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TRADE STUDY OF LEAKAGE DETECTION MONITORING & MITIGATION TECHNOLOGIES TO SUPPORT HANFORD SINGLE SHELL WASTE RETRIEVAL

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Trade Study of Leakage Detection, Monitoring, and Mitigation Technologies to Support Hanford Single-shell Waste Retrieval

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The U.S. Department of Energy has established the Tank Waste Remediation System to safely manage and dispose of low-level, high-level, and transuranic wastes currently stored in underground storage tanks at the Hanford Site in Eastern Washington.

This report supports the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) Milestone No. M-45-08-T01 and addresses additional issues regarding single-shell tank leakage detection, monitoring, and mitigation activities and technologies. The objective of this report is to evaluate identified leakage detection, monitoring, and mitigation technologies and provide an indication of the scope of leakage detection, monitoring, and mitigation activities necessary to support the Tank Waste Remedial System Initial Single-shell Tank Retrieval System project.

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TRADE STUDY OF LEAKAGE DETECTION, MONITORING, AND MITIGATION TECHNOLOGIES TO SUPPORT HANFORD SINGLE-SHELL TANK WASTE RETRIEVAL

WHC-SD-WM-ES-379

REV. 0

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Prepared For

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Prepared By

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Richland, WA

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) has established the Tank Waste Remediation System (TWRS) to safely manage and dispose of low-level, high-level, and transuranic wastes currently stored in underground storage tanks at the Hanford Site in Eastern Washington.

One of the TWRS waste retrieval components is the Initial Single-Shell Tank Retrieval System (ISSTRS). This component will provide the required systems, equipment, permits, approvals, procedures, and trained operators needed to retrieve and transfer waste from the first (initial) single-shell tank (SST) farm to be retrieved to a double-shell tank (DST). The ISSTRS task will be used to demonstrate production-scale retrieval of saltcake waste from one SST utilizing past-practice sluicing. A part of the ISSTRS design includes engineered and operational/administrative consideration of leak detection, monitoring, and mitigation (LDMM).

This trade study provides a systems engineering evaluation of currently available and new/candidate LDMM technologies in the context of planned waste retrieval operations to determine feasibility of use, contribution to risk reduction, and cost-benefit. This trade study supports the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Milestone M-45-08-T02, shown below.

> Establish the criteria, through stakeholder participation and Ecology approval, for: (1) Determining allowable leakage volumes, and (2) acceptable leak monitoring, detection, and mitigation measures necessary to permit sluicing operations. - April 1997.

ROLE OF LDMM

The LDMM technologies are applicable wherever significant leakage of liquid waste from the SSTs may occur, as during hydraulic sluicing. Hydraulic sluicing was used for past waste retrieval campaigns at the Hanford Site and is commonly referred to as past-practice sluicing. Past-practice sluicing is the method that has been selected to remove saltcake and sludge waste from some of the 149 Hanford Site SSTs.

The three major areas of concern during sluicing are (1) determination that leakage has occurred, (2) adequate surveillance of existing and new leakage plumes, and (3) taking responsible retrieval actions that minimize the potential for leakage to occur or continue. These major topical areas and operational goals are represented in the terms "leakage detection," "leakage plume monitoring," and "leakage mitigation" (i.e., LDMM).

Leakage Detection

During retrieval, leak detection information will contribute to decision-making regarding continuing or stopping sluicing. Leakage detection can play an immediate and significant role in achieving the goal of minimal achievable leakage. Leakage detection data that are reliable and provided in a timely fashion (i.e., within the retrieval operational time frame and at intervals that will support operational decisions) will be advantageous. During retrieval, leakage detection information will contribute to operational decisions to determine if sluicing should be stopped or not. Lower leakage detection levels and timely leakage detection information will result in better operational decisions.

Leakage Monitoring

Monitoring for leakage includes: (1) surveilling possible leakage, and/or (2) concurring whether or not leakage has occurred. Leakage monitors are devices or methods that typically can be applied outside the tank. Monitoring will be of little or no value during a sluicing campaign to support operational go/no-go decisions because information is not provided in time for taking response actions that result in mitigating leakage.

The LDMM devices and methods that do not fulfill the quantitative and timeliness requirements to be classed as leakage detectors can generally be considered as leakage monitors. A candidate leakage detection tool or method may first be developed as a monitor. As the tool or method is refined, developed, tested, evaluated, and proven to be reliable, it may also qualify as a detection device.

