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# ENGINEERING CHANGE NOTICE



1. ECN 651178

Proj. ECN

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|---|---|---|---|
| 2. ECN Category (mark one)<br>Supplemental [ ]<br>Direct Revision [X]<br>Change ECN [ ]<br>Temporary [ ]<br>Standby [ ]<br>Supersedure [ ]<br>Cancel/Void [ ] | 3. Originator's Name, Organization, MSIN, and Telephone No.<br>JS Hertzel / Retrieval System Development / R3-74 / 373-2616 | 4. USQ Required?<br>[ ] Yes [X] No | 5. Date<br>10/27/1998 |
| | 6. Project Title/No./Work Order No.<br>Waste Management | 7. Bldg./Sys./Fac. No.<br>200G | 8. Approval Designator<br>NA |
| | 9. Document Numbers Changed by this ECN (includes sheet no. and rev.)<br>WHC-SD-WM-ES-379, Rev 0 | 10. Related ECN No(s).<br>NA | 11. Related PO No.<br>NA |

| | | | |
|---|---|---|---|
| 12a. Modification Work<br>[ ] Yes (fill out Blk. 12b)<br>[X] No (NA Blks. 12b, 12c, 12d) | 12b. Work Package No.<br>NA | 12c. Modification Work Complete<br>NA<br>Design Authority/Cog. Engineer Signature & Date | 12d. Restored to Original Condition (Temp. or Standby ECN only)<br>NA<br>Design Authority/Cog. Engineer Signature & Date |

13a. Description of Change

13b. Design Baseline Document? [ ] Yes [X] No

This is a revision to an ealier report that describes various LDMM technologies. This revision focuses on improvements in ~~prevously~~ previously identified technologies, and introduces new technologies that might prove to be useful.

14a. Justification (mark one)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Criteria Change | [X] | Design Improvement | [ ] | Environmental | [ ] | Facility Deactivation | [ ] |
| As-Found | [ ] | Facilitate Const | [ ] | Const. Error/Omission | [ ] | Design Error/Omission | [ ] |

14b. Justification Details

This revision is intended as an update to include the most recently developed technologies and information.

15. Distribution (include name, MSIN, and no. of copies)

| | | |
|---|---|---|
| JS Hertzel | R3-74 | 1 |
| PJ Certa | R3-74 | 1 |

RELEASE STAMP

DATE: NOV 17 1998

STA: 4

HANFORD RELEASE

ID: 58

# ENGINEERING CHANGE NOTICE



1. ECN (use no. from pg. 1): 651178

| 16. Design Verification Required | 17. Cost Impact – ENGINEERING | | 17. Cost Impact – CONSTRUCTION | | 18. Schedule Impact (days) | |
|---|---|---|---|---|---|---|
| [X] Yes | Additional | [] $ | Additional | [] $ | Improvement | [] |
| [] No | Savings | [] $NA | Savings | [] $NA | Delay | [] NA |

19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

| | | | | | |
|---|---|---|---|---|---|
| SDD/DD | [] | Seismic/Stress Analysis | [] | Tank Calibration Manual | [] |
| Functional Design Criteria | [] | Stress/Design Report | [] | Health Physics Procedure | [] |
| Operating Specification | [] | Interface Control Drawing | [] | Spares Multiple Unit Listing | [] |
| Criticality Specification | [] | Calibration Procedure | [] | Test Procedures/Specification | [] |
| Conceptual Design Report | [] | Installation Procedure | [] | Component Index | [] |
| Equipment Spec. | [] | Maintenance Procedure | [] | ASME Coded Item | [] |
| Const. Spec. | [] | Engineering Procedure | [] | Human Factor Consideration | [] |
| Procurement Spec. | [] | Operating Instruction | [] | Computer Software | [] |
| Vendor Information | [] | Operating Procedure | [] | Electric Circuit Schedule | [] |
| OM Manual | [] | Operational Safety Requirement | [] | ICRS Procedure | [] |
| FSAR/SAR | [] | IEFD Drawing | [] | Process Control Manual/Plan | [] |
| Safety Equipment List | [] | Cell Arrangement Drawing | [] | Process Flow Chart | [] |
| Radiation Work Permit | [] | Essential Material Specification | [] | Purchase Requisition | [] |
| Environmental Impact Statement | [] | Fac. Proc. Samp. Schedule | [] | Tickler File | [] |
| Environmental Report | [] | Inspection Plan | [] | None | [X] |
| Environmental Permit | [] | Inventory Adjustment Request | [] | | [] |

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

| Document Number/Revision | Document Number/Revision | Document Number Revision |
|---|---|---|
| | | |

21. Approvals

| | Signature | Date | | Signature | Date |
|---|---|---|---|---|---|
| ~~Design Authority~~ (PJC) JS Hertzel | J.S. Hertzel | 10-27-98 | Design Agent | | |
| Cog. Eng. | | | PE | | |
| Cog. Mgr. PJ Certa | Paul J. Certa | 10-28-98 | QA | | |
| QA | | | Safety | | |
| Safety | | | Design | | |
| Environ. | | | Environ. | | |
| Other | | | Other | | |

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

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# Leak Detection, Monitoring, and Mitigation Technology Trade Study Update

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U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: 651178 UC: 2030
Org Code: 81200 Charge Code: 1D2631
B&R Code: EW3130010 Total Pages: ~~53~~ 54

Key Words: LDMM, Leak Detection, Leak Monitoring, Leak Mitigation, Technology Trade Study

Abstract: This document is a revision and update to the initial report that describes various leak detection, monitoring, and mitigation (LDMM) technologies that can be used to support the retrieval of waste from the single-shell tanks (SST) at the Handford Site. This revision focuses on the improvements in the technical performance of previously identified and useful technologies, and it introduces new technologies that might prove to be useful.



Printed in the United States of America. To obtain copies of this document, contact: Document Control Services, P.O. Box 950, Mailstop H6-08, Richland WA 99352, Phone (509) 372-2420; Fax (509) 376-4989.

11/10/98
Release Approval Date

DATE HANFORD
STA: 4 RELEASE ID: 58
NOV 17 1998
Release Stamp

**Approved for Public Release**

## RECORD OF REVISION

(1) Document Number: HNF-SD-WM-ES-379

Page 1

(2) Title
Leak Detection, Monitoring, and Mitigation Technology Trade Study Update

CHANGE CONTROL RECORD

| (3) Revision | (4) Description of Change - Replace, Add, and Delete Pages | Authorized for Release (5) Cog. Engr. | Authorized for Release (6) Cog. Mgr. Date |
|---|---|---|---|
| 0 | (7) **Trade Study of Leakage Detection Monitoring & Mitigation Technologies to Support Hanford Single Shell Waste Retrieval** (EDT 605653) | | |
| RS 1 | **Leak Detection, Monitoring, and Mitigation Technology Trade Study Update** (ECN 651178) Revision 1 is an update of LDMM technologies supporting SST waste retrieval. This revision focuses on improvements in technologies and newly identified technologies. | JS Hertzel (design Authority) J.S.Hertzel 11-17-98 | PJ Certa PJ Certa 11-17-98 |
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# Leak Detection, Monitoring, and Mitigation Technology Trade Study Update

LMHC Subcontract No. MKG-SDD-A44451
Vista Research Project No. 2106

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September 1998

# Executive Summary

This document is a revision and update to an earlier report[1] that described various leak detection, monitoring, and mitigation (LDMM) technologies that can be used to support the retrieval of waste from the single-shell tanks (SSTs) at the Hanford Site. This revision focuses on improvements in the technical performance of previously identified and useful technologies, and it introduces new technologies that might prove to be useful. A number of existing and new commercial technologies have been identified in each of the LDMM areas (detection, monitoring, and mitigation) that can be adapted to the SSTs and have the potential to improve and better support waste retrieval operations. These technologies include: (1) ***volumetric methods*** for leak detection; (2) ***horizontal directional drilling*** (HDD) for the deployment of leak detection and leak monitoring methods like electrical resistance tomography (ERT) and tracer-gases, and for point-specific post-retrieval soil sampling; and (3) ***continuous self-priming bottom suction trash pumps*** for leak mitigation during hydraulic retrieval.

This report was written with the following viewpoint and objectives: First, it seeks to identify LDMM methods that are likely to be successful at Hanford. These are expected to be adapted from LDMM-equivalent methods used in the petroleum industry, and from methods used at the Oak Ridge National Laboratory. Secondly, since not all petroleum-based methods will work at Hanford all of the time, the report seeks to identify less-proven, but emerging technologies that have the potential for successful application given further development and demonstration. In this same vein, this report seeks to dismiss methods that are not expected to be successful or would be less useful than others identified. Thirdly, this report emphasizes the need to establish the *performance* of all of the LDMM methods used at Hanford. This is because a performance-based methodology is the only way to reliably and consistently detect and mitigate leaks that might occur from an SST and to effectively use these methods without adversely impacting operations. Lastly, this report advances the premise that the selection of LDMM technologies should be based on the method of waste retrieval that has been determined appropriate for a given tank (see the table below). The selection of the retrieval method itself should be based on factors such as tank integrity, volume of sludge, salt cake and supernate, and waste constituents.

[1] Foster Wheeler Environmental Corporation, "Trade Study of Leakage Detection, Monitoring, and Mitigation Technologies to Support Hanford Single-Shell Tank Waste Retrieval." Prepared for the Westinghouse Hanford Corporation, Report No. WHC-SD-WM-ES-379 Rev. 0 (March 1996).

| | Technology | | |
|---|---|---|---|
| *Retrieval Method* | **Leak Detection** | **Leak Monitoring** | **Leak Mitigation** |
| **No Action**† | None | None | None |
| **Enhanced Sluice** | Volumetric | Post-Retrieval Soil Sample | Inherent Liquid Minimization |
| **Low Flow Sluice** | Volumetric | ERT | Auxiliary Pump |
| **Confined Sluice** | Volumetric | ERT | Auxiliary Pump |
| **Mechanical Retrieval**‡ | None | Post-Retrieval Soil Sample | None |
| **LVDG Dissolution** | Volumetric | Post-Retrieval Soil Sample | Inherent Liquid Minimization |

† **No Action Retrieval** implies tanks that are ready for direct closure (i.e., tanks that contain very little residual waste due to previous sluicing or operational campaigns). For these cases, additional leak detection, leak monitoring, and leak mitigation while the tanks await closure are not necessary.

