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A Survey and Description of Candidate Technologies to Support Single Shell Tank Waste Retrieval, Leak Detection, Monitoring, and Mitigation

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Prepared for the U.S. Department of Energy
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Pacific Northwest Laboratory
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A Report for Westinghouse Hanford Company

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Summary

The subject report is part of a two-year, three-phase activity that will 1) establish functions and requirements (F&R) for leak detection and monitoring (LDM) of Hanford single shell tanks (SST) during waste retrieval, 2) identify candidate LDM technologies that could be applied to this task, and 3) apply risk-based decision making to determine activities and technologies that should be implemented to support planned retrieval tasks. Three separate documents have been prepared to address these issues:

1. Functions and Requirements for Hanford Single-Shell Tank Leakage Detection and Monitoring (Cruse et al. 1995)

2. A Survey and Description of Candidate Technologies to Support SST Waste Retrieval, Leak Detection, Monitoring, and Mitigation (this report)

3. Technology Issues Related to SST Waste Retrieval, Leak Detection, Monitoring, and Mitigation: A Qualitative Assessment of the Potential to Reduce Risk Through the Use Of LDMM Technologies (Peters and Treat 1995).

Leak detection consists of three elements:

1. Detection
2. Confirmation
3. Quantification.

This report evaluates and recommends candidate technologies according to their capability to support these three requirements. The final recommendations are in the following table.

Comparison of Recommended Technologies for External Leak Detection			
Technology	Detection	Confirmation	Quantification
TDR	◩	●	○
Neutron-Neutron Logging	○	●	○
Passive Gamma Ray Logging	○	●	○
FID/ENRAF	○	◩	●
ERT	●	○	◩
Tracer Gases	◩	●	○
Key	●	Best	
	◩	Good	
	○	Poor	

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1.0 Introduction

1.1 Background

There are 149 single shell tanks (SSTs) at the Hanford Site designed to store high-level wastes generated during the separation of plutonium from fission products. The first SSTs became operational during the 1940s, and many still contain high-level wastes. With the exception of tank C-106, retrieval of waste from the SSTs currently is scheduled in a 15-year processing campaign to begin in 2003 and end in 2018. Waste in tank C-106 is planned for retrieval in 1997 to provide a demonstration of retrieval technology (Cruse et al. 1995).

Currently, 67 SSTs are classified as assumed leakers. An estimated 2,271 to 3,407 m^3 (600,000 to 900,000 gallons) (Hanlon 1993) of waste has leaked from these tanks over the past 40 years. Leaks have resulted primarily from corrosion, cracking, and mechanical damage in various locations in the tanks. In some cases, leak pathways have subsequently been plugged with waste salts. Retrieval of waste from SSTs using the design basis retrieval system (i.e., hydraulic sluicing) will involve the addition of liquids to break up and mobilize the waste for transport and is likely to result in some additional waste leakage. Understanding the mechanisms and characteristics of leakage and the rate and magnitude of leaks that may occur during waste retrieval are part of the design and planning process of remediation activities. Current technical and operational response to leakage during waste retrieval will be evaluated and planned in the context of risk reduction and cost benefit. The subject document is part of the first phase to identify and evaluate candidate leak detection technologies that may play a part in the SST waste retrieval effort.

Tri-Party Agreement (TPA) milestone M-45-08 addresses the mitigation of tank leakage during waste retrieval operations. Milestone M-45-08-T02 requires the establishment of criteria to determine allowable leakage volumes and acceptable leak detection, monitoring, and mitigation (LDMM) measures to permit retrieval operations. The goal of the ongoing LDMM activity, and the subject report, is to support the TPA milestone. Leak detection technologies (LDTs) identified within this study will be evaluated along with retrieval operations, closure, and other related issues to determine risk reduction and cost-benefit that could be derived if they were deployed.

The subject report is part of a two-year, three-phase activity that will 1) establish functions and requirements (F&R) for leak detection and monitoring (LDM) of Hanford SSTs during waste retrieval, 2) identify candidate LDM technologies that could be applied to this task, and 3) apply risk-based decision making to determine activities and technologies that should be implemented to support planned retrieval tasks. Three separate documents have been prepared to address these issues:

1. Functions and Requirements for Hanford Single-Shell Tank Leakage Detection and Monitoring (Cruse et al. 1995)

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3. Technology Issues Related to SST Waste Retrieval, Leak Detection, Monitoring, and Mitigation: A Qualitative Assessment of the Potential to Reduce Risk Through the Use Of LDMM Technologies (Peters and Treat 1995).

Cruse et al. (1995) provides a preliminary identification of functions and requirements for SST leak detection and monitoring. The document identifies applicable or relevant and appropriate requirements (ARARs) for volumes of leakant and introduces the concept of a leakage threshold value (LTV). The LTV is a preliminary risk-based quantity of leakage calculated for each tank that equates to either a 10^{-4} excess cancer risk or a Hazard Quotient of 1.0. The risk is based on fate and transport modeling of contaminant leaked from a SST, with a surface barrier, leaching to groundwater, and migrating down gradient where a future resident would be exposed through ingestion of groundwater and ingestion of vegetables irrigated with groundwater. A LTV was calculated for each SST based on the volume of contaminants of concern (COC) measured in the respective drainable liquids. The resulting LTVs range from 0.05 L (0.014 gallon) to 10,200,000 L (2.7 million gallons). In addition to LTV values, Cruse et al. (1995) also provides enabling assumptions, operational restraints, and potential methodologies to determine the risks presented by SST leaks.

This report provides a screening of currently available LDTs, and focuses on candidate technologies that could potentially support SST waste retrieval operations. Such technologies are considered potentially capable of supporting the LDM functions and requirements. The initial scope and purpose of this report was to perform a comprehensive evaluation of leak detection technologies that could be applied to the SSTs during their entire life cycle: storage, retrieval, and closure. The evaluation would also have recommended a toolbox of LDTs that could address potential tank leakage scenarios in light of the LTVs developed in Cruse et al. (1995). Unfortunately, the budget for this task had to be accordingly and a complete evaluation was not possible. A comprehensive evaluation was not performed, and this report was instead limited to recommending a LDT toolbox for retrieval based on 1) an earlier abbreviated evaluation of external LDTs (Lewis and Teel 1994), plus 2) the findings of an ongoing evaluation of internal LDTs. The focus of this study has been on LDTs that would support waste retrieval operations that used the design basis, high-volume/low-pressure hydraulic sluicing method (Bazinet 1993).

Peters and Treat (1995) addresses potential risk reduction and cost benefit that could be realized from deployed leak detection technologies. Data and information from the other two documents were combined to determine if LDTs can cost-effectively mitigate future risks that could arise from leakage during SST waste retrieval. Leakage mitigation would be pursued using LDTs to support the retrieval process and operational leakage response strategies and procedures. This document was also subjected to budget cutbacks, resulting in a product of greatly reduced scope. However, a qualitative study of potential risk reduction by deployment of LDTs was prepared and will serve as the technical and reference basis for a planned LDM trade study that will specifically address the first SSTs to be remediated.

1.2 Leak Detection Philosophy

A philosophy, or approach, to leak detection arose from consideration of the LDM functions and requirements. The technical assumptions, operational constraints, and primary LDM roles stated in the F&Rs provide the bounding case conditions/tests that generally can be applied to any candidate LDM technologies in order to determine a potential contribution to support SST waste retrieval.

"False positive" leakage indication (i.e., the indication of a leak when one has not occurred) was one such constraint. This document addresses leak detection during SST waste retrieval; therefore, it was important that candidate leak detection system deployed minimize the potential for a false positive. This constraint has been addressed by recommending LDTs that are expected to have a low probability of false positives and, more importantly, recommending the use of multiple technologies that would use different physical measurements to detect leaks.

The F&Rs document identified three essential elements of LDM:

1. Detection
2. Confirmation
3. Quantification.

This report evaluates candidate technologies according to the capability to support these three requirements. Technologies appropriate for detection should ideally have good sensitivities, large volumes of interrogation, and be capable of continuous operation. Detection systems should have the capability to detect a leak well before the LTV is reached.

Once a potential leak is detected, then confirmation system(s) would be deployed. Confirmation technologies should have a high degree of precision, very good sensitivity, and little ambiguity. The latter quality is very important because the results from a confirmation system would be used by decision makers to guide the operational response and remaining retrieval process. Methods to reduce ambiguity include acquiring baseline readings before retrieval, using a LDT that measures a physical property that requires little inference to link to leakant, and using a confirmation technology that measures a different physical property than the detection system (e.g., neutron moderation for confirmation, electrical conductivity for detection) measures.

The final task of a leak detection system would be to quantify the leak to determine if the LTV has been approached during a leak. The LDM functions and requirement document (Cruse et al. 1995) developed LTVs, a tank-specific quantity of leakant that could lead to an unacceptable human health risk.

1.3 Report Organization

This report was initially designed to provide a comprehensive review of potential LDTs. To this end, the report would contain several sections outlining the selection process. The purpose was twofold: 1) the reader would have a clear understanding of why specific technologies were recommended or not recommended, and 2) the reader could apply the same process in the future as new LDTs become available. Curtailment of project scope has prevented the development of the requisite judging criteria. The report has been modified accordingly.

Section 2 of this report presents the baseline and guiding assumptions that were used to judge the LDTs. These assumptions include the environment where the technologies would be employed (i.e., the tank farms), the potential leak detection targets (i.e., physical properties), and anticipated leak mechanisms (i.e., leak points, rates).

Section 3 presents a brief review of the methods used to arrive at the recommended LDTs. It also includes a description of the different technology families considered. Curtailment of funding and project scope midway through the task prevented complete discussion of the requisite judging criteria that was applied. Only the final results of this effort are presented.

Section 4 presents the recommended LDTs along with detailed descriptions of each that include sensitivities, operating parameters, and costs.

2.0 Tank Farm Assumptions

As stated in Section 1, the purpose of this report is to provide a screening of currently available LDTs, with a focus on candidate technologies that could support SST waste retrieval operations. This section of the report presents the baseline assumptions that were used to judge the LDTs. These baseline assumptions included the structure and operational guidelines employed at the SSTs and associated tank farms, brief description of wastes that could be leaked, anticipated leak mechanisms and volumes, LDTs currently employed at the SSTs, and potential SST waste retrieval technologies.

