only in PVC-cased wells. Transmitters and receivers will be diametrically opposed across the tank, with the central leak point included in the plane thus formed (e.g., between wells C3628 and C3623 in Figure D.1), and at right angles to this plane (e.g., well C3621). Both vertical and horizontal (if existing ERT wells are used) tomograms may be constructed for the data. The collection of each complete set of data for both methods will require 1 to 2 days (a few hours per well pair per method).

Data from both methods will be collected in time series, with the baseline data being used to map subsurface sedimentary features (particularly for XBS) in the formation and to compare with post-release images. The latter aspect will be evaluated to determine the feasibility of the XBS method in leak detection. Because the XBS method responds to elastic or mechanical properties of the medium, it is recognized that the acoustic signal is attenuated as soils become progressively saturated with fluid. This behavior may be key in adapting the method to leak detection.

Zones of low resolution at the bottom and the top of the tomogram occur with both methods and could represent a potential problem when imaging leaks at shallow depths beneath the Mock Tank. Horizontal tomography, using several of the existing PVC wells, would help alleviate this drawback.

In both XBS and XBR, a leak will be detected by changes in amplitude and/or travel time (XBS) of the signal from background conditions. For XBR, changes in the relative permittivity will be related to the volume of solution released. These changes will be calibrated by relating known quantities of released solution to the recorded data.

4.6.3 Cross-Borehole Electromagnetic Induction

The CEMI system will be deployed within the three new PVC wells and the existing 16 ERT wells surrounding the tank. The transmitter and receiver will be on diametrically opposite sides of the tank on a line extending through the center solution release point, and, alternately, with the receiver offset to either side of the diametric center line. Thus, a complete set of measurements will optimally use three transmitter wells and nine receiver wells. The new PVC wells will be used for deployment of the transmitters, and the existing ERT wells used for receiver(s). Both transmitters and receivers will be deployed at 0.5-m (16.4-ft) intervals in the wells. The transmitter will be held in position at a specific interval while the receiver(s) is moved through several intervals (~20 intervals) within the receiver wells. Once the receiver(s) has tranversed a well from top to bottom, the transmitter is moved to the next interval, and the process is repeated.

Two deployments of the system will occur, one for background and one midway through the leak-release schedule. Four to five complete data sets (measurements using all wells) each will be made for the background determinations and the solution-release period.

The specific criteria for determining the detection of a leak versus non-detection have not been established, but will depend on levels of background interference (noise) in comparison to signal change and empirical data and numerical modeling of the data derived from the Mock Tank experiment. For the Mock Tank experiment, it is expected that the minimum usable signal will be at least two orders of magnitude above the background noise levels.

The output to the data recorder is vertical magnetic field intensity, which is then used to calculate apparent resistivity. As with other methods, Archie’s law will be used to relate electrical conductivity (or resistivity) change to volume of saturated medium.

4.6.4 High-Resolution Resistivity

The HRR method is perhaps the most sensitive to the initial detection of a simulated leak, depending on where the system's electrodes are located. Several experimental configurations will be used during the Mock Tank test, including combinations of surface-emplaced electrodes, long vertical electrodes (the entire steel well casings of the new wells), some of the existing ERT arrays, and connections to the tank itself and the solution release point.

One method is termed the "in-container" dynamic casing method, which utilizes an electrode connected to the release point (i.e., inside the tank) and several electrodes, such as steel well casings, outside the tank. This array is ultra-sensitive to the detection of a leak (less than 1 L [0.26 gal]), but the validity or feasibility of such an array in an actual SST is problematic.

HRR will be applied to the vadose zone at the Mock Tank to demonstrate whether this method can quantitatively monitor the movement and dimensions of the injected solution. A two-dimensional electrode array will be installed on the surface of the injection site for surface-only measurements. The specific number of electrodes to be installed and the array dimensions will be determined onsite. In addition, three steel casings installed at the Mock Tank will be used as electrodes by connecting the system to the tops of the wells and energizing the entire length of casing. Thus, existing tank-farm conditions will be partially simulated. Measurements will be made using various combinations of the surface and downhole electrodes, potentially including: (1) use of the steel casings as long electrodes, (2) "short-circuiting" the ERT arrays to simulate steel casing, and (3) connecting to the central leak point in the Mock Tank to simulate a leak scenario which might occur in an SST with continuity between waste and conductive surface structures (e.g., liquid observation wells, etc.). Data repeatability is evaluated using reciprocal measurements between electrodes. Graphic comparisons of data plots are used for identification of trend deviations. These deviations are individually evaluated to determine if they are due to acquisition problems or represent actual anomalies in the subsurface. The results will be represented by color-contoured plan maps of potential distribution as a function of depth, two-dimensional profiles showing quantifiable changes in time and distance, and in a three-dimensional format showing wet-volume changes as a function of time.

4.7 Coordination of Testing with PITT Demonstration

The PITT technology demonstration for the Mock Tank site, and the adjacent "RCRA Well" site (see Figures 2.2 and D.1) will be deployed simultaneously with the five geophysical methods. The PITT operation will involve the installation of up to six wells near the Mock Tank that will be used for the injection and extraction of vapor passed beneath the tank (see summary of PITT technology in Appendix D). This process will require that pumps and other ancillary equipment be located in the vicinity of the tank. Thus, measures are being taken to minimize interference with the geophysical techniques, such as screening pump motors/controllers for RF noise elimination. The PITT demonstration will begin at the Mock Tank approximately 1 week before the beginning of fluid injection and continue until the end of solution release events, or until data acquisition goals are achieved (see Gauglitz et al. 2001). Results of the PITT application are expected to be invaluable as cross-comparison and confirmatory data for the geophysical methods.

5.0 Equipment and Materials

Basic equipment and materials required to conduct the field tests are listed below. The FY 2001 tests will use existing and new infrastructure to monitor the leak tests.

PNNL will provide the following materials required for the FY 2001 field test:

1. Mixing/holding tank 18,920 L (5,000 gal)
2. Delivery metering system capable of delivering approximately 38 L/h (10 gal/h)
3. Sodium thiosulfate 36% solution 15,140 L (4,000 gal)
4. Site trailer or instrument shelter vehicle with power supply(ies)
5. Thermocouple array and data loggers for temperature monitoring
6. Boreholes constructed to specifications noted in Appendix D.2
7. Method-specific geophysical equipment described in Appendix D.3.2.

6.0 Data and Information Management

A project database has been established for storing and managing laboratory and field data. A project data custodian will be designated to control and maintain the data and to make them available on a secure project web site. The data will be stored electronically in a widely compatible format, and task leaders will provide electronic copies to the data custodian for storage in the project files. During the course of the experiment, data access will be vital to the success of each test, and data sharing and their interpretation are encouraged. All raw data must be backed up or archived at the end of each collection event. Atmospheric data, such as ambient surface temperature, humidity, and pressure also will be recorded during the tests and must be incorporated into the data set as appropriate. The following information must be included, as a minimum, in a database:

- Sample identifier
- Sample (borehole/interval) spatial location
- Sampling time
- Sampling date
- Analysis date
- Variable measured and value
- Measurement unit.

Processed data and interpretive results from the FY 2001 work described in this document will also be posted on the appropriate PNNL web site. To ensure that project milestones are met in a timely fashion, it may be necessary to publish data in reports before task leaders have the opportunity to develop peer-reviewed publications. In such instances, publication of data in project reports supersedes the rights of task leaders.

7.0 Reporting

This section describes a suggested content and format for the preliminary report due in the fall of 2001. Reports will be submitted for each of the five geophysical methods. The report content should describe sources of data error, levels of precision, discussion of how accurately the imagery or tomogram portrays the subsurface environment during the tests, and what comparisons were made to calibrate or otherwise derive accuracy.

Components of the report should, at minimum, include the following content:

1. Introduction

   - Brief description of the method principles and prior applications that apply to the TLDD and the Mock Tank application (background)
   - Description of the objectives for testing the method

2. Methodology and Approach

   - Type and brand of sensors, sources, and recording equipment
   - How were the data recorded, processed, analyzed, and stored
   - How the instrumentation/sensors were deployed and the rationale for the configuration of deployment

3. Results

   - Success of method in detecting the leak
   - Success of method in estimating volume(s) of leak
   - Success of method in discriminating recent leaks from early leaks
   - How the method performed in PVC versus steel boreholes (where applicable)
   - Sources of error or interference discovered during the testing and how these were addressed
   - Comparison of results with other methods (if available)

4. Recommendations and Conclusions

   - Reasons why the method should (should not) be further investigated
   - Next steps in deployment
   - Estimated costs of further study
   - Estimated cost of a permanent operating system.

8.0 Testing Schedule

Geophysical tests will be run simultaneously during the course of the experiment by a multidisciplinary team of collaborators from other National Laboratories and commercial vendors. The participants are listed in Appendix A.

Planning meetings with collaborators is continuing as site-preparation work progresses. The project schedule, developed from the planning meetings and precedent work at the VZTFS (Sisson and Lu site) is shown in Table 8.1. Incompatibilities (e.g., electrical interferences) between various geophysical techniques (e.g., HRR and ERT) during operation are recognized. Thus, proper sequencing of measurements is required and is considered in the development of the final schedule. The schedule for method deployment, compared with the release schedule, is shown in Figure 8.1. The schedule, volumes, and discharge rates for solution release are shown in Table 8.2. A more refined schedule (i.e., within each release block of Figure 8.1), particularly for the early portion of the first solution injection, is being developed through further consultation between collaborators to circumvent incompatibilities. Adjustments to this scenario will be applied as technical considerations dictate. Adjustments to the start dates may be made as field conditions demand.

Table 8.1. Projected Schedule for FY 2001 Mock Tank Leak-Detection Demonstration

Start Date	Action	Method 1 HRR	Method 2 ERT	Method 3 XB Radar	Method 4 XB Seismic	Method 5 CEMI	PITT
7/9/01	Background						
7/23/01		5 days		5 days	5 days		
7/30/01			Set up & check existing system			5 days	Set up
8/2/01			3–4 days				3+ days
8/06/01	Injection 1 (4 days)	Monitor (4 days)	Monitor (4 days)	Monitor (5 days)			Monitor Continuously
8/11/01	Injection 2a (2 days)	Monitor (2 days)			Monitor (2 days)	Monitor (3 days)	Monitor Continuously
8/14/01	Injection 2b (3 days)	Monitor (2 days)	Monitor (4 days)	Monitor (2 days)	Monitor (3 days)	Monitor (2 days)	Monitor Continuously
8/18/01	Injection 3 (1 day)	Monitor (2 days)	Monitor (2 days)				Monitor Continuously
8/20/01	Injection 4 (1 day)	Monitor (2 days)	Monitor (1 day)	Monitor (2 days)	Monitor (2 days)		Monitor Continuously

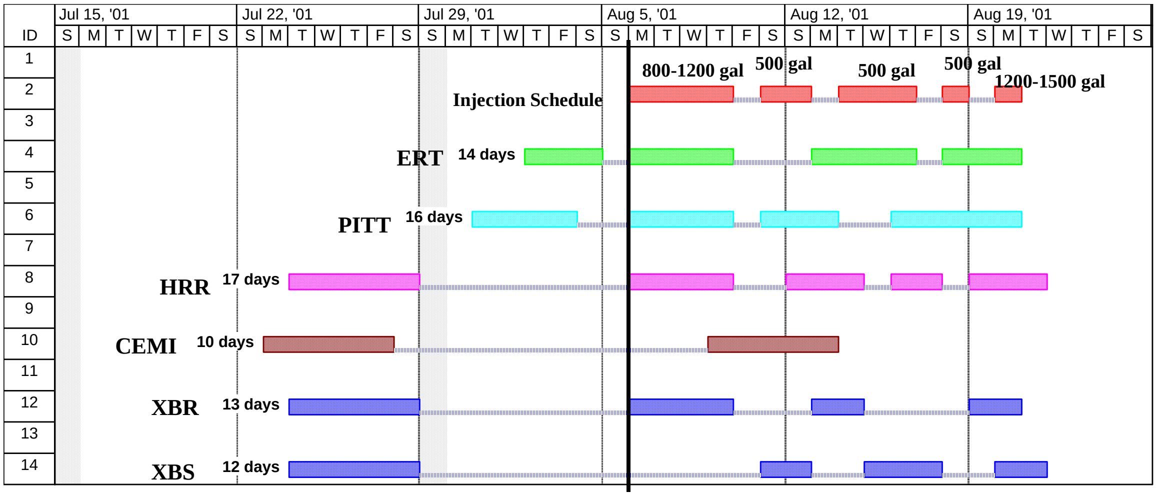

Figure 8.1. Deployment Schedule in Comparison to Solution Releases (after Vista Engineering Technologies, L.L.C. 2001)

Table 8.2. Projected Release Volumes and Rates for Sodium Thiosulfate Solution (after Vista Engineering Technologies, L.L.C. 2001)

Injection Test Run	Injection Volume (gal)	Injection Duration (days)	Injection Time (hr/days)	Injection Rate (gal/h)	Accumulated Volume (gal)
1	*800-1,200*	4	10	20.0 – 30.0	800 - 1,200
2a	500	2	6	41.66	1,300 - 1,700
2b	500	3	8	20.8	1,800 - 2,300
3	500	1	24	20.8	2,300 - 2,800
4	*1,200-1,500*	1	24	50.0 – 62.5	3,500 - 4,000
(a) The volume of the shaded injection volumes will not be disclosed at the time of the testing.					