‡ **Mechanical Retrieval** implies a dry or nearly-dry retrieval process with no liquids to detect or leaks to mitigate. It may be appropriate to sample the surrounding soils after the retrieval is complete if leaching from an external liquid source (e.g., rain water) is suspected.

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# Acronyms

| | |
|---|---|
| DCRT | Double-contained receiver tank |
| ENRAF™ | Enraf-Nonius tank level gauge |
| EPA | Environmental Protection Agency |
| ERT | Electrical resistance tomography |
| FIC™ | Food Instrument Corporation tank level gauge |
| HDD | Horizontal directional drilling |
| ILL | Interstitial liquid level |
| LDMM | Leak detection, monitoring and mitigation |
| LOW | Liquid observation well |
| LVDG | Low volume density gradient (sprinkler) |
| MDLR | Minimum detectable leak rate |
| VIB | Volumetric Inventory Balance |
| $P_D$ | Probability of detection |
| $P_{FA}$ | Probability of false alarm |
| SIR | Statistical inventory reconciliation |
| SST | Single-shell tank |
| TDR | Time-domain reflectometry |

# 1 Introduction

This report updates the information presented in an earlier report, "Trade Study of Leakage Detection, Monitoring, and Mitigation Technologies to Support Hanford Single-Shell Tank Waste Retrieval" [1]. It reviews and updates the leak detection, monitoring, and mitigation (LDMM) technologies described in Revision 0 and introduces additional LDMM technologies that can be used to support the retrieval of wastes from the single-shell tanks (SSTs) at Hanford. The reader is referred to Revision 0 for a detailed description of the LDDM technologies.

The waste retrieval approaches covered in this report include the three that were contemplated when the earlier report was prepared (mechanical removal, confined sluicing, and past-practice sluicing) and another approach that has been proposed since that time (low volume density gradient (LVDG)).

In Revision 0, six technologies for leak detection and monitoring were identified (mass balance, tracer gas, leak detection pits, electrical resistance tomography (ERT), borehole logging, and time-domain reflectometry). These technologies were directed at detecting tank leaks, not piping leaks; thus, this report only addresses leak detection in tanks. In the petroleum industry, three methods of leak detection for underground storage tanks (USTs) have been used effectively, and indeed have been required, for the last 10 years. Thus, a comprehensive review of petroleum industry practices allows addition of volumetric methods (including mass-based methods) and statistical inventory reconciliation (SIR) methods to the list of identified technologies. (The third petroleum-industry method, tracer gas, was already identified in Revision 0.)

As described below, the use of volumetric methods for leak detection has significant implications for designing a robust and cost-effective leak detection and monitoring program, because it allows a variety of approaches to be used that could not previously be considered. This is possible because volumetric methods both detect and quantify the flow rate due to a leak, have high and field-verifiable performance, and can be implemented with instrumentation that is already in place in the SSTs. A recent study involving a large number of Hanford SSTs shows that volumetric methods will be able to test these tanks reliably and accurately by using level measurements of the supernatant liquid [2].

Two technologies—horizontal directional drilling (HDD) and cone penetrometer—are being investigated as a means for deploying tracer-gas and ERT methods of leak detection and monitoring more effectively and for enhancing their performance. Both technologies are presently being evaluated in field demonstrations at Hanford. In this report, the leak detection and monitoring technologies are discussed in the context of the waste retrieval approach.

This report also presents, and recommends the use of, an unambiguous and industry-accepted definition of performance (in terms of probability of detection and probability of false alarm) and describes how to evaluate the performance of any system in terms of this definition. The adoption of this ASTM/EPA approach addresses a major issue identified in the earlier report. Revision 0 evaluated only minimum and maximum leak detection sensitivities, an approach that can lead to ambiguities about method selection. These ambiguities can be avoided if the performance of leak detection methods is evaluated. Also, for most, if not all of the technologies described, it is the only way to make a defensible estimate of performance.

Finally, three leak mitigation methods are included in this report. The subsurface-barriers method discussed in Revision 0 is updated, and a method that makes use of self-priming submersible pumps for advanced emergency pumping is discussed.

In this report, the following definitions, which are consistent with Revision 0, are used for leak detection, leak monitoring and leak mitigation.

- **Leak Detection**—a leak detection system is any method or system that can detect a leak.
- **Leak Monitoring**—a leak monitoring system is any system that can map out the concentration and/or spatial extent of a contamination plume due to a release of the contaminant from a tank (or pipe).
- **Leak Mitigation**—a leak mitigation system is any system that can prevent a leak during waste retrieval operations or minimize its impact.

The overriding goal in selecting and implementing a waste retrieval technology is to minimize the total volume of liquid waste that would be released to the environment if a leak were to occur. The triangle shown in Figure 1 links together the three elements necessary for a release of liquid waste from a tank; a fourth element, time, is necessary to obtain a leak volume. If there are no holes in the tank, then by definition there is no possibility of a leak. If however, there are one or more holes in the tank, the volume of liquid released can be minimized by minimizing the volume of free liquid or the hydraulic head of the liquid, or both. If any of the legs of the triangle are severed, then no leak will occur.

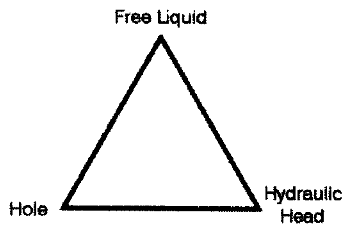

**Figure 1.** Leak minimization triangle.

The report is organized into seven sections. Section 2 defines the performance of a leak detection system and standard industry accepted procedures for estimating the performance of a system. It also describes briefly the most commonly accepted methods for tank leak detection in the petroleum industry, which has been actively and successfully testing many hundreds of thousands of tanks for leaks over the past 10 years. In this section, a brief description of horizontal directional drilling , a technology that can be used to effectively deploy LDMM technologies is described. Section 3 reviews and updates the leak detection and leak monitoring technologies, and Section 4 reviews and updates the leak mitigation technologies. Several additional technologies are introduced in both sections that were not included in Revision 0. Section 5 describes waste retrieval technologies that could be implemented at Hanford. In Section 6, the LDMM technologies are discussed in terms of each of the possible waste retrieval approaches that could be used. The conclusions and recommendations are presented in Section 7.

# 2 Leak Detection

Leak detection technologies can be broadly divided into two basic approaches: internal and external. Internal methods determine whether a tank (or pipe) is leaking by attaching or inserting a sensor into the tank (or pipe) and measuring the changes in the fluid in the tank. Volumetric systems (e.g., level- or mass-based systems) and acoustic systems are examples of internal systems. Volumetric systems measure the change in the level of the liquid and report variances in the level that may be indicative of a leak. For high performance, volumetric systems must comprehend such apparent changes in liquid level as instrument drift and recording errors, as well as influences that can affect the measured level and could otherwise be interpreted as a leak. At Hanford, examples of these influences include the effects of barometric pressure on the dissolved gasses in the SST liquids, temperature effects that cause expansion and contraction of the liquid volume, and evaporation. For a variety of reasons, internal systems are the most widely used systems of leak detection.

External systems determine whether a tank (or pipe) is leaking by making measurements outside the tank. ERT and tracer systems are examples of external systems. The performance of external systems is controlled by the physical and chemical properties of the backfill and soil beneath the tank. Most external systems seek to establish baseline conditions for soil and groundwater and then to monitor any change in baseline conditions that would be indicative of the release of liquid from a tank. External systems must clearly understand the leak history of the target tank in order to declare a change in the baseline and thereby declare a leak. With some systems this can be difficult, because background levels of various physical or chemical components may change over time (e.g., the seasonal changes in soil properties and groundwater levels). External systems can be very effective when the release contains a tracer or constituents not naturally present or not previously released to the soil/groundwater. External systems can be used for leak detection, but in their application to SST waste retrieval operations they tend to be better suited for leak monitoring.

## 2.1 Performance of a Leak Detection System

The ***performance*** of any type of leak detection or leak monitoring system (i.e., its accuracy and reliability) can be defined unambiguously as long as that system provides a quantitative measurement of the sensed entity. Furthermore, performance can be determined by means of a straightforward evaluation procedure first developed by the EPA [3,4] and then developed into an ASTM standard practice [5]. Performance is defined in terms of the ***probability of detection*** ($P_D$) of a specified ***leak rate*** (LR) and the ***probability of false alarm*** ($P_{FA}$). The terms probability of detection and probability of false alarm refer, respectively, to the statistical probability of detecting a leak when a leak is actually present, and to the statistical probability of incorrectly declaring a leak when there is no leak. These two terms are deeply rooted in the expression of performance applied to detection devices such as radars and sonars, and for the past 10 years have been used in the leak detection industry for underground storage tanks (USTs) containing petroleum fuels and other hazardous substances. *Leak rate* (or the volumetric flow rate through a hole in a tank or pipe) refers to the temporal rate of change of liquid volume due to a defect or loss of liquid integrity. At Hanford, "leak rate" refers to a volume loss from an SST (or a related pipeline) over some time interval, due to a breach in the liquid integrity of the tank. This is an important concept, because the term *"rate"* allows us to complete the performance of different systems and to determine the required frequency of conducting a test.

The $P_{FA}$ can be determined from measured data once a ***detection criterion***, usually defined in terms of a ***detection threshold*** (T), is selected. Once the LR of interest has been selected, T can be selected such that it yields a certain $P_D$ and $P_{FA}$. Once $P_D$ and $P_{FA}$ are specified, a ***minimum detectable leak rate*** (MDLR) can be estimated. Also, once the detection criterion is selected, the $P_D$ can be computed for any leak rate. A $P_D$ of 95% means that the system will (on average) detect 95 out of 100 leaks at a specified leak rate. A $P_{FA}$ of 5% means that the system will falsely indicate the presence of a leak 5 out of 100 times when no release is actually present.

The term *minimum detectable leak rate*, or MDLR, is a quantity that can be used to define the performance capability of the system; however, it may or may not be representative of the performance of the system as it is operated. For example, a system might have a MDLR of 3.0 gal/h, at $P_D = 95\%$ and a $P_{FA} = 5\%$. If such a system were to be used as a monitoring system, then a $P_{FA} < 1\%$ might be more appropriate than one equal to 5%, so that false alarms could be reduced to a level that is operationally acceptable. The resulting performance of the system as operated, then, might be $P_D = 95\%$ against a LR = 5.0 gal/h and a $P_{FA} = 0.25\%$. It is in everyone's interest to use a system with a very high performance, so that it can be operated efficiently and cost effectively. The MDLR provides a reference and a starting point for selecting a leak detection system that has adequate performance for making sound operational decisions.