Leakage monitoring outside the tank produces semi-quantitative or qualitative data. Existing leakage plumes are being monitored. Leakage plume monitoring will also be used as a pre- and post-sluicing tool to provide general tank perimeter surveillance and to confirm whether or not leakage has occurred from a tank.

Leakage Mitigation

Leakage mitigation entails all actions undertaken at any time prior to, during, or after sluicing, to eliminate the possibility of leakage or reduce leakage if it does occur. Effective mitigation devices or actions will be made available and used throughout the retrieval effort. At present, only specific operational procedures and retrieval devices have been shown to provide the potential for leakage mitigation.

LDMM Evaluation Approach

The LDMM technologies were assessed against the functional requirements and ranking variables identified in Table ES-1. The requirements on the table identify the criteria that must be met to fulfill the functional role. The ranking variables on the table are qualitative criteria that serve as additional bases for comparing LDMM alternatives.

Table ES-1. Leakage Detection, Monitoring, and Mitigation Criteria.

CRITERIA	Leakage Detection		Leakage Monitoring		Leakage Mitigation	
	Requirement	Ranking Variable	Requirement	Ranking Variable	Requirement	Ranking Variable
Available	✓		✓		✓	
Deployable	✓		✓		✓	
Reliable	✓		✓		✓	
Detection Regardless of Leak Location	✓					
Timely Detection	✓					
Plume Location/Direction			✓			
Leakage Rate	✓					
Leakage Volume	✓					
Leakage Constituents				✓		
Lowest Detectable Leak		✓				
Minimize Further Leakage					✓	
Effluent Treatment		✓		✓		✓
Secondary Waste Generation		✓		✓		✓

TECHNOLOGIES EVALUATED

Six technologies were evaluated for the leakage detection and monitoring applications: (1) mass balance, (2) tracer gas, (3) leak detection pits, (4) electrical resistivity tomography (ERT), (5) borehole logging, and (6) time domain reflectometry (TDR). Seven general leakage mitigation technologies were evaluated: (1) past-practice sluicing, (2) limited sluicing, (3) robotic sluicing, (4) mechanical retrieval, (5) chemical subsurface barriers, (6) freeze wall subsurface barriers, and (7) circulating air barriers.

RESULTS AND CONCLUSIONS

The baseline LDMM system is composed of all LDMM technologies that are both available and deployable. The leakage detection component consists of liquid/waste level measurement devices inside the tank (i.e., mass balance) and leakage detection pits (where available). The leakage monitoring component consists of borehole logging. Improved equipment and operational, procedural, and administrative methods will be used to mitigate leakage during past-practice sluicing.

Comparisons of the LDMM technologies against the functional requirements and performance criteria are provided in Tables ES-2, ES-3, and ES-4, respectively.

Leakage Detection

Excluding leakage detection pits that are specific only to the AX Tank Farm, mass balance and ERT leakage detection technologies are applicable or potentially applicable to support past-practice sluicing. Of these three, only mass balance can be considered as available and deployable (Table ES-2). The cost, cost-benefit, and detection limits range for

Table ES-2. Comparison of Leakage Detection Technologies Based on Functional Requirements and Performance Criteria.

DETECTION TECHNOLOGY	REQUIREMENTS: AVAILABLE	REQUIREMENTS: DEMONSTRATED DEPLOYABLE	REQUIREMENTS: DEMONSTRATED RELIABLE	REQUIREMENTS: DETECTION INDEPENDENT OF LEAKAGE LOCATION	REQUIREMENTS: TIMELY DETECTION	REQUIREMENTS: LEAKAGE VOLUME	REQUIREMENTS: LEAKAGE RATE	RANKING VARIABLE: SECONDARY WASTE GENERATION	RANKING VARIABLE: EFFLUENT TREATMENT	RANKING VARIABLE: KNOWN DETECTION LIMIT
Mass Balance	●	●	◐	●	●	●	◐			◐
Tracer Gas	●	○	○	○	◐			●	●	○
Leak Detection Pit	●	◐	●	●	●	●	◐			●
ERT	◐	◐	○	○	◐	◐	◐			○
Borehole Logging	●	●	●							◐
TDR	◐	◐	○							○

● YES

◐ YES with Qualifications

○ POTENTIALLY but unproven for SST application

Table ES-3. Comparison of Leakage Monitoring Technologies Based on Functional Requirements and Performance Criteria.