9.0 Environmental Health and Safety

The excavation permit to be used in FY 2001 for the Mock Tank site is provided in Appendix B. The work will be conducted in an environmentally compliant manner. Safety and health issues relating to the Mock Tank site are addressed in site-specific safety documents (Appendixes B and C) that identify industrial safety health hazards as well as other measures to protect against these hazards. Safety documents include specific training requirements that must be met by all site workers and visitors. Job-specific health and safety plans for drilling, instrument-installation activities, and sampling activities are also specified in Appendixes B and C. Briefings will be conducted with all site visitors to ensure that health and safety issues are understood and that safe practices will be followed during the course of the experiments. All Mock Tank site participants and visitors are required to read and sign the health and safety plan before entering the field site. Certain areas of the site will have limited access to reduce the risk of injury and disruption of work.

10.0 Waste and Residuals Management

PNNL will be responsible to manage wastes and residuals. These activities will be accomplished according to specific procedures followed during drilling and sampling operations.

10.1 Management Activity A–Solid Waste Management Plan for Borehole Construction

Scope: This plan covers waste disposition for the waste generated from installation of boreholes for the Mock Tank site.

Anticipated Waste Streams: Based on the project test plan, the only anticipated waste streams from the above activities are non-regulated, non-hazardous solid wastes, which may include paper, plastic, rags, etc. These materials have been designated as non-hazardous. The determination has also been made that the test site is a non-radiological area, and therefore, none of the waste would be classified as radiological low-level waste.

Waste Management: The waste stream described above will be disposed of to a normal "trash" receptacle. The management of any other unanticipated solid waste will be in accordance with PNNL internal waste management procedures.

Contingency Plan: In the event of a spill or accidental release of a material to the environment, the procedure for spill response (http://sbms.pnl.gov/standard/0e/0e00t010.htm) will be in effect.

If a spill occurs, call **375-2400**.

10.2 Management Activity B–Soil and Water Sample Management Plan

Scope: This plan covers the disposition of the soil and solution samples generated from drilling activities for the Mock Task site (Cold Test Site).

Anticipated Waste Streams: Based on the project test plan for the drilling activities, there are *no* anticipated waste streams from these activities.

The soil from the drilling activity is environmental media and, other than soil samples to be taken for characterization and analysis, all will be backfilled in the borehole annulus.

If solid waste is produced during these activities, it is anticipated that it would be non-regulated, non-hazardous solid wastes, which may include paper, plastic, rags, etc. These materials have been designated as non-hazardous. The determination has also been made that the test site is a non-radiological area, and therefore, none of the waste would be classified as radiological low-level waste.

Waste Management: The waste stream described above (paper, plastic, etc.) will be disposed of to a normal "trash" receptacle.

The management of any other unanticipated solid waste will be in accordance with PNNL internal waste management procedures.

Contingency Plan: In the event of a spill or accidental release of a material to the environment, the procedure for spill response (http://sbms.pnl.gov/standard/0e/0e00t010.htm) will be in effect.

If a spill occurs, call **375-2400**.

11.0 Quality Assurance

All work conducted by PNNL shall be performed in accordance with appropriate standards of quality, reliability, environmental compliance, and safety based on client requirements, cost and program objectives, and potential consequences of malfunction or error. To provide clients with quality products and services, PNNL has established and implemented a formal Quality Assurance (QA) Program. These management controls are documented in the PNNL Standards-Based Management System (SBMS). Staff at PNNL, CH2M HILL Hanford Group (CHG), and DOE-RL (DOE Richland Operations Office) can access the SBMS menu. PNNL staff can go to PNNL's internal home page at http://labweb.pnl.gov/ and select "Policies & Procedures (SBMS)." Offsite users can access SBMS by going to http://sbms.pnl.gov/. Netscape Communicator 4.5 is the recommended and supported World Wide Web browser at PNNL. This QA Plan also complies with the format requirements of QAMS-005/80 (Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans). If other quality-related activities are later performed, the appropriate SBMS requirements and procedures shall be applied, unless specifically excluded.

12.0 References

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Appendix A

Collaborators in the FY 2001 Tank Leak Detection Demonstration and Personnel Roles and Responsibilities

Appendix A

Collaborators in the FY 2001 Tank Leak Detection Demonstration and Personnel Roles and Responsibilities

The fiscal year (FY) 2001 test is a multidisciplinary and collaborative effort among National Laboratories, commercial vendors, and geophysical consultants who are experts in vadose-zone monitoring. Table A.1 is a list of the collaborators involved in the FY 2001 field tests at Mock Tank 105-A (Mock Tank). Table A.2 lists Pacific Northwest National Laboratory (PNNL) staff responsible for the development and implementation of the testing and related logistical considerations for the geophysical methods.

Table A.1. Participating Collaborators in FY 2001

Institution	Collaborator	Expertise
LBNL[a]	Mike Hoversten	Geophysics
	Ernie Majer	Geophysics
LLNL[b]	Bill Daily	Geophysics
	Abe Ramirez	Geophysics
HydroGEOPHYSICS, Inc.	Jim Fink	Geophysics
PNNL[c]	Brent Barnett	Geology/Hydrology
	Rick Cameron	Engineering
	Phil Gauglitz	Geochemistry
	Glendon Gee	Soil Physics
	Mike Johnson	Engineering
	Susan Narbutovskih	Geophysics
	Mark Sweeney	Geology/Geophysics

(a) LBNL = Lawrence Berkeley National Laboratory.
(b) LLNL = Lawrence Livermore National Laboratory.
(c) PNNL = Pacific Northwest National Laboratory.

Table A.2. Role and Responsibilities (Pacific Northwest National Laboratory)

Personnel	Role	Contact
Brent Barnett	Assistant Project Manager	376-3416
Glendon Gee	Project Manager	376-6096
Mark Sweeney	Assistant Project Manager	373-0703

Appendix B

Site Operating Requirements and Excavation Permit

Appendix B

Site Operating Requirements and Excavation Permit

B.1 Excavation Permit

Excavation permit DAN 1761 was completed on June 21, 2001. The permit allows drilling and cone penetrometer techniques (CPT) installations at Mock Tank 105-A (Mock Tank) site as illustrated by Figure D.1. The composite map referenced in Section 8 of the permit is the same as Figure D.1, which shows prominent ground-penetrating radar (GPR) results (linear features) in conjunction with planned borings and installations.

FROM : FAX NO. : May. 19 2000 08:15AM P1

05/20/01 TUE 15:11 FAX 1 509 376 2998 MECHANICAL/CIVIL ENG 002

HANFORD SITE EXCAVATION PERMIT

Excavation Permit No.: DAN-1761

1. Work Package No.: —
2. W.O./Project No.: —
3. Location of Excavation: 105A Mock Tank Site in 200 East Area
4. Originated By: Mike Stephenson / Jennifer Williamson — Date: 5/17/01
5. Engineering Change Notice (ECN): —
6. Drawings Required (Identification Numbers): —
7. Description of Work (Attach composite drawing of excavation location and all known interferences)

See attached drawings for location of test site and cone penetrometer (CPT) boreholes and injection wells.

Call 1-800-424-5555 prior to digging.

Call Ted Parry 24hrs prior to drilling on 373-4635 or 531-7330 cell. Keep drill rig 5ft from any water line.

8. Special Instructions or Comments (When anything unusual or unexpected is identified in an excavation, STOP and carefully hand dig until the discovery can be properly evaluated. Also refer to any company-specific safety procedures.)

For Required RCT coverage, see attached special instructions

NON-HAZARDOUS EXCAVATION

ENSURE ALL EXCAVATIONS REMAIN AT LEAST 15 FT. SOUTH OF EXCAVATION BOUNDARY AND AT LEAST 5 FT. FROM ALL OTHER UNDERGROUND LINES AS SHOWN ON ATTACHED COMPOSITE MAP.

9. List Facilities, Services, and Utilities Affected by Excavation

APPROVALS

		Date			Date
10. Project/Field Engineer	[signature]	5-17-01	18. Traffic Engineer	N/A	
11. Environmental	[signature]	5/18/01	19. Track Maintenance	N/A	
12. Radiological Control	[signature]	5/23/01	20. 600 Area Landlord	N/A	
13. Steam System	Chuck Tallent per FAX	5/18/01	21. Safeguards and Security	Jon R. Smith per FAX	5/17/01
14. Electrical Utilities	Eugene P. Lanin Sr. per FAX (see attached)	5/30/01	22. Land Use Planning	Ron Ingram per FAX	5/22/01
15. Water Utilities	Ted Perry per FAX	5/22/01	23. Other	Phil Miller per FAX	6/1/01
16. Telecommunications	Ken Fergussen per FAX - QWEST	5/18/01	24. Facility/System Owner	[signature]	6/21/01
17. Process Sewer - 300 Area	N/A		Facility System Engineer	J.D. [illegible]	6/21/01

Locate Request No. ________

[illegible]

FROM : FAX NO. : May. 19 2000 08:15AM P2

Attachment for Excavation Permit #DAN-1761

Section 8, Special Instructions

For the PITT project, RCT coverage will be required when pushing the initial CPT closest to the 218-C-9 burial ground.

For the PHYS project, RCT coverage will be required when drilling the first borehole between existing #6 and #7. The agar flights and spoils pile will be surveyed. See attached map. At the end of the project, an equipment scan and survey of the entire spoils pile is required.

All samples taken by these projects will be processed for radiological contamination using direct radiation survey techniques in accordance with procedure PNL-MA-266, RCP-5.5.11, *Radiological* Surveys. If any evidence is found of radioactive contamination, other than from naturally occurring radon and radon progeny, the material shall be placed under proper radiological controls and work will be suspended pending further evaluation of radiological conditions.

05/30/01 WED 08:18 FAX 509 373 4362 Util & Telcom 002

BLOCK 9 SPECIAL INSTRUCTIONS (for #14); DAN 1761

There are no EU underground electrical equipment, but there are existing overhead lines, poles, transformers, lights, etc. in the vicinity. Horizontal and vertical clearances must be maintained per HNF-PRO-088. **If during mobilization, excavating, or demobilization, excavating or other equipment could approach within twenty (20) feet of power lines, or within five (5) feet of power poles, call Electrical Utilities' Dispatcher at 373-2321 forty-eight (48) hours prior to activity for standby lineman.**

In advance of excavation, scan for underground power lines. If underground power lines are encountered, STOP, and call Electrical Dispatcher at 373-2321. Hand excavate within five (5) feet of underground power lines.