The performance of a system depends on the strength of the signal and the total noise in the signal band. For a given system, the instrumentation and uncompensated ambient noise (e.g., barometric pressure and temperature effects) usually limits the performance of the system. The performance of a system might be improved if another type of tank gauge were employed, or if there were modifications made to the instrumentation, data collection equipment, signal processing algorithms, or a combination of all of these elements. One way to determine performance is to conduct many tests on a tank (or tanks) whose integrity is known a priori; these tests must be conducted over a wide range of operational and environmental conditions based on those that might be encountered once the system has been implemented. EPA/ASTM evaluation procedures require about 25 tests [3-10].

If a leak detection system has a very high level of performance (in terms of MDLR), one can select a detection criterion that meets budget, schedule, engineering, and operational requirements. In other words, the budget, engineering and operational requirements can be used as the basis for selecting an appropriate detection criterion.

## 2.2 Performance Evaluation Example

The performance of a leak detection system is to determined by conducting many tests on a tank (or many tanks) whose integrity is known. Consider the volume data in the time series shown in Figure 2. These data, taken from four months of daily samples from an ENRAF™ level gauge on SST Tank U-105 at Hanford, show how the measured volumes appear to vary with time. The volume covers a range of 1,100 gal (from about 447,800 to 448,900 gal) in a more or less random way. Since the tank is not active and is (presumably) not leaking, the observed fluctuations in level are simply "noise." The magnitude of the noise can be statistically estimated from a series of volume rate measurements obtained by fitting a regression lines to periodic segments of the level data. The four straight lines shown going through the volume time series in Figure 2 represent the regression lines obtained through an analysis of the four one-month periods. It can be observed that the data blocks each have distinct and different trends. The slopes through the data sets representing each of the four one-month periods are shown in Table 1.

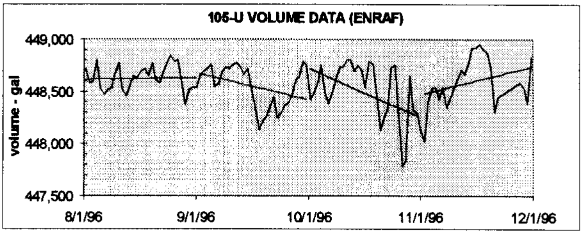


**Figure 2.** Raw volume data from Tank U-105 over a four-month period.

As described below, by examining a larger number of these one-month periods, a statistical estimate of the performance of a leak detection system based upon this data can determined. A plot of the slope of the regression of 24 one-month-long data segments from the ENRAF™ gauge on Tank 105-U is shown in Figure 3. An analysis of these data [2] shows that the ENRAF™ data yields an average volume rate of 0.21 gal/h over the 2-year period, with a standard deviation of the slope estimates of 0.62 gal/h. The standard deviation represents the uncertainty of the method and is used to make the estimate of performance. The mean suggests that there is a small inflow of 0.21 gal/h. If this inflow is constant, it does not effect performance. An estimate of the performance of this system can be made using the histograms of the noise and the signal-plus-noise.

**Table 1.** Volume Rate Data from Tank U-105

| Date | Slope of regression, m |
|---|---|
| August 1996 | +0.02 gal/h |
| September 1996 | -0.35 gal/h |
| October 1996 | -0.65 gal/h |
| November 1996 | +0.37 gal/h |

Assuming that the histograms of the noise and the signal-plus-noise are normally distributed, as prescribed by the ASTM/EPA standard test procedure for evaluating the performance of a volumetric leak testing system [5,8], it can be shown that by using a threshold of -1.05 gal/h, a leak rate of -2.11 gal/h can be detected with a $P_D$ of 95% if a month-long test is conducted. Using this threshold, a $P_{FA}$ of 5% would be expected. The performance would degrade if the test were conducted over periods shorter than one month. This degradation could be partially (or entirely) offset by sampling the level sensor more frequently than once per day (typical sample rates are once per minute), and by compensating for some of the known influences such as temperature, barometric pressure, and so on.

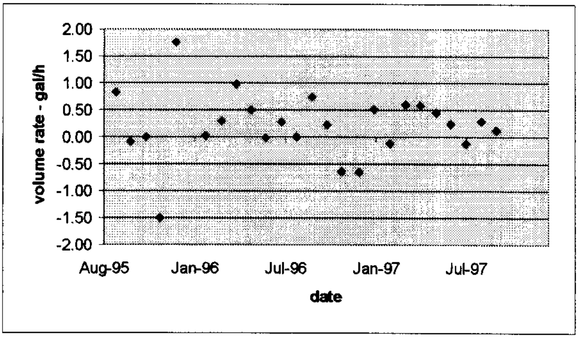


**Figure 3.** Regression slopes of 24 one-month volume periods from Tank U-105.

## 2.3 Leak Detection in the Petroleum Industry

The petroleum industry has developed and successfully used a variety of leak detection and monitoring techniques for environmental protection and regulatory compliance. The systems used in this industry are *evaluated* for performance according to standard test procedures and practices prescribed by ASTM [3] and EPA [8-10]. A list of over 100 EPA-evaluated technologies that have MDLRs of 0.1 and 0.2 gal/h, which are in compliance with state and local regulations for USTs, is published by the National Work Group on Leak Detection, an ad hoc group of state and federal regulators [13]. This list has recently been amended for some states via the Internet to include volumetric tank testing systems for bulk tanks.

Volumetric systems, including mass-based systems, are the most commonly used approach to leak detection. Statistical inventory reconciliation (SIR) systems, which compensate for various errors present when reconciling inventory, have gained technical acceptance in recent years. Finally, there are the tracer-based systems, in which a tracer substance not found naturally in the subsurface environment is placed in the tank and detected outside the tank; in addition to leak detection, tracer systems can also be used for leak location. All three types of systems have similar performance in terms of probability of detection and probability of false alarm MDLRs of 0.1 gal/h for tightness tests and 0.2 gal/h for monthly monitoring tests), and all have gained regulatory acceptance for use in underground storage tanks (USTs) containing petroleum. In recent years, all three technologies have been successfully adapted for use on bulk fuel tanks with capacities equal to or greater than the largest SSTs at Hanford.

Volumetric systems are the most common system of testing fuel tanks, both large and small [3, 6, 7, 11-17]. Hundreds of thousands of tests on USTs, using 25 to 50 different types of systems, have been conducted over the past 10 years. Furthermore, the performance of volumetric systems is well known and can be determined in a straightforward manner according to EPA and ASTM protocols without having to simulate a leak in a tank. (This is not true for the external systems of leak detection, where the location of the hole and the properties of the hole and backfill impact the performance of the leak detection system.) This system of leak detection was successfully applied to the liquid low-level waste (LLLW) tanks at the Oak Ridge National Laboratory [11,12]. During the past two years, volumetric systems, using differential pressure measurements, have been developed for and demonstrated on large (250,000 gal to 12,5000,000 gal) bulk fuel tanks [17].

Volumetric systems were not described in Revision 0, most likely because their application during a sluicing campaign was not obvious, and the technology had not yet been successfully adapted for the large bulk fuel tanks. The successful application of this technology to tanks larger than those at Hanford and the analysis of the level data alone from over 30 of the SSTs at Hanford suggest that accurate leak detection (better than 5 to 10 gal/h) is possible. A preliminary analysis of the performance a simple volumetric system that uses only level measurements showed that leaks of 3 gal/h or less could be detected with a probability of 95% and a probability of false alarm of 5% [2]. This analysis was based on monthly level data obtained on the supernate. The obvious advantages of a volumetric leak detection system are that (1) there is no confusion about which tank may be leaking; (2) it is an easily understood and evaluated technology; and (3) it can be used to quantify the leak rate in terms of a flow rate, a useful operational and regulatory quantity.

The petroleum industry has used *inventory reconciliation* systems for gross leak detection for the last 50 years. SIR, introduced to the industry about 10 years ago, is an enhanced inventory reconciliation system that is commonly used in the petroleum industry to meet regulatory leak detection requirement for USTs [4]. Higher accuracy is obtained with SIR by accounting for some of the larger errors in inventory reconciliation. With the addition of pipeline flow meters, this approach has also been successfully applied to large bulk tanks. As used at a retail service station, the system reconciles the volume of fuel delivered to the tank by truck, stored in the tank and dispensed by a pump from the tank into a vehicle. Accurate measurements of these quantities and the dimensions of the tank are required. As generally implemented, approximately 30 days of level and dispensing pump data collected at least once per day are required for leak detection. These data include (1) the volume of fuel delivered from the tanker truck into the tank as specified on the delivery slip, (2) the level of the fuel in the tank as determined from a stick or electronic gauge, and (3) the volume of fuel dispensed to a car as determined by the dispensing pump. This system is very similar in nature to the proposed mass balance system except that, unlike at Hanford, the density of the fuel is expected to remain essentially constant during dispensing and storage and measurements of liquid volume are made.

The third leak detection approach that is successful in the petroleum industry and that should be considered as a means of leak detection for the Hanford tanks is the tracer system. Two types of tracer systems are employed. In the first type, the liquid itself or one or constituents in the liquid, either in a gaseous or liquid state, may be used as a tracer. In most cases, these tracers are not unique and are found naturally in the surrounding soil/groundwater or are present from previous releases or accidental spills. The use of this type of tracer system has not been very successful. In the second type, a unique substance, which is not naturally present in the soil/groundwater, is inserted into the tank. The latter type of tracer system, in which a liquid tracer is mixed into the waste and is released as a gas once the liquid leaks into the soil, has been successfully used for detection of leaks in petroleum tanks [18].

The performance of both types of tracers is controlled by the properties of the backfill and soil beneath the tank. Tracer systems of the first type seek to establish a baseline soil condition and to monitor changes to that baseline due to the release of liquid from the tank. These systems must clearly understand the leak history of the target tank in order to declare a change in the baseline and thereby declare a leak. For some systems, this is very difficult to ascertain because background levels may change over time (e.g., seasonal changes). Tracer systems of the second type require more than one type of tracer for practical use, because releases and spills will introduce the non-naturally occurring tracer into the soil/groundwater.