MONITORING TECHNOLOGY	REQUIREMENTS: AVAILABLE	REQUIREMENTS: DEMONSTRATED DEPLOYABLE	REQUIREMENTS: DEMONSTRATED RELIABLE	REQUIREMENTS: PLUME LOCATION/ DIRECTION	RANKING VARIABLE: LEAKAGE CONSTITUENTS	RANKING VARIABLE: SECONDARY WASTE GENERATION	RANKING VARIABLE: EFFLUENT TREATMENT
Mass Balance	●	●	◐				
Tracer Gas	●	○	○			●	●
Leak Detection Pit	●	◐	●		●		
ERT	◐	◐	○	◐			
Borehole Logging	●	●	●	◐	◐		
TDR	◐	◐	○	◐			

● YES

◐ YES with Qualifications

○ POTENTIALLY but unproven for SST application

Table ES-4. Comparison of Leakage Mitigation Technologies Based on Functional Requirements and Performance Criteria.

MITIGATION TECHNOLOGY	REQUIREMENTS: AVAILABLE	REQUIREMENTS: DEMONSTRATED DEPLOYABLE	REQUIREMENTS: DEMONSTRATED RELIABLE	REQUIREMENTS: REDUCE/CONTAIN LEAKAGE RELATIVE TO BASELINE	RANKING VARIABLE: SECONDARY WASTE GENERATION	RANKING VARIABLE: EFFLUENT TREATMENT
Past-Practice Sluicing	●	●	●	N/A		
Limited Sluicing	◐	◐	◐	◐		
Robotic Sluicing	○	○	○	●		
Mechanical Retrieval	○	○	○	●		
Chemical Subsurface Barriers	○	○	○	○		
Freeze Wall Subsurface Barrier	○	○	○	○		
Circulating Air Subsurface Barrier	○	○	○	○	●	●

● YES

◐ YES with Qualifications

○ POTENTIALLY but unproven for SST application

each of the leakage detection and monitoring technologies are summarized in Table ES-5. The costs for both ERT configurations are higher than for mass balance.

Tracer gas is an established leakage detection technology in the petroleum industry but the application of this technology to Hanford Site SSTs has not been developed to a stage that allows any estimate of detection limit. Many issues must be resolved to establish tracer gas as a feasible leakage detection technology for SST applications.

Table ES-5. Comparison of Leakage Detection Technologies.

Leakage Detection Technologies	TNPW Cost per Tank Farm ($million)	Cost-Benefit (Public Risk Avoided/$)		Detection Limit Range (gal)
		Lower Range Limit	Upper Range Limit	
No action	0	0	0	N/A
Mass balance	0.47	184	107	5,570 - 20,000
Tracer gas	1.7	Undetermined	Undetermined	Undetermined
4,1 ERT	1.9	48	8	3,400 - 34,000
8,3 ERT	3.9	25	17	1,000 - 13,000
Borehole logging	4.1	22	0	4,100 - 180,000
TDR	3.9	23	0	4,100 - 180,000

ERT is a leakage detection technology that is in the middle stage of development. It has the potential to achieve low detection limits and to determine leakage volume. Borehole logging and TDR technologies do not meet the functional requirements for leakage detection and are insensitive to leakage in many locations around the tank.

Leakage Monitoring

As shown in Table ES-3, there are three technologies that meet or potentially meet the requirements for leakage monitoring (specifically the ability to identify the location and movement of a leakage plume). These are 8,3 ERT, borehole logging, and TDR technologies. Of these, only borehole logging is available and deployable at the Hanford Site.

The 8,3 ERT configuration can potentially map and track the three-dimensional movement of a leakage plume over time. This information can be used to quantify the leakage plume. Borehole logging and TDR technologies can only identify and monitor a cross-section or single points within a leakage plume. The successful development and deployment of ERT as both a leakage detection and leakage monitoring tool would provide the additional benefit of addressing the two functions with a single system.

The TDR technology is a commercially available technology; however, its application at the Hanford Site has not been demonstrated. The radius of interrogation is similar to that of borehole logging. The primary benefit derived from the use of TDR technology is the gathering of real-time continuous data using recorders placed outside the tank farms.