2.1 Single-Shell Tanks

2.1.1 Description of Structures

There are 149 SSTs and 28 double-shell tanks (DSTs) at the Hanford Site. They contain high-level radioactive and hazardous waste generated during the processing of irradiated fuel elements. Leaks of tank waste into the surrounding soils have been confirmed for 68 SSTs (WHC 1993); no DSTs are believed to have leaked. Thus, this report will focus upon the SSTs exclusively.

The SSTs are cylindrical, dome-topped tanks constructed of reinforced concrete with an inner steel liner (Figure 2.1). They are classified as 100 series (500,000 gal, 750,000 gal, or 1 Mgal) or 200 series tanks (55,000 gal). The 100 series SSTs are the focus of this report. Tanks in this series are 75 ft. in diameter, have a minimum of 5 ft. of soil cover atop the dome, and a below-grade invert elevation of 37 to 51 ft.

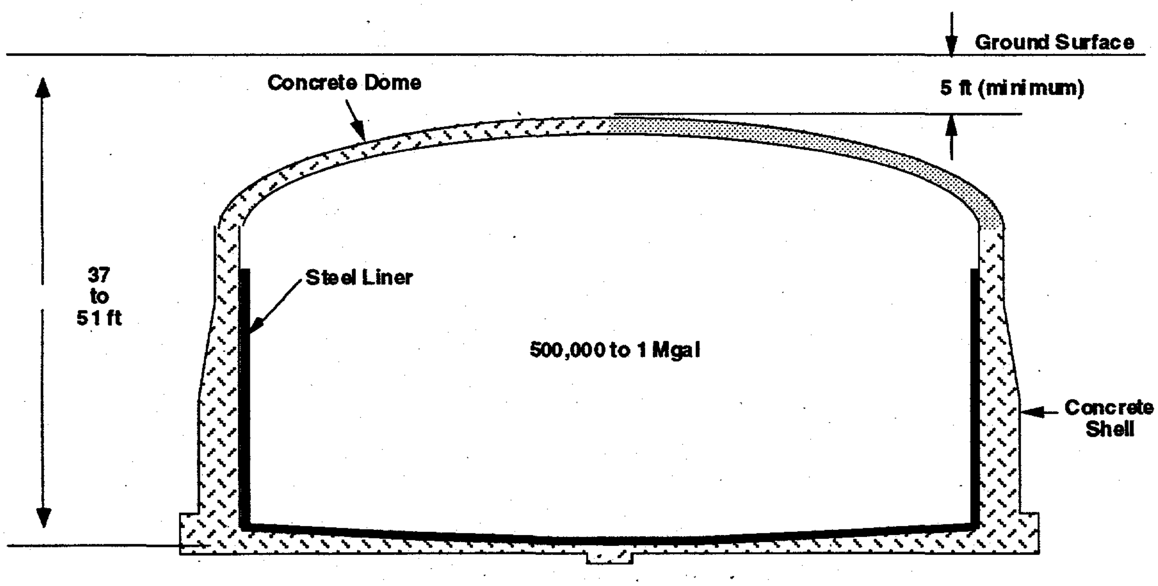

Figure 2.1. Schematic of 100 Series Single Shell Tank

The concrete shell supports the surface loads and the internal hydrostatic and hydrodynamic loads (WHC 1993). The welded steel liner, which extends almost up to joint between the wall and dome, is structurally independent of the concrete tank. The purpose of the steel shell is to provide containment of the stored liquid waste (WHC 1993). An asphalt composition material is placed between the steel liner and the concrete tank to provide an additional moisture barrier.

The SSTs are grouped into 12 tank farms located in the 200 East and West Areas of the Hanford Site. The tank farms consist of groups from 6 to 18 buried tanks. The 500,000-gal and 750,000-gal tanks were originally arranged in cascades of three, four, or six tanks. When the first tank in a cascade filled it overflowed to the next tank. Tank farms with this arrangement include 241-B, 241-BX, 241-BY, 241-C, 241-S, 241-T, 241-TX, 241-TY, and 241-U. Plugging of cascade lines between tanks was a problem. Because there was no known way of unplugging these lines, most of the overflow lines between tanks in the various cascades have been removed or blanked (WHC 1993). The 1-Mgal tanks are located in the 241-A, 241-AX, and 241-SX tank farms.

The SSTs have been inactive since November 1980. Inactive, in this context, means that the tanks no longer receive waste and have been isolated from any waste streams. Each tank farm is isolated from active facilities as a unit, generally at the nearest process pipeline diversion box.

In addition to the cascade or inter-tank pipelines, other associated structures to the tanks and tank farms may include

- active ventilation and exhaust systems (including radiation monitoring systems)
- passive ventilation system
- tank temperature instrumentation
- interior leak detection (tank liquid-level instrumentation, liquid observation wells [LOWs])
- exterior leak detection (vertical dry wells, lateral wells)
- support systems (area radiation monitors, steam supply (241-SX), AC power, raw water supply, instrument air supply)
- salt well pump
- miscellaneous pits (pump pits, sluice pits, valve pits, flush pits, service pits), diversion boxes, vaults, catch tanks.

2.1.2 Current Condition of SSTs

2.1.2.1 Steel Liner

Corrosion, particularly stress corrosion cracking (SCC), may be common in the steel liners of the SSTs. SCC is premature cracking of a metal produced by the combined actions of corrosion and surface tensile stress (Lini 1975). There is ample evidence to make a strong case for SCC failure of the SSTs in the vapor/liquid, liquid/solid, and liquid phases (Anantatmula et al. 1994). SCC preferentially attacks the welds that join the steel plates of the liner because the welds were not stress-relieved. Therefore, any of the liner welds below the waste level are potential sites for leakage. Contact with high-nitrate wastes containing insufficient quantities of hydroxide and nitrite are the primary environments for SCC. Since the wastes in the tanks have not been completely characterized, and the wastes may have stratified over time, it is difficult to predict which tanks are greater risks for SCC (Anantatmula et al. 1994).

WHC (1993) proposed that some of the SSTs probably sustained through-wall SCC first, then subsequently sustained equally damaging pitting attack and general corrosion due to the increasing chemical concentration of the waste during stabilization. As with SCC, it is also difficult to predict the specific locations of failure due to pitting attack or general corrosion because of the heterogeneous nature of the SST wastes.

It is likely, therefore, that the steel liners for many SSTs have been compromised and are no longer capable of acting as the primary containment of enclosed liquid wastes.

2.1.2.2 Concrete

Several studies have been performed to assess the long-term stability of the concrete tank shell (Baca et al. 1978, Gillen 1982, and DeFigh-Price 1981, 1982). The most potentially damaging effect to this shell would be the exposure to elevated temperatures. Elevated temperatures can create irreversible degradation to the strength of concrete (Baca et al. 1978). The decrease in strength is a function of the duration of high-temperature exposure (DeFigh-Price 1981). Potential damage to concrete strength from radioactive emissions (non heat-related) was considered to be inconsequential (Baca et al. 1978). Based in part on the above studies, the Interim Safety Basis (WHC 1993) has assigned a maximum safe waste temperature of 350 °F. It is believed that safe maintenance of single-shell tank structural integrity is possible as long as the wastes do not exceed this temperature. Currently, no SST concrete is believed to be structurally unsound due to heat.

Concrete degradation due to chemical effects is another area of primary concern. However, studies of concrete samples exposed to simulated salt cake solution for up to 19 months showed no discernible signs of degradation (DeFigh-Price 1982).

Gillen (1982) reported results of physical property tests of concrete cores from a single-shell tank 241-SX-115 (37 samples) and the 202-A PUREX building (17 samples). The cores were also visually inspected to determine the presence of cracks, voids, aggregate segregation, discoloration, or any signs of concrete deterioration. Tank 241-SX-115 was essentially empty at the time of drilling (FY 1980). It had held about 700,000 gal. of waste for about 8 years that had reached temperatures of 260 to 280 °F. Although this tank had not been exposed to very elevated temperatures, only five SSTs (241-A-101, -102, -104, 106, and 241-SX-107) are known to have contained wastes that reached greater temperatures (>350 °F) (DeFigh-Price 1982). Tank 241-SX-115 was declared a leaker in 1965. Four of the tank samples as well as two of the PUREX samples showed some cracking. None of the samples were discolored and there were no signs of deterioration of the cement matrix or aggregate. The total length of core recovered from the tank wall was about 39 ft. (DeFigh-Price 1982). However, contamination was encountered after the footing was reached. The contamination affected the drilling mud and as a result, only the upper 32 ft. of core could be released. Therefore, concrete core samples were not obtained from the interval that had possibly been responsible for the leakage (near the footing). The tank footing is the weakest structural member with respect to vertical loads (DeFigh-Price 1982).

Therefore, because the integrity of the steel liner in many of the tanks has probably been compromised by corrosion, the concrete shell apparently provides the most effective barrier to liquid leakage. The effectiveness of the concrete shell as a barrier is a function of its conductivity. According to Whiting (1988), the conductivity of low-conductivity concrete is in the range of $1x10^{-10}$ to $1x10^{-11}$ cm/s. In order for concrete to attain these low conductivities it must have low water-to-cement ratios, special additives need to be added to the mix, humid curing conditions, and relatively long curing times. None of the Hanford concrete samples have been tested for conductivity, and there is no reason to believe that the

SST concrete has conductivities as low as the values listed above. Furthermore, since cracks were documented in some of the tank core samples, these cracks will significantly increase local conductivity and may act as potential release pathways.

Micro-cracks may also be present within the concrete. Micro-cracking is a common feature of most hardened concrete and first appears as partial segregation of the aggregate and as plastic shrinkage while the fresh concrete is setting (Samaha and Hover 1992). Shrinkage during drying also creates micro-cracks. Samaha and Hover (1992) documented that at load levels of 75-90% of maximum strength, load-induced micro-cracks formed that enhanced mass-transport properties by as much as 20%.

2.2 Description of Tank Wastes

The typical interstitial liquid currently within the SSTs is variable and dependent upon individual tank history, which is not always well known. Boomer et al. (1993) have provided a general description that indicates that the wastes consist primarily of (in descending relative concentration) water, Na^+, NO_2^-, PO_4^{-3}, Al^{+3}, organic carbon, SO_4^{-2}, and OH^-. The radionuclide components of SST wastes consist primarily of fission radionuclides such as ^{90}Sr and ^{137}Cs, and actinide elements such as U, Pu, and Am (Cruse and Treat 1994). Tank wastes are typically saline with high pH.