Although a direct comparison of performance for all of the LDMM technologies covered in this report is not possible since not all of the methods have been examined, a comparison of some methods can be made. While preliminary and incomplete in this revision, a comparison of LDMM technologies as they are and have been used in the petroleum industry and at DOE sites is nonetheless revealing. This is shown in Table 2, below.

**Table 2.** Minimum Detectable Leak Rates for LDMM technologies in various applications.

| *LDMM Technology* | **MDLR Performance (@ $P_D \geq 95\%$, $P_{FA} \leq 5\%$)** USTs (<50Kgal) (gal/h) | Field-Erected USTs (100Kgal to 4.5Mgal) (gal/h) | DOE ORNL (gal/h) | DOE Hanford (gal/h) |
|---|---|---|---|---|
| **Volumetric** | 0.1, 0.2 | 0.2 to 3.1 | 0.2 | <3.0 |
| **Inventory Balance** | 0.1, 0.2 | 0.2 * | -- | -- |
| **Tracer** | 0.1, 0.2 | 0.1, 0.2 | 0.5** | -- |
| **Leak Detection Pit** | -- | -- | 0.5 | n/a*** |
| **ERT** | -- | -- | | 0.5 to 8.0* |
| **Mass Balance** | -- | -- | -- | -- |
| **Borehole Logging** | -- | -- | -- | -- |
| **Time-Domain Reflectometry** | -- | -- | -- | -- |

* Estimated; method has not undergone performance evaluation
** GAAT conductivity probe
*** method used, but performance not specified or estimated

## 2.4 Deployment of LDMM Measurement Systems

One of the more important deciding reasons for selection of a leak detection or leak monitoring technology in Revision 0 was deployability. Deploying measurement systems near or under the tanks (tank farms) at Hanford will require some type of excavation or drilling technique. The more common techniques that might be used at Hanford include vertical drilling, cone penetrometer, slant borings, and hand and mechanical excavation. While those techniques can deploy sensors near tanks, using them to attempt to deploy the sensors under large tanks (or tank farms) is problematic. Horizontal directional drilling, on the other hand, has progressed significantly in the last few years and offers an alternate for sensor deployment.

Horizontal directional drilling offers a number of important advantages to LDMM technologies. First, it can be used to deploy sensor systems which otherwise could not be deployed. Second, the performance a leak detection or a leak monitoring system can be improved because sensors can be placed directly beneath a tank in closer proximity to a potential leak from that tank. Potential borehole sensors that could be deployed in a horizontal well include resistive ERT (discussed above) to make (x,y) contour maps of the conductivity of the soil beneath the tank, conductivity detectors to sense the conductivity of the soils at the deployed locations, radiation detectors to detect the presence of radioactive materials beneath the tanks, and chemical tracers. Other sensors could also be deployed.

HDD is now commonly used in the utility industry, where fiber optic cables, telephone cables, electrical lines, and other underground utilities are to be newly installed within an existing infrastructure, or where upgrades or replacements are to be installed. HDD is used to precisely place a borehole that can be maneuvered while it is being created so that (known) existing pipelines and utilities can be avoided. In this application, it is much more cost-effective that the traditional trench-and-excavate installations of prior years.

Fundamental to the potential use of boreholes under Hanford's tanks is the question of the accuracy with which the borehole position can be determined as the bore is being drilled. There are three methods that are currently used to measure the location of the drill bit-as the hole is being drilled. For shallow applications (less than 30-ft), a walk-over sonde system can be used. For deeper drilling, accelerometer-magnetometer systems are used. This latter system can be combined with a magnetic field-reversal method to achieve 1% to 2% depth accuracy in drill path alignment.

HDD is currently being demonstrated at “cold” test sites at Hanford. These demonstrations will determine the ability of HDD to penetrate the gravel and cobbled soil in the subsurface at Hanford, and the accuracy of the drill path. Practical design decisions can then be made regarding the use of HDD to deploy measurement systems under the Hanford tanks. If the deployment issue is successfully addressed, then the main issues for application to LDMM are the cost of drilling and the cost of safety and confinement associated with the drill spoils.

# 3 Review and Update of Leak Detection and Leak Monitoring Technologies

Revision 0 of this report reviewed six baseline technologies for leak detection and leak monitoring and three barrier technologies for waste retrieval/mitigation. The "No Action" case was considered for completeness for both leak detection and monitoring, and waste retrieval. The six baseline leak detection and monitoring technologies and the no action alternative considered in Revision 0 are

- No Action
- Mass Balance
- Tracer Gas
- Leak Detection Pit
- ERT
- Borehole Logging
- TDR

Three leak detection and monitoring technologies not included in Revision 0 are

- Volumetric Methods (Leak Detection)
- Volumetric Inventory Balance (Leak Detection)
- Post-Retrieval Sampling (Leak Monitoring)

A brief review and update of the leak detection and monitoring technologies is presented below. The disposition and the technical issues associated with each technology is summarized in a "table graphic" presented at the beginning of each section. The baseline technology descriptions are taken largely from the Revision 0 description of leak detection and monitoring technologies.

## 3.1 Leak Detection and Monitoring Technologies in Revision 0

A discussion of the original six leak detection and leak monitoring technologies (and the "no action" alternative) is presented below.

### 3.1.1 "No Action" Leak Detection and Monitoring

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Dismiss |
| Revision 1, 1998 | Dismiss |
| Technical Issues | None; not a viable alternative |

The no action alternative is based on the assumption that there will be no LDMM technologies implemented during retrieval operations. Under this alternative, once retrieval of a tank has begun, it will continue until the tank has been fully retrieved. Retrieval would be terminated only if a catastrophic leak occurred—one that could be detected even without the use of a LDMM technology. If a catastrophic leak occurred, then retrieval operations would be terminated and the liquid in the tank would be removed. The no action alternative was not considered feasible for use in Revision 0 and remains so in this update.

### 3.1.2 Mass Balance

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Baseline |
| Revision 1, 1998 | Retain |
| Technical Issues | Requires liquid added to tank |

A detailed description of the mass balance method is provided in Revision 0. This method is designed to work in SSTs as the liquid is being removed from the tank during retrieval. This approach requires the use of existing ENRAF™ level gauges to monitor the volume of liquid pumped into and taken out of the SST, and a visual estimate (using a remote camera) of the waste remaining at the bottom of the tank after all of the liquid has been removed. The method requires that a small amount of liquid be added back into the SST at the end of each retrieval period (e.g., batch sluice), sufficient to cover the bottom waste. Two level gauges are required, one in the SST being remediated and one in the DST used to store the liquid waste that is transferred into and out of the SST during retrieval.

The volume data are converted to mass using characterization data and a simple balance algorithm is then applied. Although this method was determined to be immediately deployable in Revision 0, the errors associated with the dry volume estimates and characterization density data limit this application to large leaks. The performance of this technique is not known, but was estimated to be only good to many thousands of gallons.

The merits and performance of this technology should be compared to conventional volumetric technology. A static level measurement over a short period might give more accurate and reliable estimates. In Revision 0, mass balance was specified as the baseline technology. Since a liquid supernatant is necessary to adequately determine residual mass, this technology should be retained as a potential method, but replaced or combined with volumetric technology for more accuracy and reliability.

### 3.1.3 Tracers

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Dismiss |
| Revision 1, 1998 | Retain* |
| Technical Issues | Sensor deployment; tracer dispersal; waste compatibility; $P_D$ and detected rate depend on sensor locations |

*with HDD deployment

As stated above, tracer systems have been extensively used in the petroleum industry for many years to detect and locate small leaks in both underground and aboveground storage tanks (ASTs) and their associated pipelines [13, 18]. This technology has been evaluated for performance in petroleum USTs and shown to exceed the leak detection regulatory standards for underground storage tanks [4]. A tank (or pipeline) to be tested is inoculated with a suitable tracer. The backfill and soil beneath the tank (or above the pipeline) are then periodically sampled and tested, typically with a mobile gas chromatograph, for the presence of the tracer material. If the tracer is detected outside of the tank or pipeline, a leak is presumed to be present. This simple principle allows the tracer leak detection method to be applied to virtually any tank system geometry. This approach works best when a tracer that does not occur naturally in the external environment is used.

At DOE sites, tracer methods that employ radiation detectors in the soil under tanks or in the interstitial ventilation space of double-shell tanks are commonly employed. Because of small, localized spills and other sources of surface contamination that can carry the radionuclides into the detection zone, soil-sited, radiation tracers are no longer well suited to the detection of leaks from Hanford's SSTs. There may however, be a well founded SST application for chemical tracer compounds. As applied to tanks, leak detection is accomplished by placing a probe array under the floor of the tank, and vapors from beneath the tank are captured using either an active or passive extraction technique.

A typical tracer compound applicable to the SSTs would be a volatile, inert, non-toxic and non-flammable chemical concentrate that is fully miscible and compatible with the salt-laden, aqueous, liquids in the SSTs. The normal starting concentration of the tracer compound in the tank is 1 to 10 parts per million, according to the literature obtained from one vendor [18]. In one simulation using a 70-ft diameter petroleum tank, the product in the tank was inoculated with a tracer compound to a concentration of 10 milligrams per liter (mg/L) [18]. In these concentrations, in petroleum UST applications, tracers can typically detect leaks as small as 0.05 gal/h in a 2- to 3-day test. These and other tracer measurements show that this method is potentially more sensitive and more temporally responsive than other methods. The method requires a soil permeability of at least 1 darcy ($1x10^8$ $cm^2$), which is easily met in the granular soils at Hanford.

The main issues with the use of this technology for either leak detection or monitoring are (1) finding one or more waste compatible tracer substances that will dissolve in the liquid waste and be transported with the liquid waste if it leaks through a hole in the tank and then release a vapor once it is in the backfill and soil beneath the tank; (2) installing an appropriate network of sampling ports around or underneath the tank to detect the presence of the tracer if it leaks from the tank; and (3) adequate diffusion of the tracer through the supernatant and interstitial liquids. More than one tracer substance is required in case there is an accidental release of a tracer into the environment or if a leak is detected and a re-test of the tank is required. It is also important that the tracer be completely dispersed in the liquid so that it will move with the liquid through a hole, regardless of its location.