Leakage Mitigation

As shown in Table ES-4, only past-practice sluicing, which is the baseline retrieval technology for tanks that have not previously leaked, is available, deployable, and proven reliable for leakage mitigation. Planned equipment and procedural enhancements are expected to further improve waste retrieval rates using past-practice sluicing. This will reduce the sluicing time frame during which leakage can occur, thereby reducing overall leakage and public health risk. The limited sluicing alternative, which is based on fundamental mechanical principles but has not been demonstrated in an SST, may prove to be effective in mitigating leakage. Robotic sluicing and mechanical retrieval may reduce leakage and associated risk by limiting the amount of drainable water in a tank. These technologies are not available and are unproven for applications similar to retrieval of waste from SSTs, however.

Three types of subsurface barriers beneath SSTs were considered: chemical, freeze-wall, and circulating air. None of these barriers is available and each poses significant deployment challenges. The barriers would not reduce leakage and long-term risk unless they were installed in a close-coupled configuration (sealed to the exterior of the tank). Only chemical barriers can be installed in this configuration. Candidate chemical barrier materials such as grout have a sufficiently high permeability that some level of leakage into the barrier would occur. Subsurface barriers are also relatively expensive. Their high cost and low effectiveness in reducing leakage results in relatively low cost-effectiveness.

ISSUES NEEDING RESOLUTION

The cost, risk, and cost-benefit analyses presented in this document were based on assumptions made to deal with a number of identified issues. The issues, assumptions, and suggested analyses are described in this section.

Issue 1

The trade study was based on the assumption that all leakage from SSTs would contain constituents of concern at concentrations equal to the composition of average SST liquid waste. Cruse et al. (1995) developed preliminary leakage threshold values (LTVs) for individual tanks based on characterization data and simplifying assumptions. The LTVs for some tanks are below the leakage detection limits for the baseline LDMM system, indicating that sensitive leakage detection may be advisable in some cases. It was suggested that a risk-based logic be developed for applying LDMM technologies in specific tanks. The logic would be based in part on updated LTVs that reflect risk impacts of adjacent tanks and waste sites, and the physical conditions of the tanks and tank farms.

Issue 2

The applicability of leakage detection technology depends on its sensitivity to detecting and measuring the volume of leakage, regardless of leakage location and size. The trade study evaluated minimum and maximum leakage detection limits for sets of conditions most advantageous to detection and least advantageous to detection. Wide ranges of leak detection sensitivities were found for the LDMM technologies evaluated. Minimum leakage detection sensitivities appeared attractive in many cases but maximum leakage detection sensitivities were often unacceptably high. No attempt was made to evaluate the probabilities of various leakage locations, sizes, and probabilities to enable prediction of a most-likely leakage detection volume. It was suggested that design-basis leakage conditions be established, including probabilities of occurrence. The probability-weighted effectiveness of the technologies should then be determined and compared to the effectiveness of the baseline LDMM system.

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ACRONYMS

bgs	belowground surface
COC	contaminant of concern
CPT	cone penetrometer
D&D	decontamination and decommissioning
dc	direct current
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DST	double-shell tank
ENRAF	Enraf-Nonium 854 Advanced Technology Gauge
ERT	electrical resistivity tomography
FIC	Food Instrument Corporation
FTE	full-time equivalent
FY	fiscal year
GAC	granular activated carbon
HI	hazard index
HVAC	heating, ventilating, and air conditioning
ISSTRS	Initial Single-Shell Tank Retrieval System
LDMM	leakage detection, monitoring, and mitigation
LTV	leakage threshold value
MEPAS	Multimedia Environmental Pollutant Assessment System
O&M	operating and maintenance
SST	single-shell tank
SVE	soil vapor extraction
TDR	time domain reflectometry
TNPW	total net present worth
Tri-Party Agreement	Hanford Federal Facility Agreement and Consent Order
TWRS	Tank Waste Retrieval System
VEA	vertical electrode array
WHC	Westinghouse Hanford Company

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1.0 INTRODUCTION

This section describes the purpose and structure of this trade study. Technical terms and concepts are also defined.

1.1 REPORT OBJECTIVE AND SCOPE

The U.S. Department of Energy (DOE) has established the Tank Waste Remediation System (TWRS) to safely manage and dispose of low-level, high-level, and transuranic wastes currently stored in underground storage tanks at the Hanford Site in Eastern Washington.