This approval applies only to electric power systems over which Electrical Utilities (EU) has operational control. You must obtain sign off and approval from the facility owner for electrical systems not under the operational control of EU.

Eugene P. Lamm Jr.
5/30/2001

B.2 Ground-Penetrating Radar Survey Results

To ensure site safety, protect subsurface structures, and optimize the locations of boreholes, the entire area involving the FY 2001 Tank Leak Detection Demonstration (TLDD) project was surveyed with GPR. The results of this survey are illustrated in Figure B.1.

Several buried linear features, interpreted to be pipelines, are located within or near the site. The most prominent of these include the corridor southeast of the Mock Tank aligned in a southwest-northeast trending direction. At least four linear conductors were identified in this corridor. Another major linear feature is located north of the study area (i.e., north of the N130 survey line) within an excavated area. At least two pipelines and several other buried features are identified along this trend. Northwest of the Mock Tank are two buried pipes approximately 1 m deep. Of these two, the pipe trending east-west has been truncated in the area of the tank and is only 0.2 m deep in the Partitioning Interwell Tracer Test (PITT) demonstration area east of the Mock Tank. This feature will be easily avoided because of its shallow depth. The conductor labeled as “1” (indicating a depth of 0.1 m) and trending west-northwest from the N114 survey line is a #10 gauge copper wire at the surface. This was installed for grounding purposes during the 1995–1996 Electrical Resistivity Tomography (ERT) studies, and may be used for FY 2001 activities.

Isolated objects denoted by shallow depths from 0.1 to 0.3 m represent small discarded items of limited dimensions, such as drink cans or fragments of “rebar,” and can be avoided or removed without difficulty. The cross-lined areas northwest and east of the Mock Tank indicate partial disruption of the radar signal by cables leading from the ERT installations.

The “staked locations” and “alternate staked test locations” represent projected locations of CPT holes at the time of the survey and are currently being adjusted to satisfy setback guidelines for utilities and to avoid objects discovered by the survey. The current configuration of planned boreholes and CPT holes are shown with the superimposed GPR results in Figure D.1.

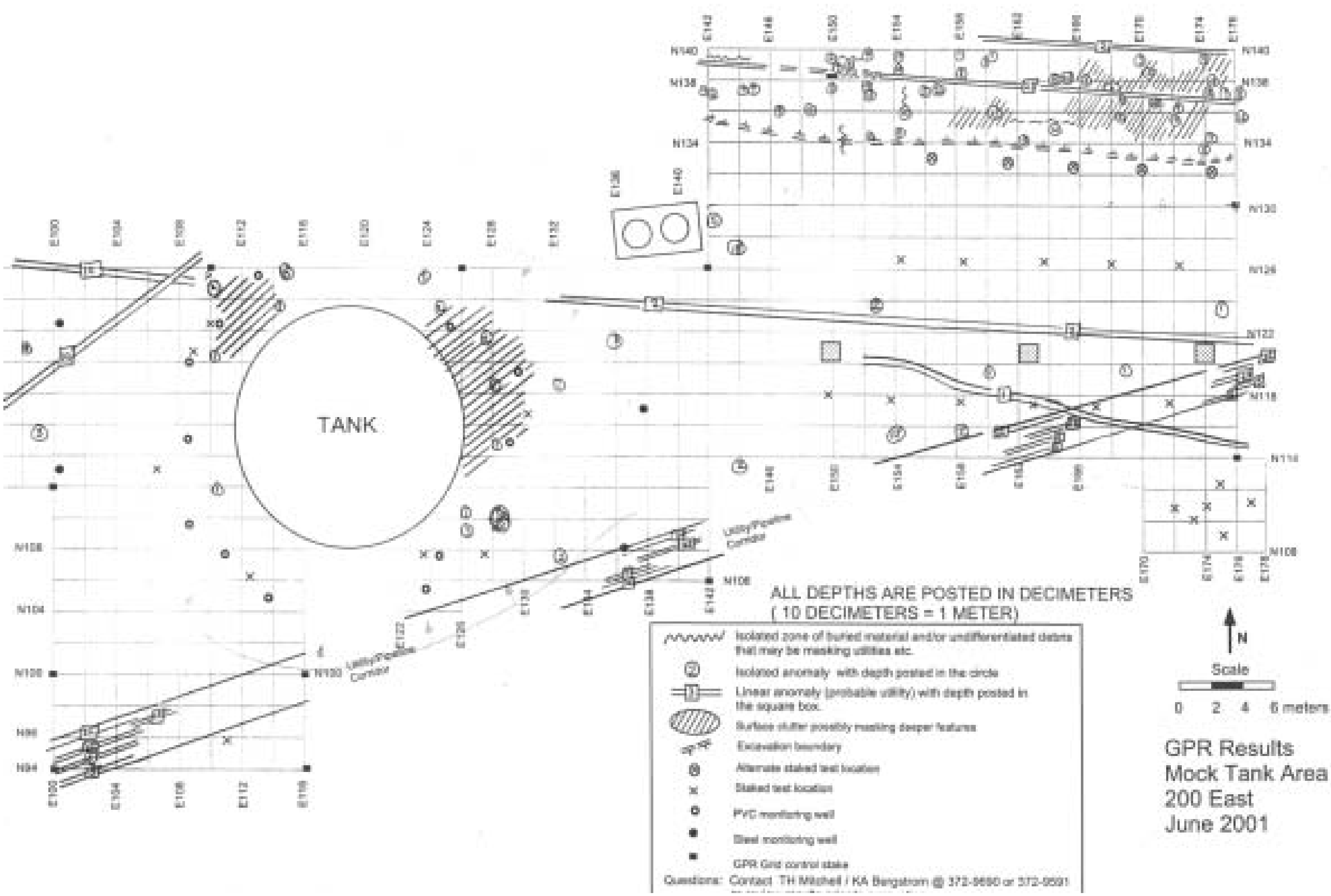

Figure B.1. Ground-Penetrating Radar Survey Results for the Mock Tank and PITT Demonstration Sites, June 2001

B.3 Solution Discharge Permit

Brent and Rick,

Items **001** and **002** from **CDRR 31674** have been reviewed and approved for discharge to ground at the Tank Leak Detection Demonstration Project test site located in the 200 East Area at and adjacent to the 105A Mock Tank. Please note the discharge conditions listed in the approval below.

These conditions are taken directly from State Waste Discharge Permit ST 4508, *Hydrotest, Maintenance, and Construction* and the *Pollution Prevention & Best Management Practices Plan*, both of which can be found electronically at http://w3.pnl.gov/safety/ems/effluent_management/hydro.htm

ST 4508 requires that specific best-management practices be implemented where appropriate, including Condition S4, which prohibits discharges within a 90 m (300 ft) horizontal radius of an active or inactive radioactive disposal site. The Washington State Department of Ecology concurs with our stance that because the volume of water discharged at this site is small, remobilization of contaminants from the nearby radioactive disposal sites is not likely. Additionally, we have had previous discussions with Ecology on the discharge of sodium thiosulfate, which, at the point of discharge, exceeds Washington State Ground Water Quality Criteria for sulfates. The long-time duration and distance to groundwater, however, will result in no impact from this discharge to groundwater.

Your main action is to act as the "responsible party" for answering questions about the project and discharges should the need arise. I will be scheduling a brief meeting with you to go over the permit and P2/BMP Plan requirements. I suggest keeping a copy of this approval and the Best Management Practices Plan (provided at the meeting) with project papers.

Thanks for your patience while we resolved all of the issues for this project.
Liz Raney

Discharge To Ground Request

The Request to Discharge the Below Items:
From: Tank Leak Detection Demonstration Project
To: 200 East 105A Mock Tank Site (and areas adjacent)

Item(s): Item 1 – 15, 140 L (4,000 GAL) OF SODIUM THIOSULFATE (36%) IN WATER (conditions as described CDRR 31674)
Item 2 – 18, 930 L (5,000 GAL) OF CLEAN WATER (conditions as described CDRR 31674)

Status: **APPROVED**

Discharge Conditions (site wide)

1. Each discharge must be less than 38 L (10 gal) per minute averaged annually. The annual average flow is calculated for each discharge as total gallons discharged in a calendar year, divided by the number of minutes in that year.

2. Each discharge must be less than 570 L (150 gal) per minute instantaneously.

3. Single discharges with a volume greater than 54,890 L (14,500 gal) in a 24-h period, or with a total volume greater than 190,000 L (50,000 gal) in a calendar year must be reported to the Effluent Management group before discharge.

4. The only allowed source waters to be used for hydrotest, maintenance, and construction activities are Columbia River water, potable water (treated Columbia River water or groundwater), or demineralized water (treated potable water).

General (site wide) Requirements and Best Management Practices

1. Each discharge must meet WAC-173-200 Ground Water Quality Criteria (GWQC) unless the discharge is expected to have a contaminant that exceeds the GWQC solely because the source water has a contaminant that exceeds one or more of the GWQC. Discharges that exceed the GWQC at the effluent, but are prevented from impacting groundwater water quality, would be covered by this permit.

2. All discharges shall follow the appropriate Pollution Prevention and Best Management Practices (BMPs) listed below and those listed in the *Pollution Prevention and Best Management Practices Plan for State Waste Discharge Permits ST-4508, ST-4509, and ST-4510* (DOE/RL-97-67, Rev. 3, date 08/99).
   - No discharge shall be allowed within a surface contaminated area (areas with dangerous waste and/or radioactive contaminants).
   - No discharge shall be allowed within 90 m (300 ft) horizontal radius of a known active or inactive crib, ditch, or trench used for disposal of dangerous and/or radioactive contaminants.
   - No discharge shall be allowed to affect an ecologically sensitive area.
   - Reasonable efforts shall be taken to prevent ponding due to discharge rates above the expected soil infiltration capacity.
   - There shall be no discharge of runoff of wastewater to any surface waters of the state or to any land not owned by or under control of the Permittee, except as authorized by a wastewater discharge permit.
   - Efforts shall be made to recycle, store, and reuse all water to the maximum extent practical.

3. Every discharge shall have an assigned responsible person on site who is familiar with the section of the *Pollution Prevention and Best Management Practices Plan* (DOE/RL-97-67, Rev. 3) that applies to the discharge. This responsible person should confirm compliance with the Plan and be prepared to answer any Ecology questions in the event of an inspection. The discharge of any wastewater not

done as specified in the *Pollution Prevention and Best Management Practices Plan* (DOE/RL-97-67, Rev. 3) shall constitute a violation of the terms and conditions of the permits.

4. Collected screenings, grit, solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters shall not be resuspended or reintroduced to the effluent stream for discharge.

Expires: October 31, 2001

-----Original Message-----
From: Johannesen, Judith M
Sent: Wednesday, May 02, 2001 4:36 PM
To: Raney, Elizabeth A
Cc: Bartel-Bailey, Gregg M
Subject: Please review item # 71906 for sewer approval

Please review item # 71906 for sewer approval.

Generator: Michael Johnson 509/376-5771 K6-96
Requestor Name: Samuel Juracich 509/372-0524 K6-78
Location: OFFSITE
Room: HOME
IRM #: 31674
IRM Line item #: 1
Waste Volume: 16000 L
pH: 7.0
Material Description: SODIUM THIOSULFATE SOLUTION
Chemical Content: SODIUM THIOSULFATE 36%, WATER 64%

Please review item # 71907 for sewer approval.

Generator: Michael Johnson 509/376-5771 K6-96
Requestor Name: Samuel Juracich 509/372-0524 K6-78
Location: OFFSITE
Room: HOME
IRM #: 31674
IRM Line item #: 2
Waste Volume: 20000 L
pH: 7.0
Material Description: WATER
Chemical Content: WATER 100%

**Pacific Northwest
National Laboratory**

Operated by Battelle for the
U.S. Department of Energy

April 24, 2001

Mr. Richard J. Cameron
Pacific Northwest National Laboratory
P. O. Box 999, MSIN K6-96
Richland, WA 99352

Dear Mr. Cameron:

BIOLOGICAL REVIEW OF THE INTERWELL TRACER TEST AND TANK LEAK DETECTION DEMONSTRATION PROJECTS, 200E Area, ECR #2001-200-034A.