2.3 Description of Past Leaks

A waste solidification program was initiated in 1960 to reduce the liquid inventory and immobilize SST waste (Baca et al. 1978). In 1975, a congressional milestone mandated that all Hanford SSTs be removed from active service by 1981. This milestone was achieved in November 1980 (WHC 1993), and an interim stabilization program to reduce the waste volumes and remove all SSTs from liquid storage service is ongoing. Free liquid is pumped out, to the extent possible, to minimize the potential environmental impact in the event of a tank leak. The status of each of the SSTs and estimates of the leaked volumes are provided in periodic status reports (e.g., Hanlon 1995).

The majority of tank leaks are believed to have occurred at low rates (<0.03 gal./min.) (WHC 1993). WHC (1993) does not reference how this leak rate was estimated. However, Kline and Khaleel (1994) show that the 67 known leaks are statistically representative of a log normal distributed population (with 300 gal. as the smallest detected leak and 115,000 gal. as the largest). Based on the log normal assumption, the most likely leak is 660 gal. (mode), the median leak is 5,200 gal., and the mean leak is 15,600 gal.

Probably the best documented leak, as well as the largest, was the 241-T-106 tank leak. The following description of this event is taken from Freeman-Pollard et al. (1994). Between January 1973 and April 4, 1973, the liquid level in tank 241-T-106 was essentially stable at 24 in. Starting on April 4, liquid waste was added to the tank. The measured waste level on April 23 was 153.3 in. The waste level on April 24, at the end of the filling operation, was 183.7 in. This leak apparently began on April 20, 1973 (based on material balances) and continued until June 10 when the tank was pumped to remove all of the liquid waste. The total leak volume was 115,000 gallons.

The fact that the tank was stable before the waste was added suggests that the leak probably occurred through the wall, somewhere between the 24-in. (the level before filling) and 153.3-in. level (the measured level on April 23). Examination of a plan and cross-sectional view of ^{106}Ru distribution from Brown et al. (1979) shows contamination beginning at approximately the 133-in. level outside the southeastern side of the tank. The shape of the plume in 1979 was elipsoidal, approximately 177 ft. by 155 ft. by 66 ft. deep. During the 1973 drilling investigation, a previously unknown leak was also found on the east side of tank 241-T-103, immediately north of tank 241-T-106 (ARCO 1973). The cause of the leak from 241-T-103 was suspected to be a failed grout seal in a spare fill line. The volume of soil originally contaminated by the 241-T-106 and 241-T-103 leaks was 25,000 m^3 and 1,700 m^3, respectively (ARCO 1973).

Using measured values (leakage of 450 m^3) from Routson et al. (1979), Smoot and Sagar (1990) simulated the ^{106}Ru and ^{137}Cs plumes emanating from tank 241-T-106 using PORFLO-3, a three-dimensional, mass transport computer code. By reducing the expected vertical hydraulic conductivity to one-half, the simulation correctly predicted the plume shapes and location. Conclusions from this simulation include: 1) the ^{106}Ru plume within the unconfined aquifer is receding because of radioactive decay, and 2) the ^{137}Cs plume has adsorbed to the Hanford formation soil particles and it essentially immobile.

Kline and Khaleel (1994) supported the reduction of hydraulic conductivity used by Smoot and Sagar (1990) by pointing out that their simulation using anisotropic moisture dependency and a similarly reduced conductivity generated the 5% moisture content present in the Hanford formation sediments subjacent to tank 241-T-106. Kline and Khaleel (1994) computed a 6,000 year transport time for ^{137}Cs and ^{90}Sr migration to groundwater, while supporting the measured ^{106}Ru plume growth. Transport of a leaked highly mobile species (e.g., ^{99}Tc and nitrate) was also simulated, and the resulting plume would migrate to the water table within 100 years, but at a significantly diluted concentration (i.e., < 30% initial concentration). The effects of surface barriers were not simulated.

Roughly 45% of the SSTs have confirmed leaks (after 40 years), and the combination of events that can lead to leaks is still present. Leak probability is a function of SST age and its content, and because almost all of the liquid has been removed from the SSTs, the potential for leakage has been reduced greatly. Waste retrieval processes, however, could increase this potential.

If a SST leak occurs, there are two key parameters that will effect growth of the resulting plume while in the unsaturated zone: 1) presence of lateral inhomogeneities within the soil layers because lateral transport dominates typical and median size spills (660 and 5,200 gal., respectively), and 2) adsorptive properties of the Hanford formation that can retard transport of some species such as ^{137}Cs and ^{90}Sr. Mobile species (e.g., nitrates and ^{99}Tc) may travel through the unsaturated zone to the groundwater, provided that there is sufficient original mass (combination of spill volume and other moisture contributors such as infiltration of meteoric water).

2.4 Description of Present Baseline Leak Detection Technologies

Several different LDTs are currently in service for the SSTs, and they have been reviewed in Schofield (1994). Table 2.1 presents a summary of this report. This section will review these different systems to allow comparison with candidate LDTs proposed in Section 4. Those systems employed within the SSTs (internal) are discussed first, followed by systems deployed outside of the SSTs (external).

Table 2.1. Specification Limits for Current SST Leak Detection Technologies

Leak Detection Technology	Specification Limit (±in.)			Waste Volume (gal. [a])
	Conductive Liquid	Conductive Liquid with Floating Solids	Solid, Floating Surface	
Surface Level				
Manual Tape	1.0	2.0	3.0	2750
FIC	0.5	1.0	3.0	1375
ENRAF	0.1(b)	ND (c)	ND	275 (b)
Dip Tube	2.7	ND	ND	7425
Zip Cord (d)	1.0	2.0	3.0	2750
Photograph/Video	ND			
LOW (e)				
Neutron Probe	3.6			9900
Gross Gamma Probe	ND			
Drywells				
Gross Gamma Probe				2700

All data from Schofield (1994).
(a) Assumes 1 Mgal. tank with diameter of 75 ft., and waste is conductive liquid.
(b) Instrumentation precision, specification limits have not been developed.
(c) ND--not yet developed or discussed in Schofield (1994)
(c) No specification limits are presented; they are conservatively kept the same as manual tape.
(e) LOW probes are used to detect changes in Interstitial Liquid Levels (ILL) and are not particularly sensitive to solids.

2.4.1 Internal SST Leak Detection

All internal SST leak detection systems currently employed at the Hanford Site use the same general principle for leak detection--inventory control. The volume of waste within the tank is monitored periodically for an unanticipated decrease. The advantages of these systems is that they 1) can be automated, 2) provide a fairly high level of precision if the surface is a conductive liquid or slush, and 3) are robust. The disadvantages include 1) they do not provide a high level of precision where the tank surface is a non-floating solid, 2) high levels of precision (conductive floating surface) require the comparison of closely spaced measurements, 3) the systems only provide a measurement in one or two positions within the tank, 4) most of the systems are not particularly adaptable for use during retrieval, and 5) several systems are not quantitative.

SST liquid levels are monitored internally by a variety of technologies and techniques. These include plummets (activated by conductivity), density variations (buoyancy probes and dip tubes), internal geophysical logging, and photography.

2.4.1.1 Displacer and Wire Technologies

The depth to the surface of SST wastes are currently monitored with several different systems. These systems include (Schofield 1994):

- Food Instrument Corporation (FIC) electrical contact probe
- automatic gauges that employ a weighted wire that detects changes in either buoyancy or contact
- manual-weighted tape measurements
- zip cords.

All of these devices exhibit problems in determining the depth to the waste surface.

The FIC system employs a probe that is automatically lowered into the waste tank. When the probe contacts a conductive surface, an electrical circuit is completed through the metallic tank liner, and the liquid level is determined by measuring the length of wire extended. The desired accuracy for measuring the surface level is ±6.4 mm. (±0.25 in.) and readings can be taken as often as every 60 to 90 seconds (Schofield 1994). The surface level is automatically recorded using a data acquisition system, depending on the status of the tank. Manual readings are still employed if computer links are broken.

An Enraf-Nonius 854 Advanced Technology Gauge (ENRAF) uses a weight (displacer) suspended within the waste on a thin stainless steel wire. The device detects changes in buoyancy or contact with a solid. A stepper motor that plays out the wire provides the depth measurement to a precision of ±0.01 in. Due to a lack of empirical experience, the accuracy is presently set to the same values as the FIC. In July 1994, FICs began to be upgraded to ENRAFs (Hanlon 1995).

The manual tape, like the FIC, uses the electrical conductivity of the tank wastes to complete its measurement. The manual tapes consists of a reel-mounted, calibrated steel tape with a ring or rod at its end. The tape is lowered until a current meter connected between the tape and the riser shows a full-scale deflection. The level reading is taken from the tape and recorded manually. Precision has been empirically set at ±0.5 in. (Schofield 1994).

Zip cords also employ a conductive probe. This system uses a pre-stretched, insulated wire with conducting probe that is lowered through a riser into the SST. Depth to waste is noted when either the operator detects slack in the cord, or a full deflection on a DC meter indicates contact with a conductive surface. The amount of cord that is released is manually recorded. Zip cords are relatively imprecise and only employed as a temporary measure (Schofield 1994).

A drawback to the FIC and manual tape is the formation of crystals on the probe or weight that form as it is withdrawn from the liquid material. This can lead to inaccuracies as subsequent measurements are made with the device. Another drawback for these two systems is that they cannot determine the level of a waste if it is nonconductive or capped with a solid material. Furthermore, the impact of the descending probe or weight may eventually produce a hole into the solid material, resulting in false readings. Finally, a solid surface may be irregular and translate laterally over time leading to false readings of the actual (average) level of material in the tanks. The manual tape can also give inaccurate readings due to thermal expansion of the steel tape. The level measurement with the zip cord is dependent on the subjective determination of slack by the operator (Cuta et al. 1993).

All SSTs have either manual tape, or FIC, with the exception of tanks S-108 and T-101, which have both. Tank T-101 also has a zip cord. All SST FICs are connect to a computerized data link, with the exception of tank BX-106. This connection, however, is broken for several tanks, and in such cases manual readings are taken. Manual readings can be taken by manual tape, manual FIC, manual readings of automatic FIC (if the data link is broken), or automatic FIC. In some cases, the surface level readings are taken using a zip cord. While less accurate, such readings are acceptable for meeting the surface level reading requirements (Schofield 1994).