Once these technical issues are addressed, one might expect similar performance to that found when testing petroleum tanks. Discussions with the vendor community indicate that such tracers do exist. The major problems are to install a suitable sampling system, and to ensure that the tracer diffuses throughout the drainable wastes. The former can be addressed by HDD; the latter can be addressed by an inoculation and sampling test. At Hanford, where the tanks are buried over 40-ft deep, probe installation beneath the tanks is problematic and was the primary reason for essentially dismissing the technology in Revision 0 of the report. If such probes could be installed in horizontal wells drilled underneath the tank, then the deployment problem is mitigated. Such wells have been used at other DOE sites for vapor extraction remediation. The utility of horizontal directional drilling is currently being evaluated at the Hanford site.

### 3.1.4 Leak Detection Pits

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Retain* |
| Revision 1, 1998 | Retain* |
| Technical Issues | Limited to 4 tanks in AX-farm; false alarms |

*Limited Application

As pointed out in Revision 0, this method of leak detection should be used when available. However, only the AX tank farm was constructed with leak detection pits. Leak detection is accomplished by instrumenting the pits of four AX SSTs with conductivity probes and radiation detectors.

An improvement to the current leak detection method is to modify the instrumentation package so that it can distinguish surface or ground water from liquid waste. This can be accomplished using a conductivity sensor that measures the conductivity of the liquid. As demonstrated at Oak Ridge, such sensors can readily distinguish the low conductivity of water from the high conductivity of liquid waste [12].

### 3.1.5 Electrical Resistance Tomography

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Retain |
| Revision 1, 1998 | Retain |
| Technical Issues | Probe deployment (spatial & number) |

The technical basis for ERT is that a leak of highly conductive saline solutions from a tank will cause variations in the electrical resistivity of the soil beneath the tank. As described in Revision 0, the ERT method employs a number of vertically oriented probes installed in boreholes circumferentially sited around the tank. Each probe contains a number of electrodes located at intervals along the probe; each electrode must be in intimate contact with the soil. To allow the conductivity beneath the tank to be measured, the electrodes must be below the bottom of the tank, and the analysis needs to account for the metal in the bottom and sides of the tank.

To measure the soil conductivity, a dc voltage is applied between all possible pairs of probes and the current in the path between each electrode pair is recorded. The ratio of the voltage to the current is the "transfer resistance." By inverting the resulting matrix of transfer resistances, a planar, two- (x,y) or three-dimensional (x,y,z) image (tomograph) of the soil's conductivity under the tank can be reconstructed. ERT contour maps of the subsurface are made over time and are used to determine whether or not a leak is present. Any significant change in the soil conductivity conditions between maps would indicate that a release had occurred.

Demonstrations at Hanford in 1994 and 1995, using a dilute saline solution (0.08M NaCl) to simulate the release of high level wastes (HLW) from a tank, showed that releases from a tank could be reliably detected using ERT [19]. In these demonstrations, two release rates were used. For a (simulated) leak at the side of the tank, the saline solution was released at a rate of about 7 gal/h; for a (simulated leak near the middle of the tank, a release rate of about 0.85 gal/h was used. In both cases, the processed data was able to detect the release by the time about 50 gal of liquid had accumulated.

The spatial resolution and detection sensitivity of ERT is strongly related to the deployment of the electrodes used—in terms of both the number of electrode-bearing probes (azimuthal distribution) and the number of electrodes on each probe (depth). Fewer electrodes in azimuth and depth lead to poorer tomographically reconstructed imaging and poorer release detectability. While increasing the number of electrodes will improve the performance of ERT, such action entails additional installation and signal processing costs. Thus, the "correct" ERT configuration is a balance between performance and cost items. During the demonstration program described in Revision 0, three configurations were considered. One was a "4,1" configuration which utilized a single electrode at the bottom of each of 4 probes installed in vertical boreholes located at 90-degree intervals around the test tank. The 4,1 configuration results in six independent pairs of probes whose data can be processed to form an "image" (albeit a very coarse one). During the demonstration, the 4,1 data required about 20 min of processing time using a Sun™ SPARC10 workstation to form the image after the resistance data had been obtained [20]. Another configuration was an "8,3" configuration (8 probes, each with 3 equally spaced electrodes near the bottom of the probe). The 8,3 configuration provides 168 probe pair combinations that can be tomographically processed; four hours was required to process a single plane of this data. A third configuration was a "16,8" configuration (16 probes, 8 electrodes). The 16,8 configuration provides nearly 5,000 probe pairs, and a processing time of several days was estimated. The authors of Revision 0 recommended the 8,3 configuration, which allows good detection sensitivity with acceptable processing times.

The most important advances associated with ERT are associated with computing power and deployment. These advances, when combined with advances in cone-penetrometer deployment and the potential for HDD deployment, make ERT an attractive method for leak monitoring, and if required, could be used for leak detection, especially if deployed directly underneath the tank. If deployed with HDD, the ERT electrodes would be placed on the exterior of a casing, thus providing intimate soil contact.

### 3.1.6 Borehole Logging

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Dismiss |
| Revision 1, 1998 | Retain* |
| Technical Issues | No "methods" are identified, requires HDD for under-tank logging |

*with HDD deployment for characterization

A borehole geophysical logging technology operates by lowering a measuring device into a borehole by a cable connected to a logging truck. The downhole device measures physical properties of the formation as it is pulled up the borehole, transmitting the information up the cable to the logging truck. The data are processed in real time, and a continuous measurement of the appropriate physical parameters is displayed as a function of depth.

Borehole technology was dismissed in Revision 0 mainly because the spatial coverage of the measurements made in each borehole was limited to several feet around the borehole. The potential for HDD deployment of borehole logging would greatly improve the performance of this technology. The same number of boreholes drilled horizontally underneath a tank would provide significantly better coverage than holes drilled vertically outside the perimeter of the tank. The number of horizontal holes required for complete spatial coverage for a borehole leak monitoring system would be significantly greater than required for ERT or tracer measurements. As a consequence, borehole logging is recommended when detailed measurements are needed to characterize a plume that has been detected and characterized spatially with ERT or tracer measurements.

### 3.1.7 Time-Domain Reflectometry

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Dismiss |
| Revision 1, 1998 | Dismiss |
| Technical Issues | Multiplicity of wires and deployment under tank |

Time-domain reflectometry was dismissed in Revision 0 because of a number of deployment problems. While the use of horizontal holes might solve some of the deployment issues, it does not address all of the problems. ERT and tracer methods are both easier to deploy, have better performance and have been more extensively used. Therefore, no further consideration of this technology is warranted unless some major breakthrough in its deployment, cost, or performance occurs.

## 3.2 Technologies Not Included in Revision 0

A discussion of three technologies not included in Revision 0 is presented below.

### 3.2.1 Volumetric Methods

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Not Reviewed |
| Revision 1, 1998 | Retain |
| Technical Issues | Requires quiescent liquid surface; compensation for external effects |

A static or conventional volumetric leak detection test can be performed in a tank in which no liquid is added to or removed from the tank during a test. Such a test would be useful to establish the overall leak integrity of a tank before waste retrieval operations begin, when they are completed, and during short breaks in the retrieval operations. In general, longer tests result in higher performance and better and more reliable leak detection. The same volumetric system can be used to test for small leaks before and after a retrieval campaign (less than 5 gal/h) and for larger leaks during the retrieval. An evaluation of a bulk leak detection system to test 90-ft diameter underground fuel tanks for the Navy showed that the performance in terms of the minimum detectable leak rate (MDLR) was 0.38 gal/h for a 48-h test and 0.46 gal/h for a 24-h test, and 0.65 gal/h for a 4-h test [17]. The accuracy of a leak detection test in a large diameter tank (e.g., a tank with a diameter of 75 ft) is dependent on the precision of the level sensor and how well the main sources of noise are compensated.

Volumetric methods require either a free liquid surface or a distinct interstitial liquid surface. Most volumetric systems use a liquid-level sensing system to measure the rate of change of the liquid surface. There are a wide variety of sensors that can measure liquid level (e.g., an

ENRAF™ gauge or a differential pressure sensor). The precision of both of these types of sensors would be more than sufficient to conduct a leak detection test on a SST. Recently, an estimate of the performance of a volumetric leak detection system was made using only the existing level gauge data in over 30 of the SSTs at Hanford. Daily measurements of level collected with ENRAF™ and FIC™ gauges and manual tapes were analyzed assuming a test duration of 30 days. No attempt was made to compensate for noise effects such as temperature barometric pressure, and so on. Even without compensation, the MDLR (i.e., at a $P_D$ = 95% and a $P_{FA}$ = 5%) was between 0.5 and 3.0 gal/h for most of the SSTs examined [2]. This same level of performance might be achievable in a test with a shorter duration test (hours to several days) in which the level data were sampled more frequently (once per minute to once per hour), if adequate compensation were employed. The purpose of this analysis was to demonstrate that volumetric technology was viable and not to develop a leak detection system. It is clear, however, from the monthly test results that reliable and definitive statements could be made about the integrity of a tank. It is equally clear that a robust volumetric leak detection system could be developed using existing SST instrumentation. Such a system was developed and is currently used at the Oak Ridge National Laboratory to test operational waste tanks containing liquid low-level waste (LLLW) and to test the inactive (50-ft-diameter) GAAT tanks prior to their being remediated. In both instances, the existing tank instrumentation was used. The performance of the LLLW system was significantly better than the 0.2-gal/h regulatory leak rate [11]. The performance on the GAAT tanks was approximately 0.5 gal/h [12]. Both systems are very different, and DOE and EPA approved both systems for use at ORNL.