One of the TWRS Waste Retrieval components is the Initial Single-Shell Tank Retrieval System (ISSTRS). This component will provide the required systems, equipment, permits, approvals, procedures, and trained operators needed to retrieve and transfer waste from the first (initial) single-shell tank (SST) farm to be retrieved to a double-shell tank (DST). The ISSTRS task will be used to demonstrate production-scale retrieval of saltcake waste from one SST, utilizing past-practice sluicing. A part of the ISSTRS design includes engineered and operational/administrative consideration of leak detection, monitoring, and mitigation (LDMM).

This trade study describes an approach for addressing LDMM for tanks selected for sluicing as part of the ISSTRS project. The trade study provides a systems engineering evaluation of currently available and new/candidate LDMM technologies in the context of actual, planned waste retrieval operations to determine feasibility of use, contribution to risk reduction, and cost-benefit. The evaluation was performed in conformance with the TWRS Systems Engineering Procedure TSEP-03. This trade study supports the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Milestone M-45-08-T02. The text of the Tri-Party Agreement Milestone M-45-08-T02 is shown below.

> Establish the criteria, through stakeholder participation and Ecology approval, for: (1) Determining allowable leakage volumes, and (2) acceptable leak monitoring, detection, and mitigation measures necessary to permit sluicing operations. - April 1997.

The evaluation of the LDMM technologies provided in this study assesses the feasibility and life-cycle cost of the LDMM technologies as part of complete retrieval systems. The schedule risk, effectiveness, public risk, worker risk, and environmental risk associated with each LDMM system are quantified and/or ranked, and a cost-benefit value is determined for each. The cost effectiveness values of the LDMM technologies and a no action alternative are compared.

This study builds on several documents that address various aspects of applying of LDMM to Hanford Site SST waste retrieval. These documents include *Functions and*

Requirements for Hanford Single-Shell Tank Leakage Detection and Monitoring (Cruse et al. 1995) and *Draft Functions and Requirements for Single-Shell Tank Leakage Mitigation* (1994). The general requirements presented in these two documents were combined and updated in a revised *Functions and Requirements for Hanford Single-Shell Tank Leakage Detection and Monitoring* (Foster Wheeler 1996).

During fiscal year (FY) 1994, a survey of all known leak detection and monitoring technologies was conducted by staff from the Pacific Northwest National Laboratories (Lewis and Teel 1994). The objective of this work was to identify all potential and existing LDMM technologies and devices that could be applied to the SST waste retrieval effort. A very simple screening approach was applied that produced a listing of several major technology "families" (e.g., electrical, seismic, radar, moisture sensor, radiochemical sensor, tracer gas detection, etc.). The search also singled out those methods and devices that could potentially evolve into useful LDMM tools; these were classified as "candidate technologies." Thirty-three available and emerging technologies were identified in the study that had the potential for detecting leakage outside a tank to support SST waste retrieval activities.

A second technology survey document was prepared in FY 1995 (Lewis et al. 1995) to further screen the initial listing of candidate technologies. This effort included specific physical constraints and requirements regarding deployment in Hanford Site SST tank farms. The screening effort was improved also by experience and information gained while demonstrating and evaluating LDMM technologies in the field at the Hanford Site from FY 1994 through FY 1996. The second study evaluated all currently known technologies, including the selected candidate technologies from the first study, plus new potential methods and devices that could be applied from within SSTs. The focus was on those devices and techniques that could support waste retrieval operations that used the design-basis, high-volume/low-pressure hydraulic sluicing method. All of these technologies were considered potentially capable of supporting the LDMM functions and requirements. The evaluation recommended a LDMM technology "toolbox" for retrieval. The technologies identified by Lewis et al. (1995) as potentially capable of supporting the LDMM functions and requirements were evaluated in this trade study.

An operations response document (Stuart et al. 1996) defined options for responding to indications of leakage determined during waste retrieval/sluicing activities, using currently available technology. The description provided in Stuart et al. (1996) of the currently available leakage detection system was used to establish a baseline LDMM system against which other candidate LDMM system technologies were compared.