Project Description:

- Install bore holes for gaseous injection and extraction, and other test equipment at the Hanford Site Cold Test site (Mock Tank 105A). This letter is a re-issue of ECR 2001-200-034 (3/28/01) which, due to an inaccurate map supplied with the review request, was based on a survey of an incorrect site. This re-issue also expands the scope of the original reivew to include all related projects and activities utilizing the mock tank facility.

Survey Objectives:

- To determine the occurrence in the project area of plant and animal species protected under the Endangered Species Act (ESA), candidates for such protection, and species listed as threatened, endangered, candidate, sensitive, or monitor by the state of Washington, and species protected under the Migratory Bird Treaty Act,

- To evaluate and quantify the potential impacts of disturbance on priority habitats and protected plant and animal species identified in the survey.

Survey Methods:

- Pedestrian and ocular reconnaissance of the proposed project site were performed by C. A. Duberstein and M. R. Sackschewsky on 23 April 2001. The percent cover of dominant vegetation was visually estimated,

- Priority habitats and species of concern are documented as such in the following: Washington Department of Fish and Wildlife (1994, 1996), Washington State Department of Natural Resources (1997), and for migratory birds, U.S. Fish and Wildlife Service (1985). Lists of animal and plant species considered Endangered, Threatened, Proposed, or Candidate by the USFWS are maintained at 50 CFR 17.11 and 50 CFR 17.12.

Survey Results:

- The proposed project site has been previously disturbed, and is currently dominated by sparse, weedy vegetation.
- No migratory bird species were observed nesting in the vicinity of the proposed site.

Considerations and Recommendations:

- No plant or animal species protected under the ESA, candidates for such protection, or species listed by the Washington state government as threatened or endangered were observed in the vicinity of the proposed site.
- No adverse impacts to species, habitats, or other biological resources are expected to result from the proposed actions.
- This Ecological Compliance Review is valid until 15 April 2002.

Sincerely,

Michael R. Sackschewsky
Project Manager
Ecological Compliance Assessment Project

LB:mrs

REFERENCES

U. S. Fish and Wildlife Service. 1985. Revised List of Migratory Birds; Final Rule. 50 FR 13708 (April 5, 1985).

Washington Department of Fish and Wildlife. 1994. Species of Special Concern in Washington. (April 1994).

Washington Department of Fish and Wildlife. 1996. Priority Habitats and Species List. (January 1996).

Washington Department of Natural Resources. 1997. Endangered, Threatened & Sensitive Vascular Plants of Washington (August 1997).

Appendix C

Site Access and Conduct Requirements Industrial Health and Safety Plan—Site Safety Requirements

Appendix C

Site Access and Conduct Requirements Industrial Health and Safety Plan—Site Safety Requirements

C.1 Application and Scope

This document controls Pacific Northwest National Laboratory (PNNL) Science and Technology Project safety and conduct activities related to the Mock Tank 105A (Mock Tank) site in the 200 East Area. It serves as the **site safety briefing** and provides **general requirements** for staff, contractors, and visitors involved in performing testing and monitoring activities on the Mock Tank site.

The Mock Tank 105-A is located in the 200 East Area across 7th Street from the former Hot Semiworks. The legal coordinates for the Mock Tank site are SE 1/4, NW 1/4, Section 2, T12N, R26E.

A detailed description of the site and the past history of the site are found in the Waste Information Data System (WIDS) database accessible on the Hanford Web. Records show that the Mock Tank (Mock Tank 105-A Site) is a radiologically clean site.

Visitors accessing the site must follow safety precautions that pertain to PNNL staff working onsite. Signing of this document indicates that the individual has read the document and is willing to abide by the safety and access protocols specified herein.

Subsequent versions of this document may be prepared if access or conduct requirements change. Notification of subsequent versions will be made to project staff and authorized workers. Each new version of the document will require the review and signature of each worker before that person's continued work at the site.

C.2 Responsible Staff

The person responsible for this document is the PNNL project manager, Glendon W. Gee, and can be reached at (509) 372-6096. The alternate responsible persons are Mark D. Sweeney (373-0703) or D. Brent Barnett (376-3416).

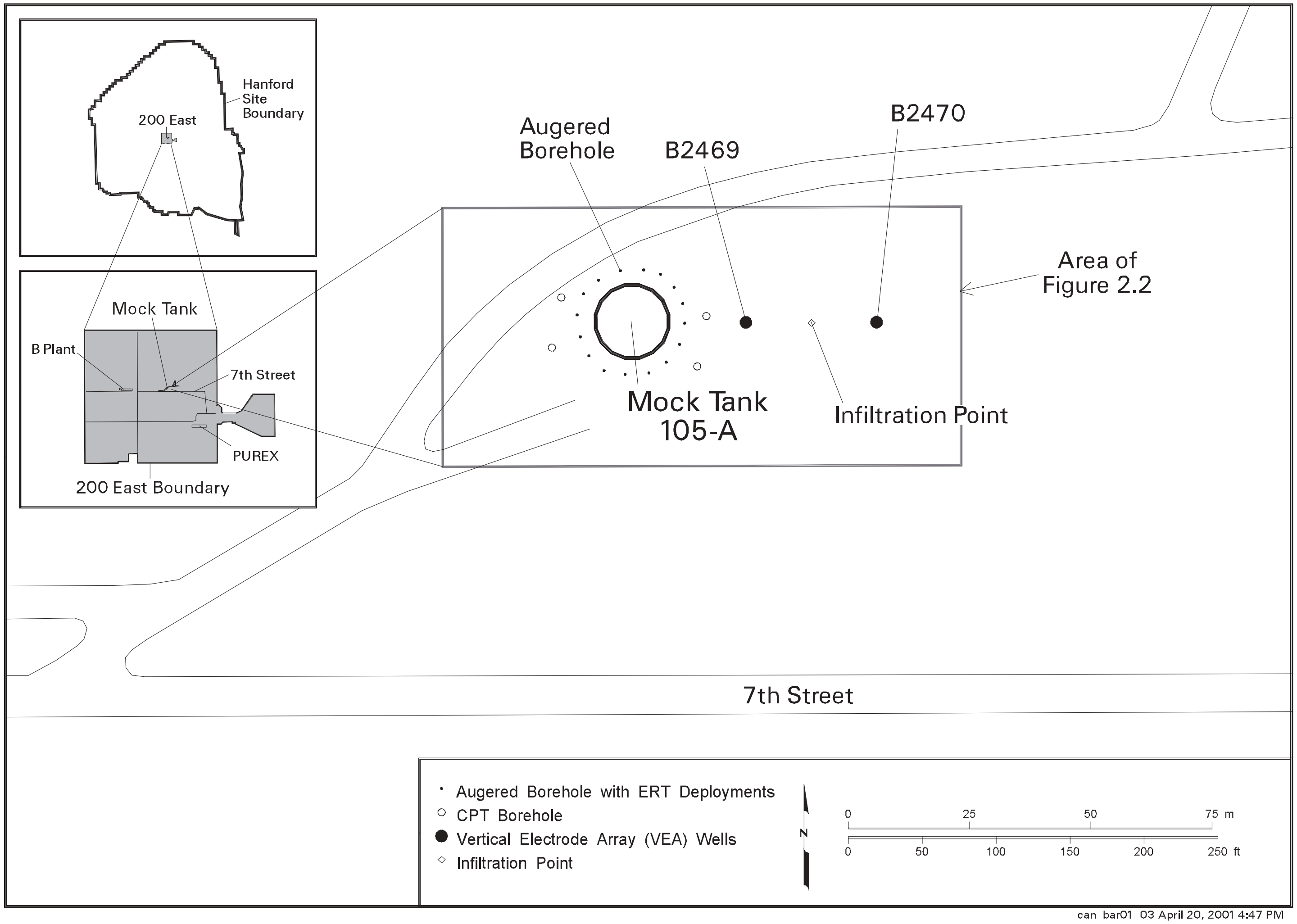

Figure C.1. Location of the Mock Tank Site

C.3 Testing and Monitoring Goals

The goals of the tests at the Mock Tank site during FY 2001 are to determine leak-detection capabilities of the five geophysical methods under controlled solution-release scenarios. The tests will be conducted in collaboration with a number of specially qualified scientists and engineers from other national laboratories and research firms, many of whom are also participating in the Science and Technology Initiative of the Ground Water Vadose Zone Project and Leak Detection, Monitoring, and Mitigation (LDMM) for the U.S. Department of Energy.

It is the responsibility of each person working at the site to ensure that his or her activities do not jeopardize the integrity of the other monitoring activities that are ongoing at the site.

C.4 Safety Requirements

Any accidents or immediate, uncontrollable safety concerns observed by workers at the site should be reported to site emergency services by calling 375-2400 or 911. *Note that 911 calls from cellular phones may be re-directed.* For additional assistance, call 373-3800 (Hanford Patrol) or radio the Safety Net at Frequency KOB743 (monitored by Hanford Patrol and by the PNNL Control Room [Station 62]). In the event that such communications are not available, a 24-h First-Aid Station is located at the intersection of Baltimore and 4th Street (Building 2719EA).

Site access and safety requirements refer only to the area within and immediately adjacent to the Mock Tank site. No radiological hazards are present at the site, but staff should be aware that radiological hazards do exist in areas surrounding the site.

Emergency Telephone Numbers

PNNL Emergency	375-2400
Hanford Emergency Response	811
Hanford Patrol/Fire/Ambulance	811

Warning Sirens

The following action should be taken relative to warning sirens:

- For all gongs and horns, go to the staging area, Baltimore Ave, 2750 parking lot
- Wavering Siren (get in vehicle, call emergency phone #, and follow directions)
- Howler (AH-OO-GAH). Get in vehicle, drive off the Mock Tank site, and leave area—preferably away from the criticality area.

Planned siren tests are frequent. Call DynCorp Emergency Prep. (373-4308) if questions arise regarding specific siren tests.

Accidents

The following actions should be performed if any accidents or immediate, uncontrollable safety concerns are observed by anyone at the site:

Immediately stop work. Evaluate the scene for safety. If safe, lend medical aid or prevent further damage. If unsafe conditions exist, deactivate and turn off applicable electrical and mechanical systems before lending assistance. Immediately notify site emergency services (above). If a telephone is available, call the emergency assistance number (375-2400) and be prepared to describe the accident and your location (the site location is described above). If no phone is available, use a radio to contact Hanford Patrol. In the absence of communication devices, send someone for help to the First-Aid Station at Baltimore and 4th Street (Building 2719EA). Notify your line manager and the project manager (Glendon W. Gee - 372-6096) or assistant project managers (Mark Sweeney - 373-0703; cell 521-4241 or Brent Barnett - 376-3416; cell 521-4895).

For General Work

When drill rigs are on the site and workers and collaborators are on the site, workers shall use hard hats and safety glasses and shall wear closed-top shoes. Steel toes in the shoes are not required for general work. For specific activities that pose additional potential hazards, such as digging or working with electrical or water-supply systems, additional requirements may include protective clothing (long-sleeve coveralls or equivalent work clothes), gloves, steel-toed shoes, or other safety needs. The project manager in cooperation with specific task leaders will analyze hazards and shall identify the additional appropriate combination of safety precautions (clothes, procedures, training, supervision, etc.) necessary for each type of work. Workers shall follow these requirements and only perform work for which they agree with procedural and safety requirements. Work shall not be performed when ambient weather conditions pose a threat to safety and health. Workers shall use caution in extended work in the full sun. To avoid heat stroke, workers are encouraged drink ample quantities of fluids.

A fire extinguisher shall be located onsite.