2.4.1.2 Dip Tubes

Dip tubes measure weight factor/specific gravity and are considered reliable and accurate under normal conditions (Schofield 1994). However, these systems are not routinely used at the SSTs because many of the wastes can frequently plug the sensing tubes. Dip tubes are used in limited cases (such as for tank C-102) where surface level measurement cannot be used and dip tube systems have already been installed for saltwell jet pumping. Used in conjunction with jet pumping operations, dip tube precision has been computed at ±2.7 in.(Schofield 1994).

2.4.1.3 Liquid Observation Well Technologies

The LOWs are in-tank, closed-bottom drywells made of either steel, fiberglass, or fiberglass-reinforced plastic tubes, with a 3-in. internal diameter. LOWs were inserted through tank risers to a position near the tank bottom, and have been left to provide permanent, dry observation of the waste. There are 58 LOWs, 56 of them operational, in the SSTs (Schofield 1994). LOWs are employed where the surface of tank wastes are solid or semi-solid, yet interstitial liquid wastes are believed to occur beneath. The levels for these interstitial liquids, interstitial liquid levels (ILL), are monitored with two different types of geophysical probes..

The neutron probe uses a chemical, fast neutron source and thermal neutron detector. The fast neutrons interact with nuclei within the waste and are slowed to thermal energies where they can be detected by the probe. Hydrogen is very efficient in slowing down the neutrons, much more so than other nuclei, so the number of thermal neutrons detected is primarily a function of the hydrogen atom concentration. The probe (lowered to the bottom of the well and read as it is pulled up) is precise to ±2.4 in. and accurate to ±3.6 in. using manual interpretation. New statistical methods may reduce both values to ±1.0 in.(Schofield 1994).

The gamma probe is a lead-shielded, highly collimated Geiger-Mueller (GM) detector. It is employed in a fashion similar to the neutron probe. The primary gamma emitter within SST wastes is ^{137}Cs. This radionuclide is soluble in the aqueous phase, so a plot of gamma count rate versus depth can indicate the distribution of liquid in a tank similar to the results from using a neutron probe. However, the gamma probe is considered less accurate at determining the ILL than the neutron probe because gamma rays are more penetrating, thus emanating from a greater volume. For this reason, gamma probes are usually used for information only and as a backup to LOW neutron probe readings.

2.4.1.4 Visual Inspection

Visual inspection refers to in-tank photography and video inspection. The greater clarity, permanence, flexibility of use, and greater ability to scale distance from reference points makes photography a preferred method for most tank inspections. Video imaging is usually faster, provides the ability to observe the tank contents during inspection and focus in immediately on items of interest, and is used for some general inspections. Photos are used largely to determine general surface conditions in a tank, to help troubleshoot problems with erratic level readings, to spot intrusions, or to provide backup information when investigating possible tank leaks. There is no formal accuracy applied to photos or video images for detecting surface-level changes (Schofield 1994).

2.4.2 External SST Leak Detection

Leak detection systems are also employed outside of the SSTs. The systems currently employed require subsurface access provided by dry wells (vertical shafts), laterals (horizontal shafts beneath the SST), or leak detection pits.

External dry wells and laterals historically have been used in combination with in-tank leak detection devices. Geophysical probes, similar to those employed within the LOWs, are used to detect changes in moisture or the activity of gamma-emitting radionuclides. Increases in either can be interpreted as evidence of a leak. The ability of these systems to rapidly detect a leak is limited when compared to internal systems.

2.4.2.1 Drywell Systems

Drywells are vertical boreholes with 6 or 8-in. diameter carbon steel casings positioned radially around 132 of the SSTs, for a total of 768 drywells (Boomer et al. 1993). They are called drywells because they do not penetrate to the water table. They range in total depth from 50 to 250 ft, and they are monitored from 50 to 150 ft. The drywells are currently logged on schedules ranging from weekly to annually, depending on tank history (Isaacson and Gasper 1981), for radiation and moisture in the soil using gamma and neutron probes. These periodic scans are used as a background for comparison against future occurrences of leakage.

Positive leak scans depend on a variety of variables, including

- distance from leak,
- level of radioactivity in the leakant
- leak volume
- soil characteristics
- monitoring frequency for the drywell
- radioactive/moisture background of the drywell
- specific probe sensitivity.

The gross count scintillation (#4 or S probe) is the primary probe used in drywells. Because of its sensitivity, this probe is normally used only in drywells that previously have not shown the elevated radiation levels that could result from a nearby tank leak. This probe will detect about 5 μR/h above background for a single observation (data point), over a range of four decades (5 μR/h to 100 mR/h) above background (Schofield 1994). Empirically this probe has an accuracy of ±10 c/s. If an S probe detects a leak, it can be monitored by a high level (Red) GM, which is a small, shielded GM detector suited to high level radiation. This system has a declared accuracy at least ±2,700 gal. According to Key (1987), the system can detect a 1,500-gal. leak, which, due to the waste interim stabilization process (removal of liquids), is above the expected most likely 660-gal. leak (Kline and Khaleel 1994).

These gamma detection probes measure gross counts; they cannot distinguish between different gamma-emitting radionuclides. Weaknesses with the gross gamma systems currently used for leak monitoring have been noted (GAO 1992). Two sophisticated spectral gamma probes have recently been purchased to provide a baseline reading for each of the drywells.

They use a high purity germanium (HPGe) detector that has superb selectivity and thus provide a log of the activity of the different gamma-emitting radionuclides. Measurements with this system began in FY1995. Baseline measurements are expected to be complete in an additional two years.

The Soil Moisture Monitor is a neutron probe similar to that used in the LOWs. The detector is a BF_3 tube with an active length of 8.1 in. that can be used with or without a lead shield. This detector can operate in any gamma filed encountered in the drywells. This probe can accurately detect changes in soil moisture in any soils with more than a few percent moisture content (Schofield 1994).

2.4.2.2 Lateral Systems

The laterals are 4-in.-diameter steel pipes located horizontally 8 to 10 ft. below a tank's concrete base and into which 3-in.-diameter tubing is inserted. The tubes rise to instrument enclosures through vertical caissons adjacent to the tank. One of two types of GM radiation detectors is forced pneumatically from the caisson to the end of the tube and then retracted by a cable drive mechanism. A radiation profile scan is obtained during the withdrawal. The instrument readout system records total gamma response for each 1.05 ft. of travel.

The Green Probe - Type 1 is a standard GM detector similar to the probe used for drywell monitoring. It has a functional range of ~40 μR/h to 1 R/h. At background, the detection limit is 10 c/s, and the measurement precision is ±5 c/s, empirically computed.

2.4.2.3 Leak Detection Pits

Leak detection pits collect any liquid that might accumulate beneath a tank bottom. The only SSTs with leak detection pits are those in AX farm. Liquid is collected from channels under the tank and drained into a collection pit for each tank. These tanks are monitored for weight factor, specific gravity, and gamma activity. The pit consists of a tall pipe section that extends from grade level to a point adjacent to and below the tank concrete foundation. The concrete tank foundation has an interconnected grid of channels to collect any leakage, which would then drain to the pit through horizontal drain pipes. Each leak detection pit drains a single tank foundation. An accuracy of ±0.6 in. in the pit is claimed by the manufacturer. Due to water intrusions into the pits, a weight factor rise of 8 in. has been empirically set to avoid false alarms (from rain). The sensor at the bottom of the radiation well consists of two GM detectors with a functional range of about 10 μR/h to 300 R/h. The detection limit is 0.5 c/s and the measurement precision is ±1.7 c/s, empirically set (Schofield 1994).

2.5 Tank Waste Retrieval Technologies

2.5.1 Tank Life Cycle

For the purposes of this report, it has been assumed that the SSTs will undergo a life cycle consisting of three phases:

- storage
- retrieval
- abandonment.

A SST is constructed in a large excavated trench in which cement foundation is poured, and on top of it an open steel liner is welded. The liner is encased in cement and capped with a cement dome that includes the necessary vents, probe portals, and access hatches built in. The tank may have an interconnected cascade venting and filling system together with a pump pit. The entire trench is subsequently backfilled to grade.

Over its functional lifetime, a SST tank is re-filled and partially emptied several times with a variety of liquids. The interior temperature of the tanks varies, but it is likely that for at least some period of time, the lower level portion of the tank can experience temperatures higher than 250 °F. The typical SST contains sludge (hydrous metal oxides), salt cake, interstitial liquids, and air. Since 1980, a program of liquid reduction has been ongoing, and most of the SSTs have had their interstitial liquid content significantly reduced, which lessens the opportunity and extent of possible leakage.

Eventually, either the mobile liquid within the SST is stabilized in the tank and/or the tank contents, including solids and liquids, is removed and processed for permanent storage at another location.

Abandoned SSTs will be sealed for permanent storage (95% of waste removed, dome refilled and stabilized) and will become a closed hazardous waste site for the future. No definitive data were found about cement structural integrity over long time periods (e.g., 500 years), but structural failure is expected by that time unless the tank is re-engineered (i.e., emplacement with filler) to resist all outside influences. It is appropriate to note here that the Interim Safety Basis (WHC 1993) uses a waste temperature of 350 °F as the maximum that will allow for safe maintenance of SST structural integrity. DeFigh-Price (1982) did parametric heat transfer calculations for SSTs and double shell tanks to predict maximum temperatures possible in the waste and concrete structure during in-situ disposal (without heat-producing waste removal). For all procedures, except a no-backfill process, the generated heat exceeded the Interim Safety Basis.

Eventually, the tank will fail. The conditions that will cause that failure are each extremely low probability occurrences (dead/live loads, seismic loads, hydrostatic loads, thermal loads, explosions, missiles, etc.), but separately or together they will occur. Failure can be either functional (the inability of the waste tank to contain or isolate the waste from the environment) or structural (SST cannot support additional applied loads). Functional failure depends both on the condition of the tank and the waste form in the tank (liquid may escape but the solids cannot). Structural failure is described as a safety factor of zero for loads beyond the "operating" loads. Within this definition, a tank may appear adequate, but may not be capable of withstanding future loads such as an earthquake or overhead heavy equipment assumed within load limit specifications(DeFigh-Price 1982).