1.2 REPORT STRUCTURE

The structure of this trade study is shown schematically in Figure 1-1. A description of the terms and concepts used in discussion of LDMM is given in Section 1.3. The LDMM technologies are identified and briefly described in Section 2. The currently available

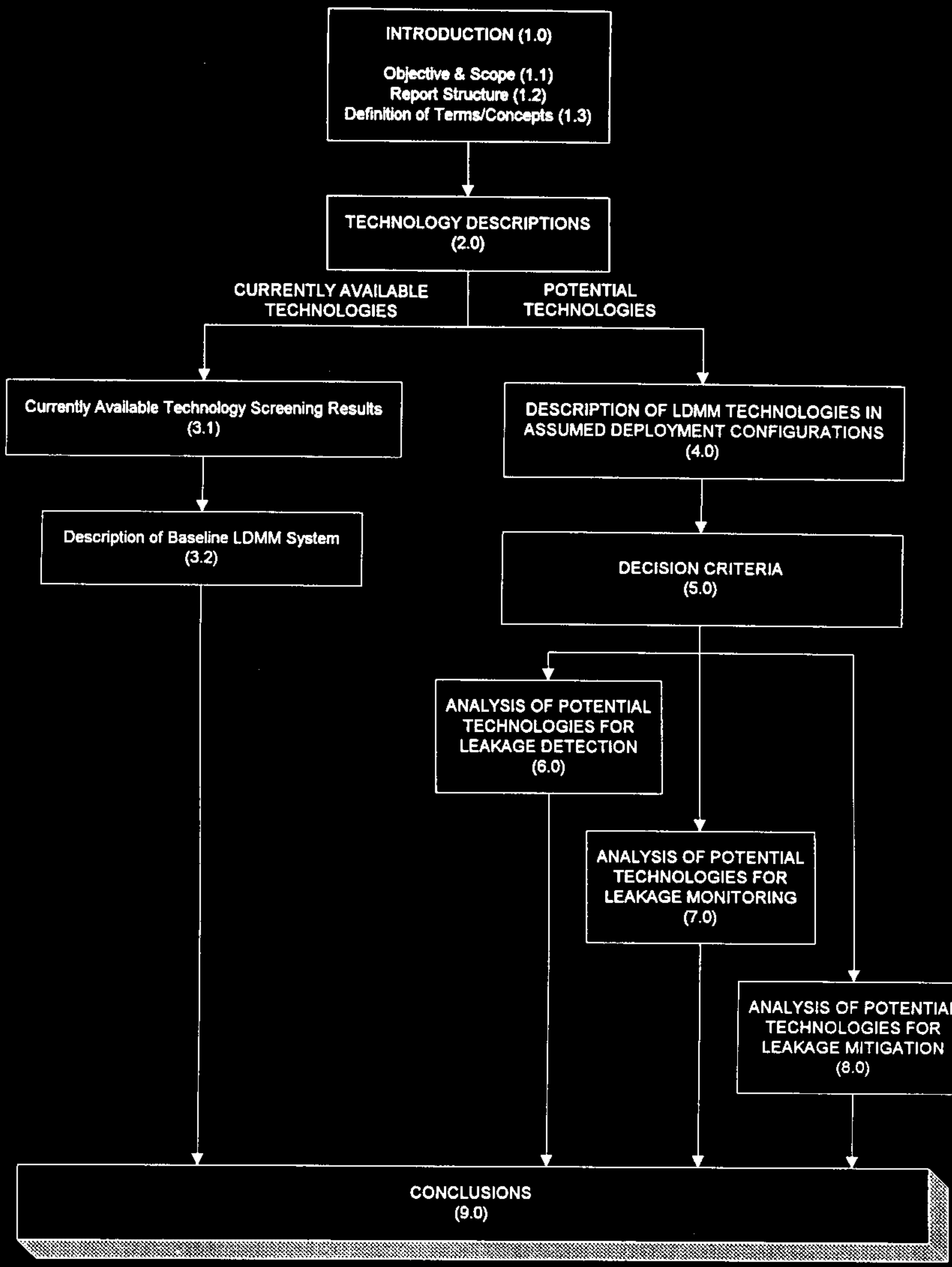


Figure 1-1. Trade Study Structure.

technologies, which make up the baseline LDMM system architecture are screened in Section 3. This architecture is also described in Foster Wheeler (1996).

The LDMM technologies that are not currently available or "candidate" are evaluated against the functional requirements identified in Foster Wheeler (1996) in Sections 4 through 8. This detailed evaluation was completed to assess the potential cost-benefit of these technologies were they to be developed, demonstrated, and deployed in the SST farms. The technologies in assumed deployment configurations in the SST Tank Farms are described in detail in Section 4. The decision criteria by which the technologies were evaluated are presented in Section 5. Sections 6, 7, and 8 present the evaluation methodology and results for leakage detection, monitoring, and mitigation, respectively. Conclusions of the trade study are provided in Section 9.