Additional Safety Requirements

The general requirements of this procedure are based on PNL-MA-43 and applicable Standards Based Management System (SBMS) Subject Areas. Specific requirements for other activities typically conducted at the site include:

Workers shall adhere strictly to all postings, caution, warning, and danger signs. Failure to do so shall result in immediate work stoppage. Workers shall pay attention to personal safety.

The need of a particular job to be controlled by a procedure shall be determined using PNL-MA-43 and applicable SBMS subject areas (e.g., working with chemicals, electrical safety, machine guarding). In this study, operation of neutron probes is the only task requiring a procedure and is governed by PNL-PSB-10-0. Workers performing these jobs must demonstrate knowledge of hazards associated with the work before commencing work.

C.5 Site Access Requirements

There are no formal site-access requirements. Access is gained via gravel roads from Seventh, and vehicular traffic is encouraged to travel only on the gravel roadways. Parking of vehicles adjacent to the roads is permitted, but vehicle parking is restricted to the north side of the Mock Tank injection site. Vehicles can be turned around by driving on the gravel perimeter road that goes around Crib 216-A-38-1.

In general, workers and collaborators should be cognizant of monitoring activities and work together under the defined schedule for the selective monitoring activities that are ongoing throughout the duration of the project.

Because there is a possibility that radioactive contamination may migrate onto the site, it is recommended that staff walking on the vegetation because of requirements to conduct civil and biological surveys should be aware of the potential for surface contamination via biotic pathways of biologic activity. For this reason, no animal droppings (feces) are to be removed from the surface without first contacting radiation safety and the project manager.

C.6 Potential Site-Impact Requirements

Activities that pose the potential to significantly affect monitoring conditions must be authorized and documented by the project manager. Examples of activities that pose such potential include (1) excavating sediments in unauthorized locations, (2) driving vehicles onto the Mock Tank site when monitoring is ongoing unless a drill rig or similar vehicle is scheduled and has been authorized for access on to the site, and (3) destroying, obscuring, or relocating radiation markers. This list is not intended to be complete, but is included to provide examples of the type of activities that may pose a potentially significant impact.

It is the responsibility of the project manager to determine if a monitoring or site-visit activity poses the risk to cause a significant impact based on the examples provided above and to obtain appropriate approval from the project manager. Before work, resolve with the project manager any uncertainty about the potential to cause a significant impact. Guidelines should be followed as outlined in PNL-MA-26 (Radiological Control Procedures) and PNL-MA-50 (Facilities Management Department PNL Operations Manual).

An activity is authorized if approval is obtained from the project manager. It is the responsibility of the project manager to determine the level of documentation needed for each unusual activity (no action, memo-to-file, or other documentation). Activities that pose the potential to affect the monitoring project must be documented in the project manager's site file. Workers who observe unexpected operations or conditions at the site must report the incident to the project manager (see Section 2.0)

C.7 Training Requirements

Signing this document provides the authority to access the site and perform monitoring work at the Mock Tank site.

Radiation Worker I training is required for operators of neutron probes. Training records for these activities will be on file with the individual worker and will be available upon request.

C.8 Site Safety Documentation

The following Job Hazard Analyses identify general site hazards associated with the deployment and operation of the geophysical methods planned for the TLDD in FY 2001. The forms have been prepared and approved by the operator for each specific activity (with borehole radar and seismic combined), and are based on expected conditions and experience with the 1995 project. The associated **Site Safety Checklist** is designed to ensure implementation of prevention and mitigation measures for the identified hazards.

The Chemical Process Permit addresses the solution release planned for the injection phase of the project. This permit requires that an eyewash station be installed at the work site during the handling and use of the 36% sodium thiosulfate solution.

Job Hazard Analysis	Geophysical Leak Detection Technology Demonstration	
Prepared by: William daily	Date: 4/4/1	Page 1 of __1_
Scope of Work: ERT at mock tank site		Contractor:LLNL
Emergency Contact Numbers: 925 422-8623 911		

Known or Potential Hazards			
Electrical (>50 V)	X	Remote Location	X
Hoisting/Overhead Work		Sharp Objects	
Manual Lifting/Carrying (>25 lb)	X	Pinch Points	
Heat Stress	X	Other (list) ____________	
Uneven Terrain/Tripping Hazards	X		
Hazardous Animals	X		

Work Activity	Hazards	Hazard Mitigation
Electrical resistance tomography	Voltages > 50 volts	High voltage elements covered
General	Remote location	2 working together and cell phone
General	Lifting	Two working together- proper lifting
General	Heat Stress	Drinking water; rest in shaded area
General	Hazardous Animals	Don't touch
General	Tripping	Site hazards barricaded and flagged

APPROVAL: [signature] DATE: 4-17-01

Job Hazard Analysis		Geophysical Leak Detection Technology Demonstration
Prepared by: Barry Kirkendall	Date: April 4, 2001	Page 1 of _1_
Scope of Work: 3-dimensional borehole electromagnetic induction imaging at the mock tank site.		Contractor: LLNL
Emergency Contact Numbers: Arleen Allsup (LLNL) 925-422-2305 Barry Kirkendall (LLNL) 925-423-1513		

KNOWN OR POTENTIAL HAZARDS			
Electrical (>50 V)	X	Remote Location	X
Hoisting/Overhead Work	X	Sharp Objects	
Manual Lifting/Carrying (>25 lb)		Pinch Points	X
Heat Stress	X	Other (list) ____________	
Uneven Terrain/Tripping Hazards	X		
Hazardous Animals	X		

Work Activity	Hazards	Hazard Mitigation
Electrical Transmitter Antenna Activation	Electrical Shock	Sealed Antenna Unit can not be opened during operation
Lowering Antenna (25 lbs.) into borehole	Overhead Work	Area around antenna is coned off and hardhats are used
Lowering Antenna (25 lbs.) into borehole	Pinch Points	Access to wench limited to timeframes where system is de-energized
General	Remote Location	2 working together and cell phone
General	Heat Stress	Drinking water; rest in shaded area
General	Hazardous Animals	Don't touch
General	Tripping	Site hazards barricaded and flagged

APPROVAL: [signature] DATE: 4-17-01

Job Hazard Analysis		Geophysical Leak Detection Technology Demonstration
Prepared by: J. B. Fink	Date: 09 April 2001	Page 1 of 1
Scope of Work: Electrical geophysical surveying at the Cold Test Facility		Contractor: HydroGEOPHYSICS, Inc. (HGI)

Emergency Contact Numbers:

(520) 647-3315 office — hydroGEOPHYSICS, Inc. (Tucson, AZ)
(520) 647-3461 home — Jim Fink

KNOWN OR POTENTIAL HAZARDS			
Electrical (>50 V)	X	Remote Location	X
Hoisting/Overhead Work		Sharp Objects	
Manual Lifting/Carrying (>25 lb)		Pinch Points	
Heat Stress		Other (list)	
Uneven Terrain/Tripping Hazards	X		
Hazardous Animals	X		

Work Activity	Hazards	Hazard Mitigation
String wires to ~1000'	Hazardous Animals	Avoid contact
Electrical surveying	Minor shock hazard	Insulate contacts
General	Minor trip hazard	Flag wiring
General	Heat stress	Desert acclimated

APPROVAL: [signature] DATE: 4-17-01

Job Hazard Analysis		Geophysical Leak Detection Technology Demonstration
Prepared by: E. L. Majer	Date: 4/17/01	Page 1 of ___
Scope of Work: Application of borehole seismic and borehole radar techniques at the Cold Test Site (Mock Tank-105A)		Contractor: Lawrence Berkeley Nat. Laboratory

Emergency Contact Numbers:
(510) 486-6709
911

KNOWN OR POTENTIAL HAZARDS

Electrical (>50 V)	X	Remote Location	X
Hoisting/Overhead Work		Sharp Objects	
Manual Lifting/Carrying (>25 lb)	X	Pinch Points	
Heat Stress	X	Other (list) ________________	
Uneven Terrain/Tripping Hazards	X		
Hazardous Animals	X		

Work Activity	Hazards	Hazard Mitigation
Cross hole radar and Cross hole seismic	Remote location	Cell phone, two people on site all times
	Lifting	Two working together- practice proper lifting technique
	Heat Stress	Drink water, rest in shaded area
	Hazardous animals	Gloves, be aware of reaching into blind areas
	Tripping	Flag hazardous areas or barricade
Cross hole seismic	Electrical > 50 V	High voltage elements are covered/insulated

APPROVAL: [signature] **DATE:** 4-17-01

CHEMICAL PROCESS PERMIT	**Permit No.: CPP-D9T81-Mock Tank** **Rev. No.: 0**	
Title: Subsurface injection	**Author: Mark Sweeney**	**Page** 1 of 4

Location(s): Geophysical Leak Detection Technology Demo (200E)	**Effective Date: April 3, 2001**

Permit Approvals/Signatures

Author — (Mark Sweeney) — 4-19-01 (Date)

Approval:

Immediate Manager — (Wayne Martin) — 4/19/01 (Date)

Concurrence:

S&H Representative — (PA Wright) — 4/23/01 (Date)

Additional Concurrences, as Appropriate:

Technical Reviewer — (Brent Barnett) — 4-20-01 (Date)

(Sam Juracih) — 4/23/01 (Date)

(Signature) — (Date)

(Signature) — (Date)

Identify Use Category: [ ] Mandatory Use
[X] Reference Use

4.0/0305e010.doc (9/99)

CHEMICAL PROCESS PERMIT	Permit No.: CPP-D9T81-Mock Tank Rev. No.: 0	
Title: Subsurface injection	**Author: Mark Sweeney**	**Page** 2 of 4

CHEMICAL IDENTIFICATION

The chemical hazards of each of the individual chemicals must be assessed. Chemicals with similar hazards may be grouped below. Chemicals on the OSHA-regulated chemicals, compounds, and carcinogens list (see "Exhibit: OSHA-Regulated Chemicals, Compounds, and Carcinogens" in *Working with Chemicals* SBMS subject area) must be identified individually.

Chemical/ Chemical Group	Chemical Hazard	Volume/ Quantity per Use	Frequency of Use
• Sodium Thiosulfate • Sodium Chloride	• Irritant • None	• 5000 Gal (5 injections @1000 gal each)	• Weekly

Description of Chemical Process: 1000 gal of saturated sodium thiosulfate with a small concentration of sodium chloride will be injected into test wells weekly using an elevated tank and a pump/flowmeter to transport the liquid from the tank into the well. The solution will be metered in at a rate to allow absorption of the solution by the soil.

CHEMICAL PROCESS HAZARDS ANALYSIS

☐Flammable/ Combustible	☐ Pyrophoric	☐ Toxic	☐ Oxidizer	☐ Asphyxiant
☐ Corrosive	☐ OSHA Regulated	☐ Compressed Gas	☐ Cryogen	☒ Other

Description of Hazards: Sodium thiosulfate is an irritant.

☒ Toxic by Inhalation	☐ Toxic by Absorption	☒ Toxic by Ingestion	☒ Toxic by Injection

Description of Risk Analysis: Sodium thiosulfate can be toxic at high enough concentrations if exposed for long periods of time or if exposure is to sensitive (e.g. mucous) tissues.

ENGINEERED CONTROLS

☐ General Ventilation	☐ Local Ventilation	☐ Snorkel Ventilation	☐ Enclosure	☐ Separation	☐ Storage

Description of Engineered Controls: None

ADMINISTRATIVE CONTROLS						
☒ Labels	☐ Chemical Inventory	☐ Operating Limits	☐ Inventory Limits	☐ Medical Surveillance	☒ MSDS	Exposure Monitoring ☐Yes ☒No
Description of Administrative Controls: All hazardous chemicals are properly labeled. MSDSs are available on line.						

PERSONAL PROTECTIVE EQUIPMENT			
☒ Safety Glasses with Side Shields	☐ Chemical Safety Goggles	☐ Chemical Splash Shield	☐ Respiratory Protection
☒ Gloves	☐ Gauntlets	☐ Lab Coats	☐ Lab Aprons
Description of Personal Protective Equipment: Since the solution is transported through a closed system, only safety glasses with side shields are required for eye protection. Latex gloves will be worn (under leather gloves if appropriate) when exposure to the sodium thiosulfate is anticipated.			