2.5.2 Waste Retrieval

The mission of the Tank Waste Retrieval Systems (TWRS) Program is "to store, treat, and immobilize highly radioactive Hanford waste in an environmentally sound, safe, and cost-effective manner." As previously mentioned, the Hanford SST tank farms are currently scheduled for retrieval of waste from the SSTs during a 15-year period beginning in 2003, except tank C-106, which is scheduled for a prototype retrieval to begin by FY 1997(WDOE et al. 1989, Barnes et al. 1991). The most likely technology for tank C-106 retrieval is sluicing.

The sluicing process uses an articulated mechanical arm with a large hose attached to a variable nozzle. Water can be introduced by the nozzle either as a cutting tool or as a spray, dissolving and suspending solid waste for removal by dredging and/or pumping. The waste is processed out of the water (for storage in a double-shell tank), and the water is recycled back through the system or used to dilute the waste in alternate storage. Equipment will be run from a command center away from the tank farm. The in-tank robot systems (including but not limited to, cameras, sluicing arm, and pump) can be based on a bridge (to limit overhead load on the dome) built over the tank, with sealed vent(s) built through the tank dome for access.

Three distinct levels of sluicing exist as available technology. Past practice sluicing uses existing risers for entry, an articulated arm, and available pump pits. High-pressure water is used to erode waste into a slurry with viscosity low enough for pumping and the waste is processed/stored as necessary. Some contact of the high-pressure water stream with the steel liners is inevitable, and excess water is present.

Limited sluicing involves articulated arm hose manipulation as does past practice sluicing, but the nozzle is placed closer to the waste to maintain better control over the flow, amount, and direction of the jet stream; there is uncontrolled contact with the steel liner and somewhat less water is needed. Complete control is still not possible, and excess water will still be introduced.

Confined sluicing is a process using an articulated arm that has at its foot a 3-ft. dome with eight air and water nozzles. These mobilize the waste for removal by pumping water inside the end processor. The confined sluicing end processor can be placed inside another dome so that it is functional under water. It has the advantage of very localized added water, with little opportunity for the jets to hit the steel liner without operator error or intent.

Gibbons et al (1993) concluded that past practice sluicing is the first choice retrieval technology where tank leakage is not a problem. Tank 241-C-106 is scheduled for high-volume, low-pressure sluicing to retrieve the high-heat sludge and move it to the 102-AY double-shell tank. This process is expected to take less than 2 years. At the end of this time period additional technology will be used to remove more sludge (from ~80% to ~95% reduced) by the Long-Reach Manipulator (LRM) system employing alternate techniques. The LRM system may deploy a confined sluicing scarifier together with an air-conveyance or pumping system for waste transfer. Technology is available, with some modifications, for this retrieval system (Bazinet 1993).

Past practice sluicing (as differentiated from confined sluicing, limited sluicing, or dredging) to remove existing solids requires the re-injection of liquid (on the assumption that the tank is leak free) to form a slurry that can be pumped out of the tanks. If pathways are present, the slurry may leak out of tanks, while the dust and fog raised inside the tank could make internal inspection difficult.

In light of the potential for further leaks during retrieval, three fundamental concerns regarding such leakage need to be considered: detection, confirmation, and quantification, all in the near-field zone. The purpose of this report is to recommend candidate LDTs that can be applied to a SST during waste retrieval. Section 3 presents the criteria that were used to determine which LDTs were most promising in light of the assumptions and baseline LDTs discussed in this section.

3.0 Technical Approach

This section presents a brief review of the methods used to arrive at the recommended LDTs. The initial scope and purpose of this report was to perform a comprehensive evaluation of leak detection technologies and recommend LDTs after completion of the evaluation. Unfortunately, the budget for this task was cut and a comprehensive evaluation was not possible, which limited the selection of LDTs to 1) using an earlier abbreviated evaluation of external LDTs (Lewis and Teel 1994), and 2) using the findings of an nascent evaluation of internal LDTs.

Several additional criteria were applied to LDT selection that had not been considered by Lewis and Teel (1994). One criterion was recommending only LDTs that have already been demonstrated at the Hanford SSTs or a similar site; thus, the selected systems could be deployed rapidly, if necessary, at a SST. Another criterion was the assumption that the LDTs would be used during tank waste retrieval, a potentially dynamic period both physically and operationally. Physical limitations centered around the additional noise created within the tanks and transfer pipelines; operational limitations centered around the need to limit as much as possible the potential for a false positive signal from a LDT.

3.1 External Leak Detection Systems

External LDTs are systems that are deployed outside of a waste tank and detect leakage one it has migrated through the tank liner. These technologies were reviewed in Lewis and Teel (1994), where they were divided into 7 families based on implementation and methods of analysis:

- borehole geophysics
- surface geophysics
- borehole-to-borehole geophysics
- soil moisture instrumentation
- in situ sensors
- moisture removal and analysis
- vapor extraction and analysis.

The most promising technologies according to Lewis and Teel (1994) are, in general, the external LDTs recommended in the following section of this report. The technologies recommended in this report do deviate from Lewis and Teel (1994) somewhat, primarily because more information was available this year regarding the demonstration of certain LDTs including time domain reflectrometry and electrical resistivity tomography.

3.2 Internal Leak Detection Systems

Internal LDTs are systems that monitor the interior of a waste tank for evidence of leakage. These systems present several inherent advantages over external systems focused primarily on 1) waste quantification, thus quantification of leakage, 2) lag time between leak and detection. Inherent disadvantages include 1) sensitivity to dynamic conditions within the tank (e.g., during waste retrieval), and 2) inability to locate leak points.

Candidate internal LDTs can be assigned to 3 families:

- inventory control
- tracer
- remote sensing.

3.2.1 Inventory Control

Inventory control is the monitoring and recording of the quantities of materials within a waste tank. Negative discrepancies in tank volumes, once corrected for potential physical changes, can be interpreted as leaks. Inventory control is a very popular LDT, especially for the many fuel storage tanks within the private sector, because leak detection is mandated by the U.S. Environmental Protection Agency (EPA), and inventory control is one of the most cost-effective, approved technologies (EPA 1990).

Inventory control is currently used for leak detection in many of the SSTs on the Hanford Site (Schofield 1994). Methods employed include manual tape, FIC, ENRAF, and neutron probes. All are described in the previous section of this report, and several have been evaluated elsewhere (Peters et al. 1993). Each physically measures the surface interface of the wastes to calculate volume.

Remote sensing methods also show promise for inventory control. These technologies, in contrast to those currently employed in the SSTs, measure the tank surface by imaging with electromagnetic or acoustical energy. Peters et al. (1994) have developed and tested several different systems for effectiveness during SST waste retrieval, especially effectiveness in imaging through obscurants such as fog or mist. Nevertheless, the systems discussed in Peters et al. (1994) are not recommended in this report because even though several show great promise for use during retrieval, none are currently ready for deployment. Engineering and testing for deployment would require approximately 9 months. This investment should be considered because only these types of systems have the potential to provide continuous inventory control during retrieval. The current deployed inventory control systems will probably not be effective during the dynamic periods of retrieval, and their use will require retrieval suspension.

3.2.2 Tracer Technologies

Volatile tracers are commonly used for the detection of leaks from active tank and distribution systems in the private sector (e.g., Burchette 1993). The tracers are added in trace amounts to the tank contents, and the system remains operational. Sample extraction systems are deployed close to storage systems, samples are extracted periodically, and gases are analyzed for the presence of tracers. The advantage of this type of system is 1) excellent sensitivity, 2) use during continuing operations, and 3) large volume of interrogation with typical soil permeabilities. The primary disadvantage is that these technologies are not set up to monitor continuously without incurring significant labor costs.

3.2.3 Remote Sensing

This family includes systems that detect leaks by either 1) passively sensing energy created by leakage or 2) actively interrogating tanks or pipelines for leaks or potential weaknesses.

A promising and proven technology is passive acoustic sensing, a commercially available LDT in which acoustic transducers are installed within a tank and "listen" for leaks over a wide frequency range for transients associated with a leak. If multiple sensors are installed, then differences in travel time for transient reception can be used to potentially triangulate the location of a leak. These types of systems typically operate continuously, and the data are telemetered to a central facility.

However, such systems were not recommended because they are unlikely to record useful data during retrieval, thus negating their effectiveness for detection.

4.0 Recommended Technologies for Leak Detection

4.1 Introduction

This section presents a group of six technologies recommended for SST leak detection. These technologies represent 5 of the 10 different families of LDTs (both internal and external) discussed in the previous section. The goal was to represent as many families as feasible; thus, if another member of the technology family is considered more applicable, the analysis performed by Peters and Treat (1995) can be readily adapted because the costs and implementation constraints should be somewhat constant within technology families.

Only a limited number of technologies are recommended because

- Few technologies can approach the LTVs outlined in Cruse et al. (1995)
- Only proven, operational systems demonstrated at Hanford or similar sites were considered
- These technologies are flexible enough to address different leak detection needs by varying implementation
- Fewer technologies promote operational familiarity
- Fewer technologies promote the reuse of system components (e.g., software, computers) as retrieval progresses.

As stated in Section 1.0, leak detection consists of three elements: detection, confirmation, and quantification. The recommended technologies were chosen so that they can be packaged to address all three elements. A ranking of each technology versus detection element is provided in Table 4.1. The rest of this section presents the information used for the rankings.