A stilling well may be necessary to insure that a free liquid surface is available, particularly in sludge tanks. This would help ensure the liquid level measurements necessary to conduct a volumetric test. As shown in Figure 5, a stilling well is a tube that is open at the top to

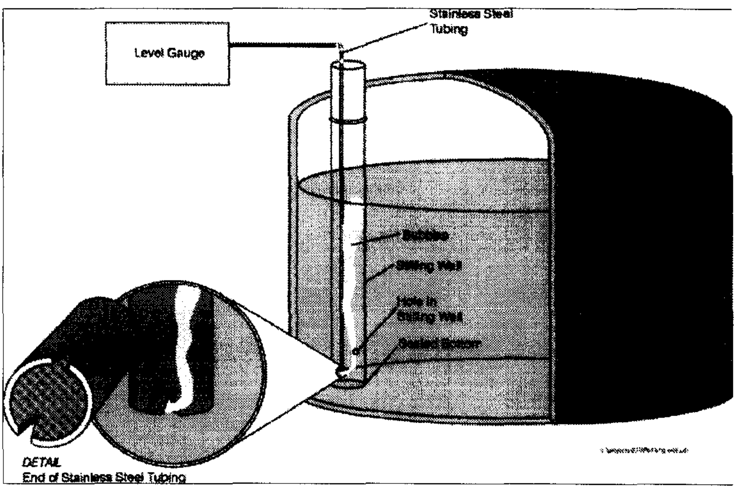


**Figure 4.** Stilling well concept employed with "bubbler" level sensor.

allow a free flow of air and open at (or near) the bottom (through a hole) that allows the liquid to flow into and out of the tube. The level sensor is deployed in the tube rather than in the tank and indirectly measures the level changes of the liquid in the tank. If measurements of interstitial liquids are required, then the tube should be inserted into the waste. If the hole at the bottom of the tube is small enough, the stilling well low-pass filters the data, which is important for making the on-line volumetric inventory measurements (described in Section 3.2.2, below) during retrieval. When the hole is small enough, it limits the flow rate of liquids between the tube and the tank and only the mean surface level is observed. If the stilling well is designed to low pass the level measurements, the diameter of the hole must be small enough to damp the high-frequency level fluctuations, yet large enough to allow prompt detection of a significant loss of volume without clogging. In principle, any type of level gauge (e.g., ENRAF™ or differential pressure cell) can be used in a stilling well. A second stilling well, which is initially filled to the same level as the first still welling well, can be closed and used as a reference level for level changes in the stilling well open to the tank.

### 3.2.2 Volumetric Inventory Balance

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Not Reviewed |
| Revision 1, 1998 | Retain |
| Technical Issues | Performance depends on precision of many sensors; errors are cumulative |

Volumetric Inventory Balance (VIB) is a method similar to statistical inventory reconciliation (SIR). VIB can be a means for real-time monitoring waste retrieval operations for catastrophic leaks. This method differs from the mass balance method described above in that measurements are made during the retrieval operations and does not require quiescent periods between retrieval batches. In this method, the volume (or mass) of the liquid pumped into and out of the tank and stored in the tank is reconciled from measurements of level in the tanks and of mass flow rate in the pipes used to transfer liquid in and out of the tank. A continuous time history of the data will be required for analysis.

It is difficult to estimate the accuracy of this method without a field evaluation, however, experience in the petroleum industry demonstrates that a very high level of performance can be achieved. Statistical inventory reconciliation, which is a method that accounts for some of the more important errors that occur when reconciling inventory in a petroleum tank, is 10 to 50 times more accurate than conventional inventory reconciliation (0.1 gal/h versus 5.0 gal/h). Further, SIR is compliant with EPA regulatory standards for leak detection. This improvement occurs even though some of the most important sources of noise (in a volumetric test and inventory reconciliation), thermal expansion and contraction of the fuel, is not compensated. Such improvement, which was initially found for 30-day tests using only daily measurements is also realized for tests with durations of hours to a day or two using measurements obtained at one- to 60-min intervals.

The level of compensation of the more important errors in this leak detection method (e.g., the geometry of the liquid level surface, the evaporation and condensation, the solid content of the waste, and the density of the liquid waste) depends on the accuracy obtained simply using the measured volume of the liquid.

### 3.2.3 Post Retrieval Soil Sampling (Monitoring)

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Not Reviewed |
| Revision 1, 1998 | Retain |
| Technical Issues | Response time |

As the name implies, post retrieval soil sampling is simply a monitoring technology that applies standard soil sampling techniques to the LDMM problem. By definition, leak monitoring implies external methods to characterize leak plume volume, location, and migration. Addition characterization of a leak plume will require either sampling or remote sensing technologies to determine chemical and radionuclide constituents. Either vertical or horizontal deployment of external sensors in boreholes around each tank for proper leak monitoring will be a significant portion of the cost to retrieve the waste from a SST. The costs associated with sampling soils surrounding an SST after a leak is detected are comparable to the costs of deploying external sensors or drilling boreholes for external sampling before retrieval operations. This is particularly true if a leaking SST generates a soil sampling effort for closure anyway.

Much of the costs associated with LDMM activities will be in deployment. By using advanced self-priming pump designs to minimize free (drainable) liquids during retrieval and internal volumetric methods to detect small leaks should they occur the probabilities of SST leaks during retrieval are significantly reduced. If it can be shown that the probability of a leak using a particular retrieval technology for a particular SST is small, then there is a cost benefit to not deploying a leak monitoring technology unless there is a leak to monitor. The major advantage associated with post-retrieval sampling is in the extreme cost savings of not deploying a leak monitoring system on tanks that don't leak during retrieval. Even a modest cost per tank for deployment of external sensors or boreholes for sampling, multiplied by 149 SSTs becomes a significant commitment. If half the tanks don't leak, a large saving can be realized over the life of the program, compared to pre-retrieval deployment for every tank.

The only technical issue associated with post-retrieval sampling is response time. Mobilization of a drilling crew and equipment to characterize a leak plume may take a number of weeks. This response time is compared to near-real time for deployed sensors. For suspect integrity tanks where leaks are expected, pre-retrieval deployment of leak monitoring sensors may be more appropriate.

### 3.3 Leak Detection and Monitoring Technologies

A pit-based detection technology should be implemented if a pit exists; its design should include a method of distinguishing between water and liquid waste.

Two new viable technologies, which have been used extensively in the petroleum industry, have been added to the list of technologies. If a free liquid surface or interstitial liquid surface exists, then volumetric and volumetric inventory balance (VIB, or SIR in the petroleum industry) technologies can be used for leak detection before, during and after retrieval operations. Mass balance can also be used in place of or combined with VIB during retrieval, if operations periodically cease long enough to allow liquid to be added to the tank and the accuracy of VIB is not sufficient. Both ERT and tracer methods can be used as monitoring methods if a leak is detected. They can also be used as leak detection systems during retrieval. Post retrieval soil sampling may be an appropriate leak monitoring application for tanks that are not expected to leak.

Deployment with horizontal directional drilling makes tracer-based detection and monitoring a viable monitoring technology, and it can improve the performance of ERT. HDD also allows traditional borehole technology and conventional sampling techniques to be used for more detailed characterization measurements. Deployment of ERT using a cone penetrometer should decrease the overall cost of this method as compared to using vertical boreholes for deployment. Ongoing work at Hanford with regard to HDD and deployment of drill-head sensors, SST volumetric (both static and on-line) leak detection, and cone penetrometer deployment of ERT will help determine the technical viability and cost of implementing these technologies.

In general, it is not possible to estimate the performance of a method (in terms of MDLR) except by a field evaluation. Analytical estimates can only bound performance with maximum and minimum detectable leak rates, and except where the underlying noise field is well known and characterized, these estimates are suspect. For most technologies, the impact of the noise is difficult to realistically predict and must be measured. As a consequence, all leak detection systems used to test USTs should be evaluated for performance following prescribed ASTM/EPA protocols.

It is the goal of any retrieval method to minimize the volume of liquid that could potentially leak out of a tank during retrieval. This is achieved by minimizing the volume of free liquid, minimizing the hydraulic head, or using a rapid response and reliable leak detection technology. If the volume of free liquid or hydraulic head can be eliminated during retrieval, then post-retrieval sampling can be used as the primary monitoring option. Ultimately, the best selection of a leak detection method will depend on the retrieval technology being implemented, and different technologies may be used for different retrieval methods.

# 4 Review and Update of Leak Mitigation Technologies

Section 4 discusses technologies and methods for containing or stopping a leak during hydraulic retrieval (once a leak is discovered). The leak mitigation technologies considered in Revision 0 are "no action" and barriers (including chemical, freeze wall and circulating air). In addition to reviewing these options, this report (Revision 1) considers *auxiliary pumping* and *inherent liquid minimization* methods as a viable leak mitigation technologies.

## 4.1 "No Action" Mitigation

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Dismiss |
| Revision 1, 1998 | Dismiss |

The "no action" leak mitigation alternative presumes that a leak into the surrounding soil is not objectionable. Although it may be shown that small volumes of some SST wastes can leak directly into the soil without significantly increasing the risk to human health, any leak is clearly unacceptable. The "no action" leak mitigation alternative was dismissed as not viable in Revision 0 and remains so in this report.

## 4.2 Barriers

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Dismiss |
| Revision 1, 1998 | Dismiss |

Barrier technology entails the creation of a distinct barrier between an area to be protected (the groundwater, for example) and an area that threatens the protected area (a waste tank, for example). While there are several types of barriers, there are two that have demonstrated DOE potential—freeze walls and grout walls. The main issues with these technologies are cost.

***Freeze-wall barriers*** entail the placement of circulation piping throughout an area underneath or surrounding the threat region. Refrigerant is then circulated through the pipes. This process freezes any moisture in the vicinity of the cooling pipes. If there is a significant amount of moisture—such as might occur if a tank began to leak—and well-placed piping, the freezing process would spread over an ever-expanding volume. Eventually, the entire region surrounding the installed piping would become frozen, creating an impermeable barrier that would contain further leakage from the tank as long as the refrigerant continued to circulate. Freeze-wall technology was demonstrated at the TRU waste disposal area at the Oak Ridge National Laboratory in 1996-97 [21].

***Grout barriers*** are an emerging technology that has evolved from advances in horizontal directional drilling. A grout barrier is made by drilling two parallel bores that go under the region to be contained and continue back to the surface on the other side. Typically, these dual bores are 4 to 8 ft apart, depending on the soil properties. Then, a "grout bar" is installed at the end of a high-pressure grouting system that has been run through the bores; the grout bar spans the distance between the two bores. The grout bar is then pulled back through the bores using the same HDD machinery that was used to drill the bores. As the bar is pulled back, it cuts through the soil material between bars. As the bar moves, grout is pumped into the now-loosened soils and allowed to harden, leaving a continuous, 4- to 6-in grout barrier. Then a new dual bore is drilled immediately adjacent to the previous, now-grouted one. The bar is pulled again, the new region is grouted, and the boring tools are repositioned for the next dual bore. This process continues until the entire region beneath the threat has been isolated by contiguous sections of grout wall. The grout-wall barrier has been demonstrated at a commercial site in Memphis, Tennessee [22].