WASTE MANAGEMENT REQUIREMENTS		
☐ Sewer Discharge Permit	☐ Satellite Accumulation Area	☐ Treatment by Generator
Description of Waste Management Requirements: Ground injection is a permitted activity.		

LOCATION OF SPILL KITS	
Acid: None	Base: None
Mercury: None	Other: None

EMERGENCY RESPONSE	
In the event of an emergency or off-normal event, call **375-2400** then notify your Building Manager. State the problem, request any needed emergency assistance, and request notification of the appropriate personnel. If you need further instructions, be sure the PNNL Control Room Technician (375-2400) has the telephone number where you can be reached. This applies 24 hours a day, 365 days of the year.	
Location of Safety Shower: Portable wash unit will be on site	
Location of Eyewash: Portable wash unit will be on site	
Cognizant Space Glendon Gee Manager (Name): (alt) Mark Sweeney	Telephone: 372-6096 373-0703

CHEMICAL PROCESS PERMIT	Permit No.: CPP-D9T81-Mock Tank Rev. No.: 0	
Title: Subsurface injection	**Author: Mark Sweeney**	**Page** 4 of 4

Formal Training: [check required training]			
☒ Hazard Communications (671)	☐ Confined Space (694)	☐ Waste Management (833)	☐ Lock and Tag (692)
☐ Laboratory Hoods (685/686)	☒ Eyewash Safety Shower (695/696)	☐ GERT (817)	☐ Other
Job-Specific Training: Staff must understand the hazards presented by their specific work tasks, how to protect themselves from those hazards, and know the location of emergency showers and eye washes. Job-specific training will be fulfilled when the user has read this document and signed his/her name above.			

Geophysical Leak Detection Technology Demonstration
Site Safety Checklist

Field Work Checklist

- Site orientation (contact Mark D. Sweeney)
- Emergency communications available (e.g., cellular telephone)
- "Buddy System" (avoid working alone)
- Appropriate attire:
  - Shirt (consider sun protection)
  - Durable slacks
  - Substantial footwear
  - Hat (recommended)
  - Sunglasses (optional)
  - Leather gloves
- Protect from sunburn (clothing, sunscreen, shade)
- Drinking water – Stay hydrated!
- Water for hand washing
- Emergency eye wash during chemical injection, battery charging, or when other chemicals are being handled
- Combustible vegetation "grubbed" or cleared well away from equipment
- Fire Extinguisher present, maintained, and inspected
- Watch for spiders and snakes – avoid them if they are present

Electrical Safety:

- Equipment grounded (including generator bonding to "earth" ground)
- Electrical wiring in good condition
- Ground Fault Circuit Interrupter (GFCI)
- Generator operated only when site is attended

Emergency Procedure

Site location: 7th Street, immediately north of Hot Semiworks in 200 East Area; legal location: SE 1/4, NW 1/4, Section 2, T12N, R26E

Medical Emergency: Contact 9-1-1 and/or 375-2400
Transport minor injuries to 200W medical aid station

Fire: Contact 9-1-1 and/or 375-2400
Fight fire if you are able
Evacuate site

200 Area Emergency Alarms:
Constant siren – evacuate
Wavering siren – leave site and seek cover in nearest building

Site Contact Mock Tank:
Mark Sweeney – 373-0703 **Brent Barnett – 376-3416**

C.9 References

PNL-MA-26	Radiological Control Procedures
PNL-MA-43	Industrial Hygiene, Occupational Safety and Fire Protect. Programs
PNL-MA-50	Facilities Management Department PNL Operations Manual
SBMS	Standards Based Management Systems-Subject Areas.

Appendix D

Construction and Testing Procedures

Appendix D

Construction and Testing Procedures

D.1 Drilling and Borehole Construction Specifications

Drilling will be concerned with construction of borehole completions for both geophysical and Partitioning Interwell Tracer Test (PITT) technology instrument deployment. Specific details for construction of the boreholes and related quality control and safety issues are provided below. Figure D.1 illustrates the work site, showing existing features and planned borehole locations. This figure is intended for general reference; precise locations of new boreholes will be staked at the site.

Drilling and construction will consist of the completion of six vadose-zone geophysical logging boreholes and six vadose-zone tracer gas wells.

Each geophysical logging borehole will be 15.24 cm (6 in.) in diameter. These boreholes will be completed with sealed PVC casings (three wells) and sealed steel casings (three wells). Annular seal materials will consist of natural formation or drill cuttings.

Each vadose-zone tracer gas well will be 10.16 cm (4 in.) in diameter with a 3 m (10 ft) screen; the screen slot size will be based on field determination of dominant sedimentary grain size. Annular seal materials will consist of natural formation or drill cuttings.

A. 2001 Geophysical Logging Borehole Installation – General Description

Six vadose-zone geophysical logging boreholes will be constructed for the Geophysical Leak Detection Technology Demonstration project under this contract. Construction shall consist of six 15.24 cm (6 in.) boreholes with appropriately sized auger flights to keep the borehole open during drilling and completion. All boreholes will be sealed (water tight) at the joints and bottom.

B. 2001 Vadose Zone Tracer Gas Wells Installation – General Description

Six vadose-zone tracer gas wells will be constructed for the Geophysical Leak Detection Technology Demonstration project under this contract. Construction shall consist of six 10.16 cm (4 in.) wells with appropriately sized auger flights to keep the borehole open during drilling and completion.

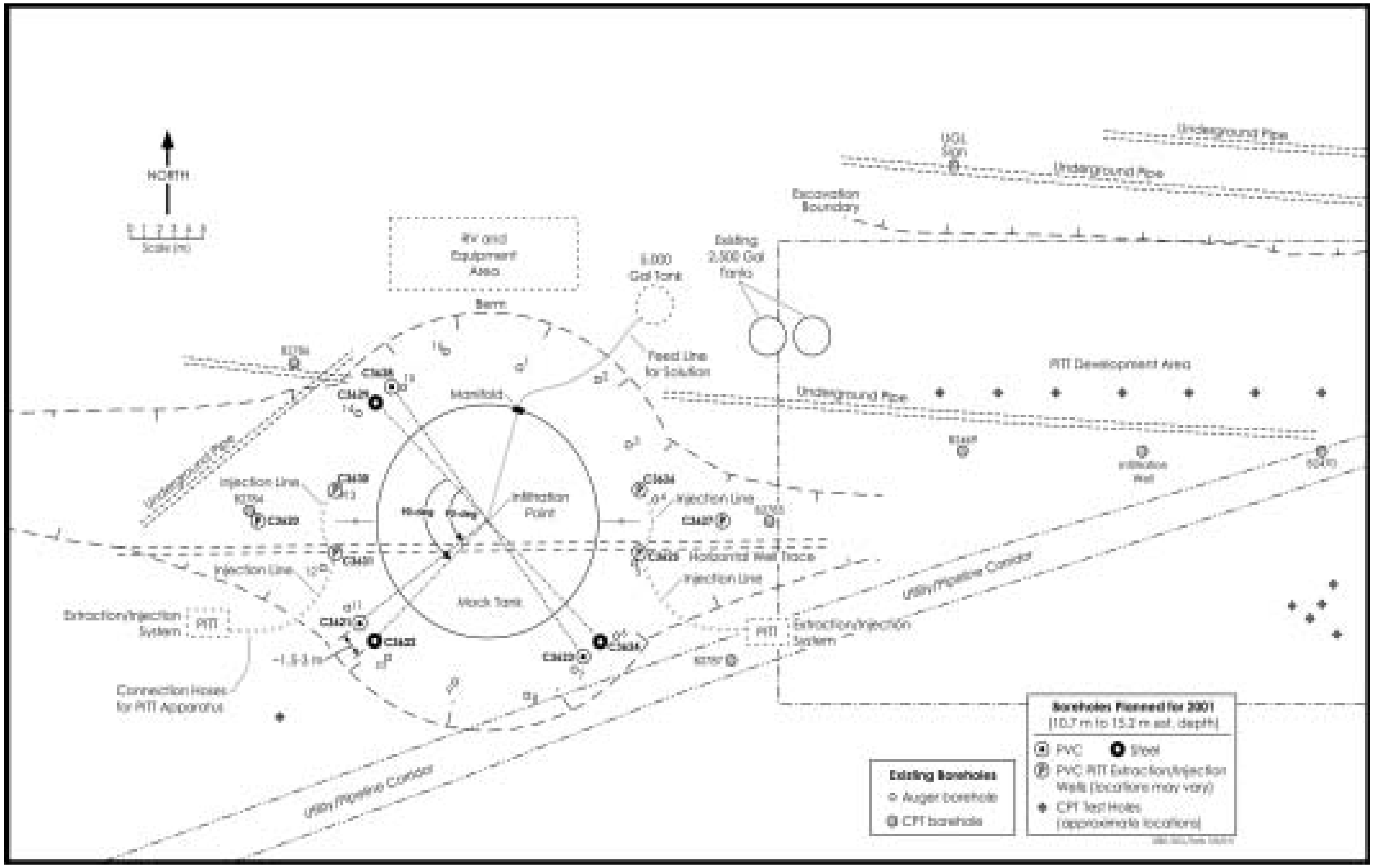

Figure D.1. Approximate Layout of Well and Borehole Configurations and Ancillary Equipment Planned for the Mock Tank Site for FY 2001. Also shown are existing infrastructure and boreholes, and GPR-determined subsurface piping.

D.1.1 Preparation for Drilling

The drilling contractor will ensure that the site is in acceptable condition for entry, all permits are secured, and commencement of drilling is advisable by:

- Submitting Washington State Department of Ecology Notification of Intent to Construct a Monitoring/Resource Protection Well forms and Washington State Department of Ecology fee in accordance with WAC 173-160 with a copy of the forms and a copy of the payment or receipt to Pacific Northwest National Laboratory (PNNL).

- Submitting at least 2 weeks before start of drilling for PNNL review, a site-specific Health and Safety Plan. All hazards not addressed in the Site-Specific Health and Safety Plan shall be addressed in a subcontractor's Activity Hazard Analysis, or Job Safety Analysis, and submitted to PNNL for review.

- Submitting worker status reports showing that workers meet the contractor's required training, medical, bioassay, and qualification expirations. Coordinate training and bioassay needs with PNNL's Training Representative.

- Ensuring that all equipment, materials, and personnel are readied for drilling and borehole construction.

- Identifying and confirming all surveyed drilling locations (designated by PNNL) with PNNL.

- Ascertaining and certifying that the site is adequately accessible for work to proceed at least 2 weeks before drilling. This should include the determination that drilling can proceed without damage to existing infrastruction, such as Electrical Resistivity Tomography (ERT) instrumentation.

D.1.2 Construction

Six boreholes and six wells shall be drilled for construction of the geophysical logging boreholes and vadose-zone gas tracer wells, respectively. Boreholes and wells will be drilled to a depth of at least 14 m (45 ft) below ground surface. The well casing will be temporarily secured and sealed. The drill rig will be moved to the next location. The boreholes will meet project test requirements for seals and backfilling boreholes, as described below.

A. Drilling

The drilling contractor will be responsible for advancing the well in accordance with this work plan to the depths required and for installing the casing and lengths of screen. Acceptable drilling methods *do not* include water, or mud, but do not preclude other circulation methods (e.g., air circulation). Sonic, auger, and cable-tool drive-barrel methods are also acceptable. The hard-tool cable-tool method shall only be used where debris fill is present in the subsurface or if boulders are encountered. Drilling will stop at approximately 14 m (45 ft), or at the point of refusal.

Drill cuttings will be placed on appropriate storage media (e.g., visqueen, tarps) for later completion of the wells. The contractor will take measures to ensure that the cuttings will not become a source of dust during storage.