Table 4.1. Comparison of Recommended Technologies for Leak Detection

Technology	Detection	Confirmation	Quantification
TDR	◪	●	○
Neutron-Neutron Logging	○	●	○
Passive Gamma Ray Logging	○	●	○
FID/ENRAF	○	◪	●
ERT	●	○	◪
Tracer Gases	◪	●	○
Key	●	Best	
	◪	Good	
	○	Poor	

4.2 Description of Recommended Technologies

4.2.1 Borehole Geophysics (Logging)

Borehole geophysics, commonly referred to as logging, represents a mature technology in which a measuring device is lowered into a borehole by a cable connected to a logging truck (Figure 4.1). The downhole device measures physical properties of the formation as it is pulled up the borehole; it transmits the information up the cable to the logging truck where the data is processed in real-time, and a continuous measurement of the appropriate physical

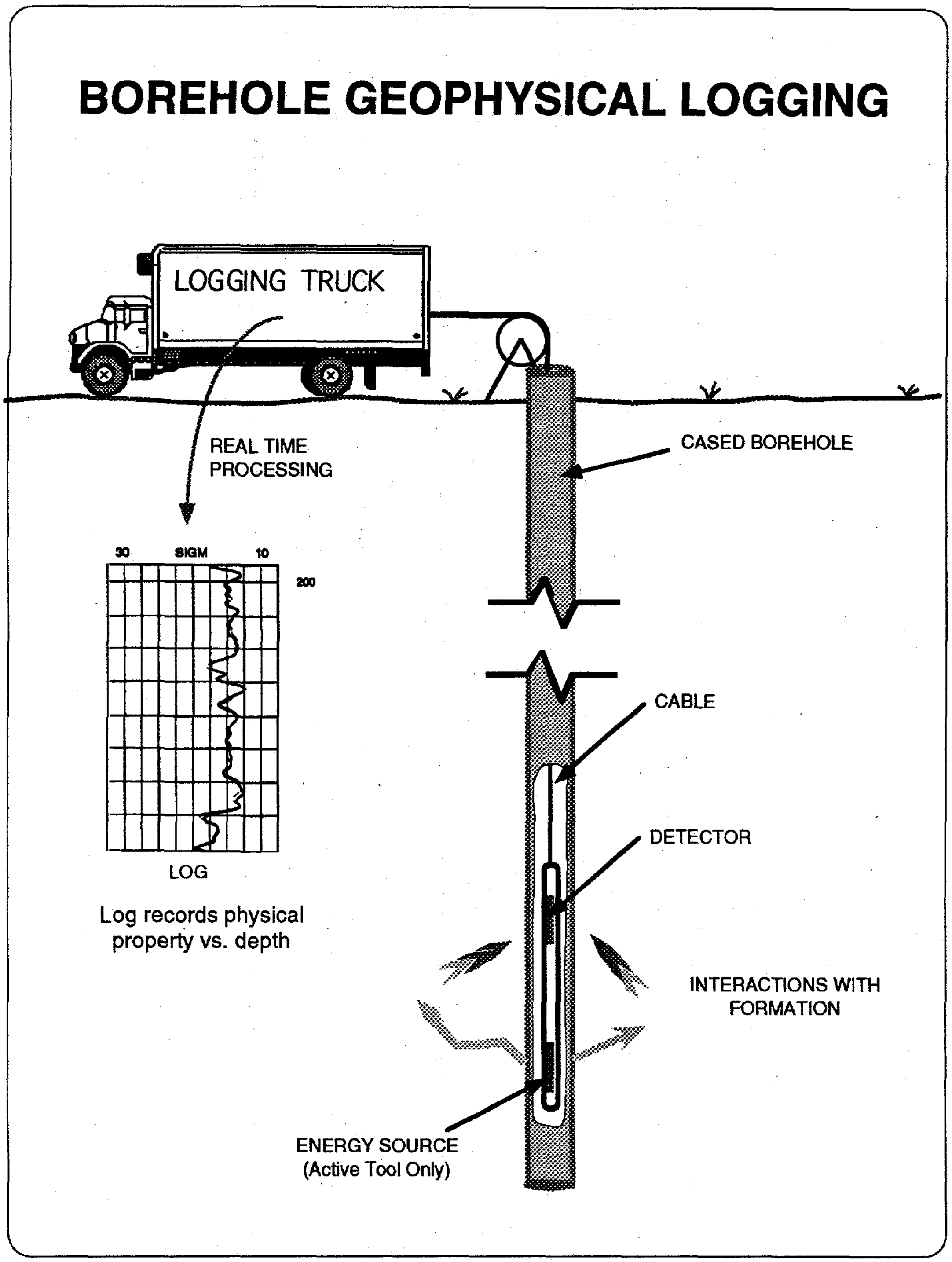

Figure 4.1. Borehole Geophysical Logging

parameters are displayed as a function of depth. Logging is the primary means for the acquisition of borehole data in the petroleum industry, and it has been used for many years in boreholes within the rock formations at DOE sites and as a means of external leak detection at the Hanford Site tank farms.

4.2.1.1 Technical Description

Neutron-neutron logging systems determine the concentration of hydrogen (moisture) in the formation by measuring either the mean free path length or lifetime of neutrons emitted from a radioactive source in the sonde. These neutrons collide with nuclei of the formation materials, and with each collision, the neutron loses some of its energy. The greatest energy loss occurs when the neutron strikes a nucleus of practically equal mass (e.g., a hydrogen nucleus).

When the hydrogen concentration of the material surrounding the neutron source is large, most of the neutrons are slowed and captured within a short distance of the source. Conversely, if the hydrogen concentration is small, the neutrons travel farther from the source before being captured. Accordingly, the counting rate at a neutron detector increases for decreased hydrogen concentration (Schlumberger 1989).

Borehole standoff (i.e., the distance that the tool is separated from the formation) is a concern for neutron-neutron tools. The response of the tools is affected significantly if they are not in direct contact with the formation. Most commercial neutron-neutron tools compensate for borehole standoff by using two neutron detectors and using the count rate ratios to determine hydrogen concentration.

Two types of sources are available for these systems: chemical and generator. The most common chemical source is AmBe, which provides neutrons with initial energies of several million electron volts (MeV). The sources are as large as 20 Curies (Ci). Neutron generators emit pulses of high-energy neutrons (14.1 MeV) typically created by reactions between deuterium and tritium (Hearst and Nelson 1985).

The neutron generator has several advantages over the chemical source: 1) it can be turned off, so it is not hazardous when not in use, 2) the neutron energy is higher, so its depth of investigation is greater, and 3) it can be pulsed, which permits an alternative way to measure moisture content. The epithermal neutron die-away technique, developed by Mobil Oil, uses a neutron generator to determine the lifetime of epithermal neutrons rather than the mean path length as the ratio tools do (Mills et al. 1988, Stromswold and Allen 1992). This tool currently does not have a correction for standoff. Schlumberger Well Services has developed a tool that used a neutron generator and measures both ratio porosity and neutron lifetime that is corrected for standoff.

Passive gamma-ray logging systems measure the intensity of gamma rays in the formation. Gamma rays are bursts of high-energy electromagnetic waves that are emitted spontaneously by some radioactive elements (radionuclides). The number and energies of gamma rays emitted are distinctive of the different radionuclides. These radionuclides can be either naturally occurring (K, U, Th), or created (e.g., ^{137}Cs, ^{60}Co). In the Hanford formation, the naturally occurring radionuclides reside primarily in clay minerals and potassium feldspar.

A gross gamma system measures the total gamma-ray activity; it does not distinguish gamma-ray activity of different energies as a spectral gamma-ray system does. The spectral gamma system measures both the numbers of gamma rays and the energy level of each and permits the determination of the concentrations of naturally occurring and created radionuclides.

There are two principal types of detectors used by gamma logging systems: scintillation and solid state. Scintillators have been used for many years while solid state germanium detectors have seen limited commercial application. Germanium detectors provide a far superior spectral response at the expense of significantly decreased detector efficiency. Logging runs in a drywell with a spectral scintillation system may take one-half hour, while those with a solid state detector can take longer than 8 hours. Germanium detectors are also more costly and must be operated at or near liquid nitrogen temperatures (Wilson 1981). Nevertheless, solid state germanium detectors do provide a very important advantage of being able to resolve many peaks in gamma-ray spectra, thereby allowing numerous radionuclides to be identified (Koizumi et al. 1994). WHC has successfully developed a germanium detector spectral Radionuclide Logging System (RLS) that has been used to characterize wells at tank farms and other Hanford Site locales. RUST GeoTech is currently testing a similar system at the tank farms for subsurface characterization.

The primary disadvantage to leak detection through passive gamma-ray logging is that many of the radionuclides that present a risk to human health (Buck et al. 1991) cannot be detected by this type of logging system. They emit either beta-particles or gamma rays that are too weak to be detected readily. In addition, gamma logging systems have a limited depth of investigation, typically around 8 in.

Gross gamma systems have been successfully used to detect leaks at SSTs and basins; however, spectral gamma logging systems present the opportunity to provide significantly more information about the gamma-emitting constituents of the leak. The extended time required to log a drywell with a germanium spectral system may mitigate against many of its advantages, particularly if the system is used routinely for leak detection. A spectral system with a scintillation detector may present the best compromise among passive gamma-ray logging systems.

4.2.1.2 Performance Results

Neutron-neutron and scintillation spectral gamma logging services are currently available from commercial vendors. Both have been adapted for use in shallow Hanford boreholes over the last several years. As part of the adaptation process, data quality objectives (DQOs) had been established to ensure that the tools met "acceptable" performance standards. Tanks farm staff (Schofield 1994) and others (Koizumi et al. 1994) at Westinghouse Hanford Company (WHC) have developed and used gamma and neutron-neutron logging systems at the Hanford Site; however, to our knowledge they have not established DQOs or published performance results. The vendor systems have been tested for steel-cased boreholes that are similar to the drywells, and the mean results for measurements at one moisture and one gamma calibration model (Ellis et al. 1995, Gadeken et al. 1995) are presented in Table 4.2.

Table 4.2. Performance Results for Borehole Logging Systems

Logging Speed	5 ft/min.
Depth Precision	±3 in.
Moisture	
Value	5% VFW
Precision	0.02%
Accuracy	5.30%
Spectral Gamma (Potassium)	
Value	53.5 pCi/g
Precision	0.48 pCi/g
Accuracy	50.5 pCi/g

Volume fraction water (VFW) is the volume of formation that consists of water. For example, if a rock with 30% porosity is saturated, then it would have 30% VFW; if it has a water saturation of 50%, then it would have 15% VFW.

Both systems have a similar depth of investigation. 90% of the signal measured by both systems comes from an annulus that is about 6 in. thick (Ellis 1987).

4.2.1.3 Implementation

Logging systems are designed to be employed periodically in a borehole through using a logging truck and a crew, usually consisting of a field engineer and helper. It typically takes around 45 min. to 1.5 hours to set up to log one borehole. This includes time to set up a mast truck to support the tool as it is lowered into the hole, let out logging cable, attach the logging tool to the cable, run a pre-log calibration check, and lower the tool into the bottom of the hole. The logging tool is pulled up through the borehole at a speed of 5 ft./min., so it takes 20 min. to log a 100-ft. drywell. The well is logged a second time to ensure that the measurement is good. A second logging tool (e.g., neutron-neutron) can be installed and set up in 30 min.; two logging runs would take another 40 min. Post-logging shutdown takes around 30 min. This time includes setting the logging tool on the ground, running a post-log calibration, running software checks, putting the equipment away, and providing the client with digital and hard copy logs. Thus, the total time to log one hole is around 3 hours. The vendors typically work around-the-clock until the project is complete.