## 4.3 Auxiliary Pumping

| *LDMM Technology Update* | *Disposition* |
|---|---|
| Revision 0, 1996 | Not Reviewed |
| Revision 1, 1998 | Retain |

Advances in self-priming pump technology have provided another means of responding to a leak that occurs during waste retrieval operations. Any free liquids (i.e., those that can leak out of the tank) are pumped directly to the waste receiver facility, in a way similar to the current stabilization program. Continuous self-priming bottom suction trash pumps, commonly referred to simply as "*trash pumps*" in petroleum sludge applications, provide enough pressure differential to prime the impellers continuously. This allows waste from the bottom of the tank to be continuously pumped to the waste receiver facility without allowing collection of free (leakable) liquids in the bottom of the tank. If the interstitial liquids are continuously pumped out of the tank; then clearly the risk of a catastrophic leak is minimized.

A novel application of a robust, trash pump within the context of the waste retrieval operations would be to auger, lance, or push such a trash pump to the bottom of an SST and then to pump out any free interstitial liquids that have accumulated there. During the actual retrieval (whether by enhanced sluicing, low flow sluicing, confined sluicing, or LVDG methods), the pump should be run at a flow rate 10% to 20% greater than that of the sluicing/dissolution water being added to the tank. In the event a leak is detected, the flow of water to the tank is simply stopped and the pump continues to remove any free liquids. This scenario would require deployment of the trash pump as an auxiliary pump for low-flow sluicing and confined sluicing where the primary waste conveyance occurs at the top of the sludge or saltcake.

### 4.4 Inherent Liquid Minimization

| ***LDMM Technology Update*** | ***Disposition*** |
|---|---|
| Revision 0, 1996 | Not Reviewed |
| Revision 1, 1998 | Retain |

Similar to the auxiliary pump described in section 4.3, this leak mitigation technology provides a continuous removal of free (leakable) liquids from the SST during retrieval. In the case of enhanced sluicing with large flows (~ 300 gal/min) an appropriately sized continuous self-priming bottom suction trash pump (a.k.a., trash pump) would be used to provide the primary waste conveyance. In the case of LVDG dissolution, an appropriately sized jet pump will be used to provide the primary waste conveyance. Both of these systems will inherently minimize free (leakable) liquids in the tank during retrieval. By inherently minimizing free liquids, the response to a detected leak is to simply stop the sluicing operations and continue to pump until there all of the free liquids have been removed.

# 5 Waste Retrieval Technologies

As retrieval technologies mature, it will become important to select LDMM technologies whose performance matches the retrieval technology selected. The four waste retrieval technologies considered in Revision 0 are: no action, bulk (or "past practice") sluice, confined sluice, and mechanical retrieval. In addition to reviewing these technologies, Section 5 of this report (Revision 1) also considers two other candidates: low-flow sluicing and, low volume density gradient dissolution, as viable waste retrieval technologies. LDMM recommendations for all five technologies are discussed.

## 5.1 "No Action" Retrieval

| *LDMM Recommendations* | |
|---|---|
| Leak Detection | None |
| Leak Monitoring | None |
| Leak Mitigation | None |

The "no action" retrieval alternative may be applicable to tanks that are essentially empty today as a result of operational transfers or previous sluicing campaigns. A tank that is selected for "no action" retrieval will be directly turned over for closure and will therefore require no leak detection, leak monitoring, or leak mitigation.

## 5.2 Enhanced Sluicing

| *LDMM Recommendations* | |
|---|---|
| Leak Detection | Volumetric system |
| Leak Monitoring | Post-retrieval sample |
| Leak Mitigation | Inherent Liquid Minimization |

There have been several important advances in sluicing technology since the original past-practice sluicing in the 1950s, '60s, and '70s. The two most significant advances are in nozzle development and pump performance. Newer sluicing nozzles can provide a continuous water jet at ranges up to 30 ft, compared to older nozzles that essentially lost the jet within the first few feet. Newly designed self-priming submersible pumps can operate with less than 2 in. of head and can remove slurry solids, compared to older pumps that required 2 ft of head and were plagued with plugging problems.

Tanks selected for this enhanced sluicing method will undergo integrity assessments; constituents of concern will also be examined. Presumably, tanks selected for enhanced sluicing will be expected to withstand the attendant rigors of this procedure without developing catastrophic leaks. It is recommended that a volumetric system be used for leak detection. Inherent liquid minimization is recommended for leak mitigation, so that the driving force as well as the source of the leak can be removed quickly. Post-retrieval sampling is recommended for leak monitoring, because it requires deployment only in the event of an actual leak.

### 5.3 Low-Flow Sluicing

| *LDMM Recommendations* | |
|---|---|
| Leak Detection | Volumetric system |
| Leak Monitoring | Electrical resistance tomography |
| Leak Mitigation | Auxiliary pump |

There have been major advances and technology breakthroughs in the area of low-flow sluicing. These advances have come largely from the Hanford Tanks Initiative program, which reviewed demonstration tests from both arm- and vehicle-based low flow sluicing technologies. Low flow sluicers will use a low flow (~ 30 gal/min), high pressure (~ 15,000 psi) water jet to dislodge waste with a continuos self-priming bottom suction trash pump as the primary waste conveyance.

Low flow sluicing has potential application in tanks that have higher percentages of residual salt cake. The advantage of low flow sluicing is that, to the greatest extent possible, existing sludge and salt cake are left on the portions of the tank most vulnerable to leaks during most of the waste retrieval operation.

In tanks where a leak is more likely to occur, it is recommended that volumetric methods be used for leak detection. Also for suspect tanks where low flow sluicing may be applied, pre-retrieval deployment of ERT is recommended for leak monitoring. An auxiliary continuos self priming bottom suction trash pump is recommended for leak mitigation, so that the hydraulic driving force as well as the source of the leak can be removed quickly.

### 5.4 Confined Sluicing

| *LDMM Recommendations* | |
|---|---|
| Leak Detection | Volumetric system |
| Leak Monitoring | Electrical resistance tomography |
| Leak Mitigation | Auxiliary pump |

Confined sluicing refers to a specific sluicing technology developed by PNNL. The confined sluicer makes use of a low flow/high pressure water jet to dislodge waste that is then pneumatically retrieved to the top of the tank. Air is sparged into the inlet to allow water droplets and waste granules to be vacuumed the necessary 30 to 50 feet to the top of a tank riser. Nearly all the advantages and disadvantages of low flow sluicing apply to confined sluicing. Confined sluicing has potential application in tanks that have higher percentages of residual salt cake. In suspect integrity tanks, volumetric methods are still recommended for leak detection and it is recommended to deploy ERT as a leak monitoring technology prior to initiating sluicing operations. The use of an auxiliary continuos self-priming bottom suction trash pump to minimize free liquids is the recommended leak mitigation.

### 5.5 Mechanical Retrieval

| *LDMM Recommendations* | |
|---|---|
| Leak Detection | None |
| Leak Monitoring | Post-retrieval sampling |
| Leak Mitigation | None |

Although there have not been significant advances or technology breakthroughs associated with mechanical retrieval, there remain a number of tanks for which hydraulic retrieval may not be appropriate.

The mechanical waste retrieval technique would use a scoop-like end effector affixed to the end of a robotic arm. The end effector would be capable of mechanically excavating the solid waste in the tank. A jackhammer end effector may be necessary for breaking up the rock-like layer of sludge known to exist in some tanks. The excavated waste would be placed by the robotic arm into an in-tank mechanical waste conveyance system and from there removed from the SST for further processing.

It is expected that the mechanical retrieval technique will be used only for the removal of dry or semi-dry wastes from tanks that are known to have leaked catastrophically in the past. Because there would be no liquids involved (the contents are essentially dried materials) there are no recommendations for leak detection or mitigation. If some sort of leak or leaching were to occur, post-retrieval sampling would be an appropriate means of leak monitoring.

### 5.6 Low-Volume Density Gradient (LVDG or "Sprinkler") Dissolution

| *LDMM Recommendations* | |
|---|---|
| Leak Detection | Volumetric system |
| Leak Monitoring | Post-retrieval sampling |
| Leak Mitigation | Inherent Liquid Minimization |

Low volume density gradient dissolution is a promising method of waste retrieval. It proposes to use low volumes of water, distributed across the surface of the salt cake, to dissolve the soluble portions of the remaining waste. The dissolved wastes are then removed by means of a low-volume jet pump that is augered, lanced or pushed into the waste at the bottom of the tank. The principle behind this method is that, as the solvent trickles through the salt cake on its way to the bottom of the tank, it will be dissolving waste along its path, making it possible for the saturated solution to be pumped from the bottom directly to a waste receiver facility such as a double-contained receiver tank.

Similarly to those selected for enhanced sluicing, tanks selected for LDVG retrieval will undergo integrity assessments, and constituents of concern will be examined. Presumably, tanks selected for LVDG retrieval will be expected to tolerate the confined solvent liquids without developing catastrophic leaks. Based on this assumption, it is recommended that volumetric methods be used for leak detection. Inherent liquid minimization is recommended for leak mitigation, so that the driving force as well as the source of the leak can be removed quickly. Post-retrieval sampling is recommended for leak monitoring, because it requires deployment only in the event of an actual leak.

# 6 Selection of LDMM Technologies by Retrieval Method

The foregoing work reviewed several LDMM technologies of potential import to the SST retrieval program. These included technologies that were identified in the Revision 0 version of this report, and several new or improved technologies that were identified in this report. Table 3, below, summarizes the results of this update in terms of the LDMM component, the LDMM technology, how these technologies are dealt with in this update compared to Revision 0, and pertinent comments related to the technology. The table shows that for most of the technologies that were identified and then dismissed in Revision 0, there have not been any significant changes in the technology, nor have there been any "new" reasons to utilize those technologies.