PNNL will log all formation cuttings as necessary and interpret lithologies in accordance with existing standard procedures for lithologic logging and recording. PNNL, in consultation with geophysical contractors as necessary, will make all decisions regarding lithologic interpretations and consequent borehole completion details.

B. Completion

B.1 Geophysical Logging Boreholes

When the drill has reached total depth, the contractor will set the permanent casing in wells. The borehole will be completed with three 15.24 cm (6 in.) schedule 40 PVC casings and three 15.24 cm (6 in.) carbon steel casings in the vadose zone to a depth of 12 m (40 ft) below grade. Both steel and PVC casing sections will be joined so as to create a watertight seal from the formation. The bottoms of both steel and PVC casings will be sealed at the bottom so as to allow containment of water without leakage. Thus, all six geophysical boreholes will be completed as 15.24-cm- (6-in.-) inside-diameter (I.D.) sealed tubes capable of holding water and isolated from the formation environment. The casings shall extend to approximately 76 cm (2.5 ft) above ground. NOTE: *It is essential that the casings are installed with as little deviation from vertical as possible.*

Backfill will consist of drill cuttings or moistened drill cuttings. For the geophysical logging boreholes, electrical coupling with the soil is required. Hence, the driller will make efforts to ensure that the moistened cuttings fill the annulus completely. PNNL will ensure that the contractor provides a means for introducing moisture into the drill cuttings and uses the moistened cuttings to backfill around the permanent casings. A PNNL representative will evaluate the moisture content of the cuttings before placement.

B.2 Vadose-Zone Gas Tracer Wells

The wells will be completed with six 10.16-cm (4-in.) schedule 40 PVC casings in the vadose zone to a depth of 12 m (40 ft) below grade. The casings shall extend to approximately 76 cm (2.5 ft) above ground. Drilling will stop at approximately 14 m (45 ft), or at the point of refusal.

When the drill has reached total depth, the contractor will set screen and permanent casing in wells. The top of the screen will be set at 9 m (30 ft) below ground surface; however, some minor adjustments may be made as determined by PNNL interpretation of field conditions.

Backfill will consist of drill cuttings; no moisture will be necessary for the drill cuttings used in completing the vadose tracer gas wells. PNNL will select the appropriate screen slot size to meet backfill conditions; the wells should not be subject to silting or sediment accumulation after completion. A means of surging the wells *with air* after completion will be employed to ensure proper development of the fill surrounding the screened interval. *No water will be used in the development of the well.*

D.1.3 Waste Handling and Site Reclamation

The contractor will handle and dispose of all wastes generated during construction, development, and mobilization/demobilization in accordance with the Site Specific Waste Management Instruction. The contractor will affix appropriate labels onto the drums once they are sealed, wiped, and moved away from the immediate work area. The basic containment strategy is as follows:

All soil to the depth of interest is clean unless determined to be radiologically contaminated by field screening. Clean soil will be stockpiled on a plastic sheet near the point of origin. Provided the screening indicates that contamination is present, contaminated soil will be drummed in 208-L (55-gal) drums with 10-mil nylon-reinforced plastic liners and non-corrosive pad, and stored neatly on barrel pallets.

Because of the drilling techniques to be used, the subcontractor needs to be cognizant of formation washouts and use best available technology to minimize.

D.2 Cone Penetrometer Testing and Detailed Soil Characterization

In preparation for geophysical testing and PITT deployment at the Mock Tank, several cone penetrometer tests will be performed around and adjacent to the tank (refer to Figure D.1). These tests will provide baseline information on soil moisture, density (lithology), electrical resistivity, and permeability as ground-truth information on geophysical and PITT tests. Specific tests will include:

- Tip and sleeve pressure (cone penetrometer techniques [CPT])
- Pore pressure (CPT)
- Air permeability
- Electrical resistance at 2.54-cm (1-in.) resolution (CPT)
- Capacitance soil moisture content (CPT)
- Neutron moisture logging (in selected holes).

In addition, as many as five CPT holes will be emplaced in the southeast portion of the PITT development area (see Figure D.1) to characterize stratigraphy and measure infiltration rates and depths. Up to 1,514 L (400 gal) of sodium thiosulfate solution will be released in this location to determine preliminary infiltration properties of the solution. These observations will be used for comparison with geophysical method and PITT results and will be presented in final project reports.

D.3 Performance Criteria for Geophysical Methods

D.3.1 Applicability of Methods to Tank Farms Conditions

Hanford Site single-shell tank (SST) farms represent a complex array of surface and subsurface infrastructural features that affect the potential utility of any method of subsurface interrogation. It was also recognized that some advantage would be realized if existing dry-well arrays around the tank farms could be used for any potential methods. This limitation was recognized at the onset of the geophysical method- selection process for tank-farm applications.

Since the early 1990s, efforts have been ongoing to identify and refine various intrusive and non-intrusive methods of sensing conditions beneath SSTs (e.g., Brodeur et al. 1993; Narbutovskih et al. 1996a, 1996b; Ward and Gee 2000). Recent and current testing at the Vadose Zone Transport Field Study (VZTFS) site (Sisson and Lu site) have also shed light on the effectiveness of the various proposed geophysical methods and have provided a basis for further evaluation of these methods. Salient elements of the performance of the methods and recommendations for continued evaluation in the FY 2001 Mock Tank study are summarized below.

Hanford Site Setting and Method Selection Criteria

The vadose zone beneath the Hanford Site is comprised of coarse sands and gravels with periodic layers of fine sands, silts, and partially cemented carbonates. The sediments are typically well drained, having water contents as low as 4% (or lower) by volume (Narbutovskih et al. 1996). This circumstance provides an ideal environment for the deployment of certain geophysical methods in determining changes in soil properties over time, particularly moisture contrasts.

Electrical and electromagnetic methods efficiently exploit these changes because the methods respond to the relative electrical conductivities or dielectric properties of the earth materials. In the case of a given volume of soil, these changes in effective dielectric properties over time will be due mostly to changes in the amount of the interstitial moisture, or change in the conductivity of the interstitial fluid, or both. In a desiccated environment such as the Hanford Site vadose zone, even small changes in moisture content will often provide enough contrast in moisture to allow detection and tracking of small subsurface fluid releases by some of these methods. Initial trials of these methods at the Hanford Site indicate that further examination is warranted (Ward and Gee 2000; Ward and Gee 2001).

In some cases, the introduction of fluid into dry soil will produce enough contrast in bulk soil density or saturation so as to provide an opportunity for imaging by acoustic methods. This involves release and recording of mechanical energy in the subsurface. It can be shown, for instance, that progressive saturation of a soil usually produces attenuation of a seismic signal.

In contrast, electrical imaging depends on the effective resistivity, dielectric constant (or relative permittivity) of the medium, and is strongly affected by the salt content of the pore fluid. The resistivity of Hanford sediments is quite high, typically above 200 ohm-meter. The addition of a saline solution of even low concentration (<0.1 M) can cause the effective resistivity to drop to a few ohm-m or less. Tank leaks are expected to be highly saline (>5 M) (WHC 1992) and thus provide a striking contrast in effective dieletric from background, and this change in property can be used diagnostically in electrical imaging to detect a tank leak.

Electrical Resistivity Tomography (ERT)

Although steel well casings create serious electrical short circuits that affect the sensitivity of all electromagnetic methods, especially in the vertical, ERT has been determined to work satisfactorily at a site when the effects of the steel casings are properly modeled. The steel casings can also be used as long electrodes to produce images of coarse resolution. ERT results compared reasonably well with neutron probe studies to show tracer plumes (Sisson and Lu site). Also, the location and general size of the plume(s) as determined by ERT and neutron data generally agreed, as did mass-balance calculations from both, which appear to be realistic.

ERT is consistent with tank farm deployment if the dry wells could be used as long electrodes. These wells could be supplemented with additional electrode arrays located outside the tank farm boundary to allow ERT leak detection underneath the tanks. Thus, the method might not require new drilling inside the farms.

ERT was deployed at the Mock Tank site in 1995 and 1996 and produced encouraging results. A set of tomographs using the original array (Ramirez et al. 1995) is shown in Figure D.2. This study tracked the leak to the bottom of the array at 10.7 m (35 ft). As shown in Figure D.2, the leak was detected after 1200 L (317 gal) was released. In the 1996 CPT tests, 11,360 L (3,000 gal) of 0.80 molar solution of NaCl was released over a period of several days at a side-leak location on the tank (Narbutovskih et al. 1996b). This leak was detected after 6,353 L (965 gal) were released. The noise-to-signal was low, which is encouraging, since this allows increased sensitivity. This test followed the leak the 21.3 m (70 ft) before it migrated out of the vertical plane of the tomograph. It should be noted that for each test, the leak rate was very low, similar to that expected for an actual tank leak.

Cross-Borehole Seismic Tomography (XBS) and Cross-Borehole Radar (XBR)

The most recent application of these two complimentary methods at the Hanford Sisson and Lu site were particularly encouraging. The XBR results indicate that the method could image up to 20 m (66 ft) if the proper frequencies are selected (e.g., 50 KHz). Seismic results show that imaging across 20 to 30 m (66 to 98 ft) is possible with retention of high resolution.

Of particular significance is the reinforcing nature of the two methods when used in combination. XBR is primarily sensitive to moisture content of the soils, and XBS is sensitive to porosity. One of the objectives of the continued evaluation of the combination is to merge and jointly interpret the XBR method's high resolution of the lithology together with the XBR high resolution of moisture changes.

Preliminary results from the Hanford Site Sisson and Lu study indicates that the XBR method delineated geological layers 0.25 to 3.5 m (0.82 to 11.5 ft) thick with 0.25 m (0.82 ft) resolution, and resolved moisture movement within 0.25 m (0.82 ft). The XBR method was documented to penetrate up to 20 m

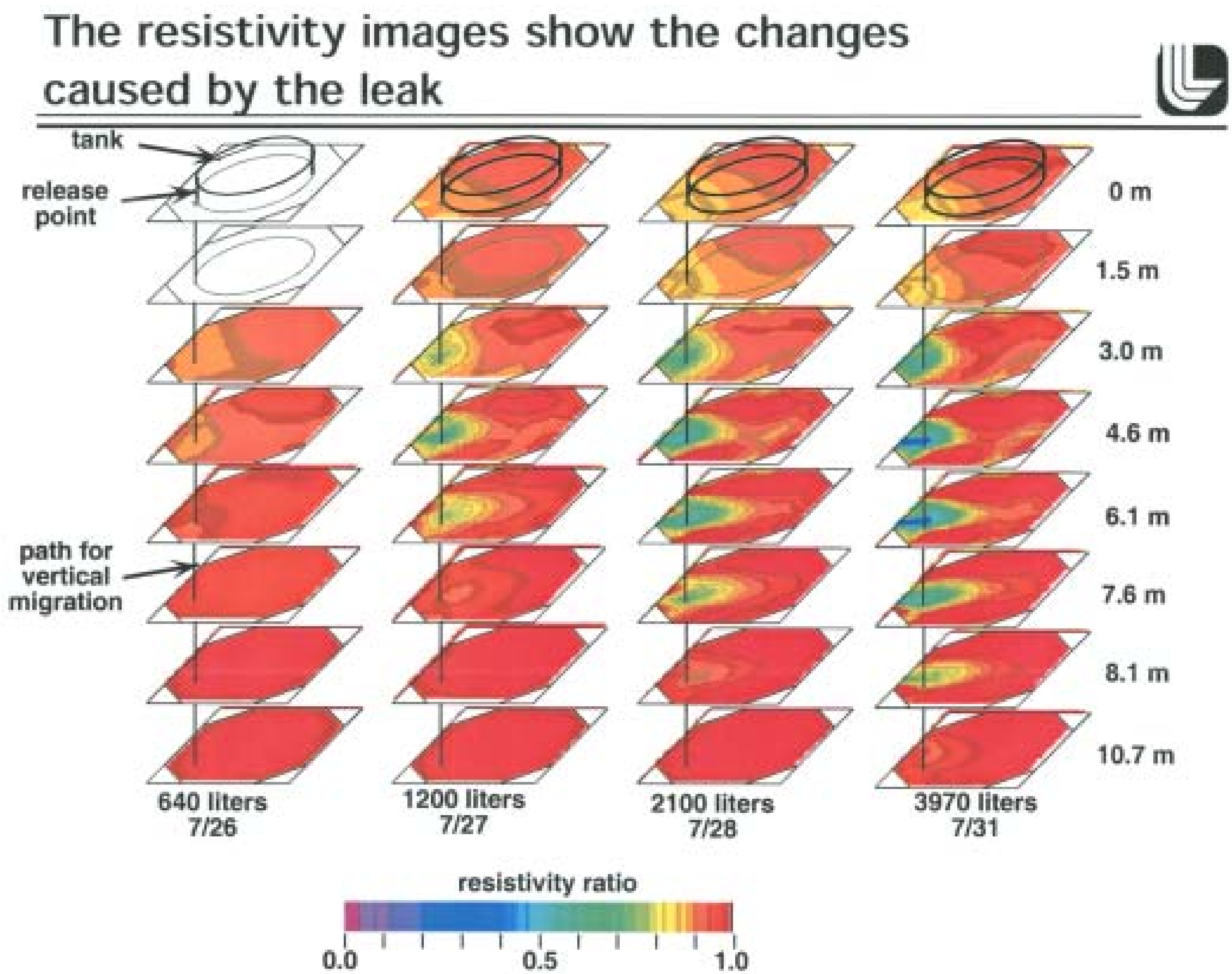

Figure D.2. Two-Dimensional Tomographs from the 16 Augered Vertical Electrode Arrays Near the Mock Tank Collected During Testing Over a 4-Day Period in 1995 (after Ramirez et al. 1995)