The closest location for vendor depots is in Sacramento and Bakersfield, California. Once they have been notified that a well needs to be logged at Hanford, it takes them about two days to reach the site. Because they have already logged about 50 wells at Hanford, they have little difficulty getting cleared to log on the site.

The vendors logging trucks have very long sections of logging cable, typically more than 5000 ft. It is anticipated that the vendor would be able to leave the truck outside of the tank farm perimeter and introduce the cable and logging tool only into the regulated area, thus reducing the risk of system contamination.

4.2.1.4 Cost

PNL has had a contract with one logging vendor for services at Hanford. This contract has expired but it can still be used as a cost guide. The cost for logging a well was based on a rate of $1000/hour, which works out to $3000/drywell. The cost to mobilize a logging truck and drive it to Hanford and back is approximately $19,000. Typically, a mast truck is provided by a Hanford contractor at a cost of $500/day. Thus, the total revenue to a logging vendor to log 6 drywells (i.e., the typical number of drywells surrounding one tank) would be approximately $37,000. Because mobilization represents much of the cost, it would be wise to log as many drywells as possible on one trip.

Please note that these costs have not been adjusted for logging within the tank farms. However, it is not anticipated that costs would increase significantly because the logging truck can be left outside of the tank farm perimeters.

The vendor is responsible for all calibrations, tool maintenance, hardware, and software improvements. Additional costs for tank farm labor has not been included.

4.2.1.5 Recommendation for Use

The neutron-neutron and spectral gamma logging system would be recommended for use as systems to confirm the presence of a suspected leak. The system can provide a calibrated measurement of moisture with a very high level of precision, perhaps the highest precision available for this type of measurement. It can provide the closest surrogate for an actual sample from the soils beneath a tank. The spectral gamma ray log can detect small increases in gamma activity or detect slight changes in the vertical location of contaminants. The systems can also use the existing drywells within tank farms. However, they do not run continuously, and the drywells do not go beneath most tanks. Thus, these systems would not be recommended as a primary means of leak detection. In order to be effectively used, all drywells around a tank should be logged before a retrieval operation starts, and redeployed if a leak is detected with another technology..

4.2.2 Conductivity-Based Automatic Level Measurements

4.2.2.1 Technical Description

The FIC automatic gauge consists of an electrically conductive plummet suspended on the end of a calibrated steel tape (Schofield 1994). A control system automatically adjusts the plummet to make contact with the waste surface at a pre-determined interval which can be as short as 60-90 seconds. Readings from the gauge are sent to the tank farm's Computer Automated Surveillance System (CASS) or can be obtained manually in the field. In order to complete a circuit, the FIC can only the monitor an electrically-conductive surface. A resistance of 200 ohms or less is the operating range for the instrument.

4.2.2.2 Performance Results

FIC automatic gauges have been used for monitoring in the tank farms since their initial purchase in 1971-72. They are a "proven, very reliable" technology that provides an uncomplicated, direct measurement (Schofield 1994). Accuracy is summarized in Table 4.3. Note that the leak-detection limits are based on a 1 Mgal. waste tank. Specification is greater than precision because of external variables, such as temperature changes, that can effect waste volume.

Table 4.3. Performance Specification for FIC Systems

Type of Tank Surface	Possible Precision (+/- in.)	Actual Precision (+/- in.)	Hanford Specification Limit (in.)	Leak Detection Limit (based on Hanford Specification)
Liquid Surface	0.01	0.25	-0.5	1307 gal
Floating Surface	0.01	0.5	-1	2615 gal
Moist Solid	0.01	—	-3	7847 gal

4.2.2.3 Implementation

FIC automatic gauges are already installed in many Hanford SSTs. Implementation of additional gauges on tanks not containing them now would be relatively simple because the procedures have already been developed and an experienced work force is available.

4.2.2.4 Cost

Costs were not available in time for this draft, but would be relatively small. Cost for installation is unknown at present.

4.2.2.5 Recommendation for Use

FIC gauges have been very reliable in past use at the Hanford SSTs. Many tanks already contain these; installation costs are relatively low.

The FIC gauge probably would not work effectively under most retrieval conditions unless the measurement is made within a "stilling" well (i.e., a well installed within the tank that would baffle higher frequency fluctuations in waste level) or if retrieval is temporarily halted. The baffling efficiency of a "stilling" well is not documented, and no designs are published for in-tank use. If a baffling system can be designed and installed, then continued use of the system for leak detection may be justified if adequate precision is retained. Nevertheless, this type of system, even without a "stilling" well, would have value for leak quantification because it measures waste elevation from which volume can be calculated (i.e., it does not infer volume). If used for quantification, accurate measurements would require that retrieval operations be shut down, probably for several days, to compensate for changes in waste density and surface fluctuations.

4.2.3 Tracer Tightness Test

4.2.3.1 Technical Description

Tracer tightness testing is performed by mixing an inert, volatile chemical concentrate (i.e., a tracer) with the wastes within a tank. The tracer must be specifically selected so that it is compatible with the wastes, but unique to the tank contents and outside environment. The amount of tracer added is typically very small, usually a few ppm. Since it is highly volatile, the tracer chemical distributes itself throughout the tank, both in the liquid wastes and in the vapor phase above the wastes. If a leak occurs, the tracer diffuses from the liquid and disperses into the surrounding soil and is detected via soil gas monitoring probes surrounding the tank. These probes are typically driven into the subsurface soils before the tracer is inserted.

4.2.3.2 Performance Results

Tracer Research Corporation has successfully conducted numerous tracer tightness tests on above- and below-ground storage tanks at various sites, primarily related to petroleum products (including 1-Mgal capacity). A detection sensitivity of 0.05 gal../hour is routinely achieved, although leaks as small as 0.00005 gal./hour can be detected theoretically. This technique has not been demonstrated at the Hanford SSTs. Estimated performance at Hanford is summarized in Table 4.4 (Tracer Research, personal communication).

Table 4.4. Estimated Performance for Tracer Tightness Testing in a SST

Probability of detection	97%
Probability of false positive	2.9%
Detection Limit	0.05 gal./hr (1.2 gal/day)
Sampling frequency	to be determined

4.2.3.3 Implementation

Tracer Research recommends installing approximately 20 probes around the perimeter of a monitored SST. These probes are installed to monitor the base of the tank with best results if the probes extract vapors emanating from near the tank bottom, or slightly lower (around 50-ft. depth for a 1-Mgal SST).

Following probe installation, a baseline test is performed before any retrieval activities begin. This baseline test is conducted in two phases. In the first phase, the tank is inoculated with the tracer, and after approximately 14 days samples are collected from the soil gas probes for analysis. The second phase begins approximately 24 to 72 hours after completion of the first phase. This phase utilizes an active flow field that consists of moving air beneath the tank bottom to move tracer from a leak to one of the detection probes. A marker tracer is added to this air stream to track the air movement. Soil gas samples collected from the probes are analyzed using an onsite gas chromatograph.

Testing frequency during retrieval operations is determined from the baseline tests. A complete round of samples could be collected from one SST in approximately 1 hour. Removal/reinstallation of the probes is not required between sampling rounds, and the probes are left in place until all activities at the site have been completed.

4.2.3.4 Cost

Tracer Research has been contacted and has provided a rough estimate for performing a tracer tightness test at one Hanford SST (Table 4.5).

Table 4.5. Estimated Cost for Tracer Tightness Testing of One SST

Mobilization	$3,000
Installation (20 probes)	$17,000
Inoculation	$3,500
Tracer	$2,600
Sampling and Analysis (during sluicing)	To be determined

Note: The installation costs are not based on Tank Farm conditions and are probably significantly underestimated.

4.2.3.5 Recommendation for Use

Tracers are proven and have been highly effective in detecting leaks from tanks similar to the Hanford SSTs. They can detect leaks very accurately and quickly. Because the effective permeability of vapors in the Hanford formation is high, this type of system has a large zone of interrogation so should be able to detect leaks beneath the center of a SST. Installation costs for soils vapor probes are unknown, but probably very high. If wells or cone penetrometer rods are used to install other detection systems, then a dual completion that would include soil vapor extraction is possible. Another possibility is perforating drywells, set packers, and using them a soil vapor extraction points.

Extraction and analysis of tracer gases is not an automated process, so anticipated costs reduce the potential for this system as a detection system. If an automated system can be developed, it should be considered as a detection system. Nevertheless, the system would do well at confirmation because it can be used with no suspension of operations and sampling duration would be limited. A baseline survey before retrieval will be important so anticipated low levels of vapor leakage into soils can be quantified. Tracer testing will not be very effective at quantification.

4.2.4 Time Domain Reflectometry

4.2.4.1 Technical Description

Time-domain reflectometry (TDR) involves two steps: the measurement of the propagation velocity of an electromagnetic pulse along a transmission line and the conversion of this measurement to an estimate of soil water content (i.e., calibration) (Hook and Livingston 1994). The key to this technology is the relative difference in the dielectric constant of most dry geologic materials (approximately 3-5) compared to the dielectric constant of water (approximately 80). Precision Moisture Instruments, Inc. produces a 2-m long TDR probe that can be driven into subsurface soils; this probe has been successfully demonstrated at Hanford as part of the protective barriers program.

4.2.4.2 Performance Results

Conventional TDR can detect changes in moisture content as low as 1% VFW. The systems can collect continuous, automatic measurements over a 2-m long interval. The data can be telemetered to remote locations for analysis. Poor sensitivity to saline fluids used to be a limitation but has recently been solved through the use of the shortened-diode technique. TDRs have been demonstrated in simulated tank wastes (A. Ward PNL, personal communication).

The radius of measurement of the probe is approximately equal to 2.5 times the diameter of the probe. Therefore, the maximum measurement radius for a shortened-diode TDR probe would be about 1 ft. at best.