The table also shows that of the two technologies identified and recommended in Revision 0—mass balance and ERT—for leak detection and leak monitoring are still considered to be viable technologies. However, mass balancing—an internal method—is replaced in this update report with the recommendation to use volumetric methods for leak detection whenever a static test can be performed and volumetric inventory balance (also called SIR) methods during retrieval operations. Volumetric methods directly measure the volume changes that occur in the tank. ERT is an external method that can be used as long as it is applied prior to the occurrence of a leak. The potential feasibility of this method is enhanced by current developments in HDD technology. This is because horizontal wells will allow ERT electrodes to be placed underneath the tank to measure x-y regions with good sensitivity and resolution. Because of the improvements of HDD technology, tracer gas is now considered to be a viable leak monitoring technology and could be used for leak detection if volumetric tests cannot be performed. With HDD deployment, conventional borehole technology could be applied, but is mainly useful for only characterization measurements. ERT and tracers both can be implemented with only a few horizontally drilled holes, whereas bore hole measurements for leak monitoring would require many holes in a dense network.

When retrieval methods are considered together with the recommendations for LDMM technologies, specific recommendations can be made. These are shown in Table 4, below. This table shows, for example, that if confined sluicing is selected as the retrieval method for a particular tank, the recommended leak detection method is a volumetric method, and that ERT is the recommended leak monitoring method. Advanced emergency pumping is recommended here as the best means to mitigate any release that might occur should a leak in the tank develop during sluicing. Similarly, if the mechanical retrieval of an otherwise dry (little or no drainable liquids) tank is selected, then no leak detection and no leak mitigation measures are recommended for this application. Post-retrieval sampling, however, is recommended as a monitoring method.

The essence of this section is the assignation of LDMM technologies, matrixed to the various retrieval methods that have been identified for Hanford's SSTs.

**Table 3.** Disposition of Leak Detection, Leak Monitoring, and Leak Mitigation Technologies Reviewed

| Technology | Disposition in Rev 0 | Disposition in Rev 1 | Comments |
|---|---|---|---|
| ***Leak Detection During Hydraulic Retrieval*** | | | |
| ***No Action*** | Dismiss | Dismiss | Dismissed in original report. No significant changes in technology or application. |
| ***Mass Balance*** | Retain | Retain/redefine | Use in conjunction with volumetric methods |
| ***Tracers*** | Dismiss | Retain | Significant LDMM potential when combined with HDD deployment |
| ***Leak Detection Pit*** | Dismiss | Retained/limited applicability | Use existing Leak Detection Pits in the AX tank farm |
| ***ERT*** | Retain | Retain | Emerging technology; significant potential when combined with HDD. |
| ***Volumetric Inventory Balance*** | Not Reviewed | Retain | Use in conjunction with volumetric methods |
| ***Volumetric*** | Not Reviewed | Retain | Allows static detection of leaks of 1 to 10 gal/h and the potential of on-line detection of leaks |
| ***Leak Monitoring During Hydraulic Retrieval*** | | | |
| ***No Action Leak Monitoring*** | Dismiss | Dismiss | Dismissed in original report. No significant changes in technology or application. |
| ***ERT*** | Retain | Retain | Emerging technology; significant potential when deployed with cone penetrometers or HDD. |
| ***Borehole Logging*** | Dismiss | Dismiss | Dismissed in original report. No significant changes in technology or application. |
| ***TDR*** | Dismiss | Dismiss | Dismissed in original report. No significant changes in technology or application. |
| ***Post-Retrieval Soil Sampling*** | Not Reviewed | Retain | Allows deployment of leak monitoring only after a leak is detected. |
| ***Leak Mitigation During Hydraulic Retrieval*** | | | |
| ***No Action Mitigation*** | Dismiss | Dismiss | Dismissed in original report. No significant changes in technology or application. |
| ***Close-Coupled Barriers*** | Dismiss | Retain | May be practical with advanced Horizontal Directional Drilling capabilities |
| ***Auxiliary Pump*** | Not Reviewed | Retain | Minimizes free liquids and hydraulic head during retrieval |
| ***Inherent Liquid Minimization*** | Not Reviewed | Retain | Minimizes free liquids and hydraulic head during retrieval |

**Table 4.** Retrieval Methods and LDMM Technologies

| | *Retrieval Method* | Technology | | |
|---|---|---|---|---|
| | | **Leak Detection** | **Leak Monitoring** | **Leak Mitigation** |
| 5 | **No Action**† | None | None | None |
| 6 | **Enhanced Sluice** | Volumetric | Post-Retrieval Sample | Inherent Liquid Minimization |
| 7 | **Low Flow Sluice** | Volumetric | ERT | Auxiliary Pump |
| 8 | **Confined Sluice** | Volumetric | ERT | Auxiliary Pump |
| 9 | **Mechanical Retrieval**‡ | None | Post-Retrieval Sample | None |
| 10 | **LVDG Dissolution** | Volumetric | Post-Retrieval Sample | Inherent Liquid Minimization |

† **No Action Retrieval** implies tanks that are ready for direct closure (i.e., tanks that contain very little residual waste due to previous sluicing or operational campaigns). For these cases, additional leak detection, leak monitoring, and leak mitigation while the tanks await closure are not necessary.

‡ **Mechanical Retrieval** implies a dry or nearly-dry retrieval process with no liquids to detect or leaks to mitigate. It may be appropriate to sample the surrounding soils after the retrieval is complete if leaching from an external liquid source (e.g., rain water) is suspected.

# 7 Conclusions and Recommendations

Based upon the work described in this update report, there are viable LDMM technologies appropriate for the Hanford single-shell tanks. Because these technologies are varied, and each has its strengths and weaknesses, there is no single technology that is appropriate for every SST. However, an LDMM technology appropriate for a given tank can be identified if it is keyed to the retrieval method that has been selected for that tank.

The most successful and robust LDMM technologies are likely to be those that have been developed and demonstrated in other venues and can be adapted to the Hanford SSTs, or those that are emerging as a direct result of Hanford's unique requirements. Given this premise, the leak detection and monitoring technologies that are likely to be most successful at Hanford include volumetric testing, volumetric inventory balance, mass balance, tracers, and electrical resistance tomography. The first three are tank-internal methods of leak detection, and the last two are tank-external methods of leak detection that can also be used for leak monitoring. Volumetric technology is best used during quiescent periods in the tanks. The others can be used any time, including periods during which the waste in the tanks is being actively retrieved. To obtain the best results with mass balance techniques, however, some quiescent period is required.

Mass balance and ERT were identified as viable technologies in Revision 0. Volumetric testing, volumetric inventory balance, and tracers are brought forward in this update report because of important developments that have occurred since Revision 0 was issued.

Volumetric methods (which have been widely used in petroleum industry leak detection) have recently undergone further development and have been applied to large (250,000 to 5,000,000 gal and 12,500,000 gal) bulk fuel tanks. Second, volumetric testing has been successfully demonstrated on DOE waste tanks at Oak Ridge and is under review at Hanford. At Oak Ridge, a thorough and robust program of monthly testing, reporting, and annual integrity updates to DOE, EPA, and the Tennessee regulators has been established and fully implemented. At Hanford, the liquid level data from over 30 SSTs have been analyzed using the tools developed for volumetric analysis, and the feasibility of routine testing of those tanks is under review. With the installation of a stilling well, a volumetric inventory balance system, similar to SIR (and mass balance), may be able to provide leak detection during retrieval

Tracers (as well as ERT) have become a more viable option for the Hanford LDMM mission because of recent advances in the field of horizontal directional drilling (HDD). These advances are currently being demonstrated and evaluated at the Hanford Site. Unlike vertical boreholes that can only place sampling wells on the periphery of the SSTs, HDD technology can precisely create well-defined boreholes immediately *under* an SST. Sensors can be then be inserted into these boreholes and placed in multiple locations beneath the tank—where they will be in the direct path of a potential leak, or at least closer to the leak than sensors located in vertical bores at the edges of the tank. Chemical and gaseous tracers could be used in these bores, as well as radiation detectors or other types of "sniffers." In addition to tracers, ERT electrodes could also be installed inexpensively in the horizontal bores as they are cased. This would allow (x,y) tomographic maps of the area beneath the tank to be created, with a sensitivity and spatial resolution that is unachievable with ERT sensors placed in vertical bores.

A nationally recognized methodology for evaluating the performance of a leak detection system was introduced in 1992. The ASTM standard test procedure, which was developed by the EPA, is the most straightforward method of determining the accuracy and reliability of a leak detection method. This evaluation protocol requires that many tests be conducted with the method of choice, with the goal of making an estimate of performance in terms of the probability of detection and probability of false alarm. The uncertainties and ambiguities of making analytical estimates of performance are eliminated. Volumetric, inventory and statistical inventory reconciliation , and tracer systems have been evaluated for many sizes of petroleum USTs.

This report has also identified two new leak mitigation technologies—auxiliary pumping and inherent liquid minimization. In the first technology, a self-priming submersible pump would be augered, lanced, or pushed into each SST and placed at the bottom. Free (leakable) liquids are pumped from the tank during retrieval, thus minimizing the amount of liquid waste that could be released into the environment if a leak occurred. In the second, free liquids are continuously removed from the SST during retrieval.

Lastly, this report has identified two new retrieval technologies that can be used in the SSTs: low volume density gradient dissolution, and low-flow sluicing. In the first scheme, fresh water would be introduced to a tank by a sprinkler (for example) and used to dissolve the soluble components of the sludge and salt cake. With the near-saturated solutions being continuously pumped off, the LVDG scheme would retrieve wastes while minimizing the amount of liquid that could be leaked In the second, low-flow, high-pressure water jets are used to dislodge wastes, which are removed with a trash pump.

Each of these (and other) LDMM technologies has been discussed in the context of its relationship to the others. A "selection matrix" prepared for this report identifies the LLDM technology (or technologies) that is most compatible with each of the retrieval methods currently being considered.

Estimates of deployment and performance are best made by demonstration and evaluation. Accordingly, it is recommended that a further investigation be undertaken to better quantify the expected performance and cost/benefit aspects of the following LDMM technologies: (1) static and inventory-based volumetric systems, and HDD deployed tracer, ERT and other borehole technologies for leak detection and monitoring and (2) deployment of self-priming submersible pumps in sludge and salt cake.

It is recommended here that, in the cases where these concepts can be applied to the LDMM systems, the EPA's $P_D$ and $P_{FA}$ terminology be adopted at Hanford, and that the detection criteria and test frequency be developed as necessary to meet Hanford's unique testing requirements. It is also recommended that bench-scale tests of LDMM technologies be undertaken to validate the findings presented in this report.

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