(66 ft) from the source well, and the XBS method penetrated over 20 m (66 ft), with a potential for extension to 30 m (98 ft) or more. The XBS method will work in both PVC and steel installations, but thus far, the XBR method is functionally limited to non-metallic casings.

Cross-Borehole Electromagnetic Induction (CEMI)

The Cross-Borehole Electromagnetic Induction method now deployed at the Sisson and Lu site is an offshoot of successful tests at this same site during FY 2000. The first test used surface and surface-to-borehole deployments, but this and other tests (Spies and Habashy 1995; Hoversten et al. 2000; Newman and Alumbaugh 1997) have indicated the prospect of successful application of CEMI deployments for Hanford tank farm scenarios. Results to date indicate that a thorough noise analysis is necessary to acquire reliable three-dimensional imaging with this method. While it is determined that the presence of steel-cased wells will not disrupt the CEMI method, the actual use of these as source boreholes is in question. Recent tests also showed consistency with high-resolution resistivity (HRR) results.

High-Resolution Resistivity

HRR was deployed at the Sisson and Lu site in FY 2000 and again in FY 2001 to detect the shape and extent of contaminant plumes. The FY 2000 test involved multiple injections (total of 18,930 L [5,000 gal]) of low salinity river water, while the FY 2001 test, which is currently ongoing, has involved multiple injections (18,930 [5,000 gal] total) of a highly saline (3 M) sodium solution.

In FY 2000, the surface-electrode method was tested and demonstrated that fluid injections could be detected in the vadose zone. The lateral spread of the plume was captured in a reasonable manner, while detail of the vertical extent of the plume is only qualitatively assessed. Because the plume could be reasonably well detected, and dielectric properties of a tank leak would cause a more dramatic change in the effective dielectric or resistivity, it was reasoned that HRR would be a good candidate for leak detection of saline fluids because the capability of HRR to detect changes of dielectric properties, even in an electrically noisy environment, has been demonstrated at the Sisson and Lu site.

In the typical tank farm environment, HRR appears to have the potential for non-invasive mapping of changes in character of the Hanford sediments, including the “footprints” of past leaks and monitoring of active leaks; by previous experience at the Sisson and Lu site, larger arrays, employing more effective electrode grounding, are indicated.

In addition to the non-invasive nature of HRR application, the method may be especially useful in conjunction with existing infrastructure at tank farms. The existing steel-cased wells at these facilities may be used as deep line-source electrodes.

D.3.2 Geophysical Instrumentation, Instrument Response, and Sources of Error

Below are provided basic system descriptions for the five geophysical methods planned for use at the Mock Tank in FY 2001.

The discussion of error and interference represents the most prominent known or documented sources of these problems.

ERT

Instrumentation: The sensors consist of 16 existing borehole electrode arrays surrounding the Mock Tank, with eight electrodes spaced 1.5 m (5 ft) apart vertically within each array (see Figure 2.4). The main components of the data collection and recording system are Zonge Engineering[1] transmitter, multi-channel receiver, multiplexer, isolation amplifier, and Hewlett Packard[2] current monitor and DC power supply.

Expected Maximum Resolution: 380 to 755 L (100 to 200 gal) of solution may be detected by the method during the first release (compared with background).

Sources of Error or Interference: ERT data cannot be effectively collected in the presence of strong direct current (DC) signals such as produced by the HRR system, which will be deployed during the testing. For this reason, ERT and HRR measurements will be alternated during critical periods, primarily during the solution-release events. Extraneous metal or conductive infrastructure in proximity to the electrode arrays may cause interference with ERT signal (e.g., steel casings installed too close to the arrays). For this experiment, new steel casings will be located so as to minimize such interference.

XBR

Instrumentation: The downhole components consist of a dipole antenna(s) (transmitter in one borehole, receiver in another) with lengths of 0.5 to 2.0 m, depending on frequencies desired. The frequencies anticipated for use are 50, 100, and 200 MHz. Measurement intervals in the boreholes will be from 0.25 to 2.0 m.

Expected Maximum Resolution: A 0.25- to 0.5-m resolution is sought in features, which will be extrapolated to volume measurements. The expected minimum volume for detection is 380 to 1,890 L (100 to 500 gal).

Sources of Error or Interference: As with any cross-borehole method, areas of low resolution exist near the upper and lower portions of the vertical tomogram in a parabolic configuration, with the maximum thickness of nonresolved image occurring at the center of the tomogram. The most favorable aspect ratio is 2:1, well depth to well separation. Horizontal tomography (using several wells) is a potential solution to this problem.

The radar signal will not penetrate steel-cased wells; therefore, only PVC or open boreholes are usable for the method. Also, a trade-off exists between resolution and range of detection in that higher

[1] Zonge Engineering, Tucson, Arizona.
[2] Hewlett Packard, Palo Alto, California.

frequencies will allow greater resolution, but penetration into the medium is limited. Conversely, greater penetration by lower frequency signals will sacrifice resolution.

XBS

Instrumentation: The receiver is either a three-axis geophone clamped to the casing at specified intervals in a dry steel or PVC well, or a string of up to 24 hydrophones suspended in a water-filled well casing. The hydrophone string would allow more rapid data collection, but wells must be filled with water, and only P wave data are collected. Both steel or PVC-cased wells are usable for the method. The energy source is a 3.8-cm x 10-cm (1.5-in. x 4-in.) long piezoelectric cylinder. An OYO DAS-2[1] recorder will be used for data collection.

Expected Maximum Resolution: 0.25-m to 0.5-m (0.82-ft to 1.64-ft) resolution of structure. The minimum volume of released fluid detectable is unknown at this time. The determination of this parameter is part of the experimental objectives.

Sources of Error or Interference: Generally the same as **XBR**, except that signal attenuation occurs with increased moisture content of the soil.

CEMI

Instrumentation: The main sensor components are a vertical magnetic field transmitter and magnetic field sensors. The transmitter generates a time-varying magnetic field that produces secondary magnetic fields in the soil. The secondary field signal in combination with the transmitter field (measurement at the receivers) is used for non-linear inversion techniques to develop a three-dimensional tomogram of the media conductivity.

At 80-KHz frequency, the CEMI system has an accuracy of approximately 2% of the well separation distance. Reproducibility of profiles, based on past experience, is within 1%. Additionally, passive data (from other sources) are collected with a 100- to 200-KHz antenna with a spectrum analyzer to determine noise levels and to avoid harmonic interference with outside signal sources.

Expected Maximum Resolution: Numerical modeling indicates that a solution release volume of <7,570 L (<2,000 gal) is detectable.

Sources of Error or Interference: The method is subject to interference by steel infrastructure or wells in the imaged volume of the medium, but may be adaptable for deployment in metallic casing with some success. Typical separation distances between transmitter and receiver that would be necessary around a tank are disadvantageous to the method, largely due to the resistive nature of Hanford Site soils (very high frequencies are required to create measurable inductive signal); as with XBR, a trade-off exists between frequency and resolution and range. The operation of this method is incompatible with simultaneous operation of HRR and ERT methods.

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[1] Trademark of OYO, Inc.

HRR

Instrumentation: Data will be collected and pre-processed using the Advanced Geosciences, Inc. SuperSting[1] R8 IP memory earth resistivity meter. Electrodes will be emplaced in the soil around the Mock Tank, and will be connected to the tank and the center leak point. Additional electrodes may consist of using the existing ERT arrays to simulate metal casing installations.

Positional accuracy is crucial in using this method. The system is usually configured using a Javad[2] geodetic-grade global positioning system operating in real-time kinematic mode.

Expected Maximum Resolution: Detection of a leak may occur almost instantaneously with the "in-container" electrode array, but the practicality of this configuration is problematic. The minimum volume needed for volume estimate, based on experience at the VZTFS site, is <3,785 L (<1,000 gal).

Sources of Error or Interference: Strong sources of direct current or surface electrical fields capable of significant induction (in proximity to connecting wires, etc.) must be avoided. Electrodes must have sufficient continuity with the formation to avoid loss of signal (high electrode-to-ground resistances can cause discrepancies in measurements). Spherical error precision on positioning is 0.02 to 0.03 ft. Positional accuracy of ±1% of distance between sensors is appropriate for the HRR system.

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D.5 Description of the PITT Technology and Process

The Partitioning Interwell Tracer Test (PITT) technology uses the principle of chromatographic separation through partitioning-induced flow retardation of tracers to quantify substances of interest in the swept zone. The elution curves of tracer concentration are subjected to first-temporal-moment analysis to provide near-real-time quantitative information on the substance of interest, and the data can be used with inverse modeling codes to provide more detailed information on location and localized concentrations; inverse modeling requires 1 to 10 h of data-processing time, depending on the degree of output detail desired. PITTs are one of the few technologies for subsurface characterization that sample and integrate over a large volume, eliminating the need for expensive "pincushion" sampling-well arrays that often fail to achieve a representative sampling of the subsurface. The PITT technology is also the only volume-integrating subsurface characterization technique that does not rely on electrical or electromagnetic methods (which are subject to interference from subsurface or above-ground metallic objects, such as tanks, pipes, or power lines).

In the proposed tank-leak application of the PITT technology, a zone underneath the tank undergoing waste removal will be swept by an air-advection flowfield into which tracer gases with varying partition coefficients (K_i) will be periodically injected and the flowfield extraction wells will be sampled to produce tracer concentration vs time data. The extraction wells will also be monitored for the presence of volatile tank-waste substances.

The tracer elution curves (tracer concentration vs. time data) will be analyzed by the first-temporal-moment method: the quotient of the curve centroids (t_p/t_n, equal to the retardation factor R_f) and the partition coefficients (K_i, equal to the ratio of equilibrium concentrations in the two phases of interest $C_{i, air}/C_{i, water}$) of the partitioning tracers will be used to establish a baseline of soil-water saturation (S_W); any increase in this saturation measured by subsequent PITTs will indicate a tank leak, as will detection of volatile tank waste vapors (e.g., ammonia, butanol, or acetone) or radioactive gases (^{135}Xe or Rn, with the Rn emanating either from tank wastes or from soil-column displacement by aqueous influx). Additionally, introduction of conservative tracer into the tank and its detection in the advective flow stream may also provide an indication of a leak.

D.6 Contacts for Additional Information on Methods

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