4.2.4.3 Implementation

Unfortunately, TDR would be difficult and/or expensive to install at the SSTs. TDR probes have been "pushed" to depths of up to only 6 ft. in Hanford soils. Pushing TDR probes to greater depths than10 ft. is probably not possible without using a drill rig or cone penetrometer. Cone penetrometer deployed TDRs are under development at Sandia and PNL. Therefore, boreholes are currently required for TDR probe installation. The boreholes would be advanced to a few feet from the monitoring interval, and the probe would be pushed to the desired depth.

The radius of measurement of the probe is approximately equal to 2.5 times the diameter of the probe. Therefore, the maximum measurement radius for a shortened-diode TDR probe would be about 1 ft. at best.

4.2.4.4 Cost

The cost for modifying a shortened-diode TDR probe for the Hanford SSTs would be approximately $20,000. The cost per probe would be approximately $3700. Borehole costs would be approximately $30,000 each (minimum).

4.2.4.5 Recommendation for Use

The primary drawbacks to TDR are its limited volume of interrogation and high installation costs. Advantages include good sensitivity to moisture (low inference for leak detection) and continuous monitoring.

TDR's limited depth of investigation translates into the installation of multiple probes, and the underside of a tank would still not be monitored. The system is probably best for confirmation because it is sensitivity to moisture, the data are straightforward to interpret, and it can be used during retrieval. TDR is not recommended for quantification because of its limited volume of interrogation.

A TDR probe can also function as an electrode for electrical resistivity tomography (ERT). If ERT is deployed, it may prove cost-effective to piggy-back TDR and use it as a confirmation and calibration system.

4.2.5 Electrical Resistivity Tomography

4.2.5.1 Technical Description

ERT measures the DC resistivity of a subsurface area or volume. The measurement is made with pairs of electrodes placed into the subsurface, each in electrical contact with the formation. Two electrodes are driven by a known current and the resulting voltage difference is measured between another electrode pair. Each voltage to current ratio is called a transfer resistance. Transfer resistance is measured repeatedly until multiple linear combinations have been measured. Numerical inversion is then used to calculate the resistivity distribution in the vicinity of the boreholes (Daily et al. 1992). Tomograhic software can be used to construct a two- or three-dimensional map of the subsurface electrical resistivity, depending on electrode geometry.

Because most minerals are insulators, current in the subsurface is typically conducted through pore liquids. The formation resistivity is a function of 1) resistivity of the formation water (i.e., salinity), 2) water content, and 3) pore structure geometry. For leak detection, the system will respond primarily to changes in the amount of water present.

4.2.5.2 Performance Results

Field experiments have been conducted at the Hanford Site to evaluate ERT for detecting leaks from a pilot-scale metallic underground storage tanks (USTs) and mapping the resulting plumes (WHC 1994). Two leak events were simulated during the testing. The first was the release of 1000 gal. of 0.08-M saline solution (NaCl) along the edge of the tank. The second was the release of 1000 gal. of 0.08-M saline solution from a point near the center of the tank. In both events, the leak was detected after approximately 100 gal. had been leaked into the formation. The leakage rate was approximately 7 gal./hour for each experiment. ERT electrodes were placed into 16 wells that ringed the pilot scale tank. The wells extended 35 ft. below the bottom of the tank and had vertical electrode spacings of 5 ft. Data from all 16 wells or from a depopulated data set, using just four or eight wells, were processed into two-dimensional plots that mapped the leak. In all cases, the leak was identified with plot anomalies that appeared after about 100 gal. of 0.08 M solution had been leaked. The quality of the graphs and the size of the pixels (e.g., the accuracy of leak location) was greatly enhanced with the addition of additional wells. A reasonable three-dimensional picture was possible with eight or even six wells. The three-dimensional image clearly delineates both the direction and the size of the resulting plume. Furthermore, it permits a reasonable computation of the total amount of leakant if calibration measurements are made in the laboratory using representative soil samples and liquids. These laboratory measurements can then be used in combination with the field results to estimate the leak volume. Coarser estimates can be made using established empirical rules such as Archie's law.

The results of the field tests indicate that the effectiveness of the ERT system is a direct function of the number and location of electrodes implanted in the subsurface. For a minimal implementation (four to six probes at a depth equal to or slightly lower than the base of a tank) the system would serve as a leak detector, with very little additional information. The detection limit would be less than 100 gal. of saline solution, and the confidence in the detection (of 6-M saline solution) would be high. Such a system could be installed with a TDR system, and would provide a simple detection and confirmation sensor set, using the same electrode for both systems.

A fully deployed system (6 to 8 wells, electrodes every 5 ft., to a depth 35 ft. below tank bottom) would yield far more quantitative information. Information in addition to the detection limit (<100 gal.) would include location and geometry of the leak, shape and direction of the resulting contaminant plume, speed and rate of growth of the plume, and a reasonable computation of the total volume of contaminant released. The physics of the system limits leak location detection to ±2/3 of the distance between 4 wells, ±1/2 the distance between 8 wells, and ±2/5 the distance between 16 wells. Because the distance between the wells is linearly reduced at each step, it is clear that a far more accurate view of the contaminant plume occurs with 8 wells than with 4. (For example, a 100-ft. tank with wells 5 ft. off-perimeter would have an approximate resolution of ±73 ft. for 4 wells, ±21 ft. for 8 wells, ±9 ft. for 16 wells.)

Neither deployment scheme for ERT will detect leaks that have not escaped into the formation (i.e., it will not detect leaks that fill the void between the cement shell and steel liner).

The time required for imaging varies with desired detail. Currently, a Sun workstation requires about 20 min. to produce a two-dimensional plot, and about 6 days to complete a full three-dimensional plot. By FY96 it is expected that the software will have improved performance to about 1 day for the three-dimensional plot.

Areas of concern include possible climatic effects, buried metal pipes, and the tendency of the formation to dry at the boundary of an electrode. Only probes near the surface experience climatic effects. The probes in the first 5 ft. of the surface register rainfall, and surface probes are sensitive to resistivity changes due to temperature variations. Proximity to the tanks has not presented a problem, while previous experience with buried metal pipes has also demonstrated no performance drop (especially noting the comparative size of a tank as a dominant factor). For data to be reliable, continuous electrical contact must be maintained with the formation and some care must be taken to insure this during implementation (William Daily LLNL, personal communication).

No empirical information is available about electrical noise from tank farm operations or from a multiple tank deployment zone. It is suggested, however, that both would cancel out in the original background baseline calibration. Further, no data are found regarding the upper limit concentration of solution that would lead to a direct conductivity, allowing no resolution. More research would be useful to study noise in tank farms, multiple tank geometry, and the effects of large or high molarity and locally saturated leaks.

4.2.5.3 Implementation

Three major concerns drive the implementation of ERT: 1) the electrodes must be continuously in electrical contact with the formation; 2) the nature of the desired final result, whether it is simple leak detection, or robust leak detection and quantification; 3) the threshold size of the leak to detect.

A variety of implementations are possible (Table 4.6). The Hanford test implementation involved probe wells using PVC casings and stainless steel wire mesh for the electrodes. These were put together onsite and dropped down the borehole. This allowed water to be inserted into the borehole to guarantee a good electrical connection for the experiment.

Table 4. 6. Implementation Constraints for Electrical Resistivity Tomography

Implementation Scheme	Detection	Quantification
4 wells	<100 gal. 0.08-M saline high confidence (a)	general area anomaly some source and transport info
6 wells	<100 gal. 0.08-M saline high confidence (a)	near quadrant area anomaly 1/2 dimension resolution
16 wells	<100 gal. 0.08-M saline high confidence (a)	single pixel resolution plume mapping leak size computation remediation affects
6 TDR probes	<100 gal 0.08-M saline requires confirmation	general area anomaly

(a) Based on good electrical contact at electrodes

An alternate method of implementation may be to use TDR probes as the lowest electrode, driven down with a cone penetrometer. Additional electrodes (each coated with dielectric gel) might be packed at any desired intervals as the penetrometer is dragged back out of the hole. Because the system is closed (when the formation collapses on the electrode), equilibrium would occur and the calibration of a baseline resistivity would be reliable. With TDR capability present at the same location, however, were an apparent difficulty to occur, the TDR would give an independent estimation of soil moisture (around that electrode) and recalibration might be possible, establishing a new baseline and allowing confidence in the results of the ERT system. Electrodes need to be little more than a stainless steel spike or wire mesh cylinder in direct contact with the formation.

At present, software to automate TDR data collection is not completed. It is expected to be complete in FY96. Currently, the data collection computer must be activated and the data hand carried to the (Sun) imaging station. With automation, the data collection can be at any desired interval, with two-dimensional images possible every 20 min., and three-dimensional images possible every 6 days using existing software. The software for three-dimensional imaging is presently being re-written to shorten the process to a 1-day turn-around time (William Daily LLNL, personal communication).

4.2.5.4 Cost

The cost for the electrodes for ERT are minimal, amounting to just a few dollars each.. The data collection computer would cost about $50,000 and the processing workstation $70,000. Additional expense for the processing software is unclear. In the test run at

Hanford, placing the electrodes on the casing and dropping them into the hole took about 1.5 hours per hole. The casing and the electrodes together cost $40 per hole. The primary cost for ERT will be electrode emplacement, probably by drilling although cone penetrometers could be used. Insertion by cone penetrometer may be less expensive and also would allow simultaneous insertion of a tracer port and TDR technologies.

Once the probes are inserted and the computers are put on-line (with automated programming and modem network), the system could be operated nearly continuously with monitoring only at the imaging station and ordinary computer maintenance onsite.

The cost and effects of maintaining contact between the electrodes and the formation is unknown, but probably not significant.

4.2.5.5 Recommendation for Use

ERT is the leading candidate for leak detection. It has a large volume of interrogation, monitors nearly continuously, is sensitive to relatively low leak volumes, and has been demonstrated at a simulated SST (WHC 1994). A simple planar arrangement of electrodes, placed approximately 5 ft. below the base of the tank, would be required for detection. The major drawback for detection with ERT is the requirement for nonconductive well casing. The existing drywells are steel-cased, so they cannot be used by ERT. Electrode insertion would have to be performed with either a borehole or cone penetrometer.

ERT can also be used for quantification; however, this will require the emplacement of a series of electrodes at different depths, probably a more expensive emplacement scenario that could not be readily performed with a cone penetrometer. Quantification also requires an estimation of the resistivity of the leakant, a value that can change with time, especially if fluid is added to the tank during retrieval.

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