1.3 DEFINITION OF LDMM TERMS AND CONCEPTS

Several terms and concepts arise repeatedly in discussions regarding LDMM. This section provides definition of those terms to ensure a consistent interpretation of their meanings.

1.3.1 Role of LDMM

The LDMM technologies are applicable wherever significant leakage of liquid waste from the SSTs may occur, as during hydraulic sluicing. Hydraulic sluicing was used for past waste retrieval campaigns at the Hanford Site and is commonly referred to as "past-practice" sluicing. Past-practice sluicing is the method that has been selected to remove saltcake and sludge waste from some of the 149 Hanford Site SSTs. The fundamental assumption of ISSTRS is derived from the fact that the initial retrieval technology selection process was completed before the ISSTRS efforts began. Westinghouse Hanford Company (WHC) has recommended past-practice sluicing as the "first choice reference retrieval technology where tank leakage is not a problem," (Gibbons et al. 1993). The U.S. Department of Energy, Richland Operations Office (DOE-RL) has concurred with that recommendation, directing that WHC "continue reference program for SST retrieval (hydraulic sluicing) [as a] high risk, single point failure program" (Erickson 1995). This action fixed the fundamental technology for the ISSTRS activities. Therefore, ISSTRS will not evaluate alternate technologies (Hagmann 1995).

Selection of the initial tanks for past-practice sluicing will be based on judgement that they can be sluiced without undue risk to the environment. For purposes of this report, it was assumed that the 67 SSTs identified as "assumed leaker tanks" in Hanlon (1995) would not be retrieved by past-practice sluicing but the 82 "sound" SSTs would be. Regardless of the confidence in the physical integrity of the selected tanks, the addition of water during sluicing increases the risk that leakage could occur due to increased hydraulic head and dissolution of solids. The three major areas of concern during sluicing are (1) determination that a leakage "event" has occurred, (2) adequate surveillance of existing and new leakage plumes, and (3) taking responsible retrieval actions that minimize the potential for leakage to occur or continue. These major topical areas and operational goals are represented in the terms "leakage detection," "leakage plume monitoring," and "leakage mitigation" (i.e., LDMM).

A goal of minimum achievable leakage can be achieved by employing the LDMM options available at the time of waste retrieval. The selection and use of LDMM tools and methods should be based on operating requirements, operating constraints, anticipated cost-benefit, and potential risk reduction. During initial SST waste sluicing operations, LDMM options will be tested in order to gather data to support decisions and actions that will help ensure minimum achievable leakage is realized in future sluicing operations.

1.3.2 Leak and Leakage

A leak is the point on a tank from which loss of contained liquid waste occurs. Leakage is the escape of contained liquid waste. In the strictest sense, leakage occurs when even a molecule of liquid waste is released to the ground.

1.3.3 Leakage Plume

A leakage plume is represented by the physical extent of an escaping or escaped liquid waste into the ground. The size of a leakage plume is not directly related to that of the original leak; rather, it is a function of several variables within the soil mass: porosity, existing moisture content, particle size, hydraulic head for the leaking waste, etc.. Leakage of several gallons can produce a leakage plume with a volume of several cubic yards.

1.3.4 Minimum Achievable Leakage

Minimum achievable leakage is an operational and environmentally responsible goal and is consistent with major Hanford Site stakeholder values. This goal challenges waste retrieval operators to minimize leakage to the greatest extent possible while achieving safe operations and cost-effective final site remediation and closure. During SST waste sluicing operations, LDMM data will be used in decision-making to ensure minimal achievable leakage is achieved.

1.3.5 Leakage Threshold Values

The leakage threshold value (LTV) is a preliminary, risk-based quantity of leakage, calculated for each tank, that equates to either a unit of cancer risk or a unit of hazard quotient. Using this approach, risk is based on transport modeling of potential contaminants of concern leaked from an SST closed with a surface barrier. The contaminants are modeled to leach to groundwater and migrate downgradient where a future resident would be exposed through ingestion of groundwater obtained from a well and through ingestion of vegetables irrigated with the groundwater.

The LTVs are useful in providing relative risk information about potential leakage from single tanks. The LTVs are not intended as specific limitations to leakage because higher amounts of leakage may be acceptable depending on factors such as previous leakage, the amount of residual waste in the tank following sluicing, and the amount of waste in nearby waste sites. The LTVs serve as leakage "sensitivity guidelines" that may be used during the formulation of operations retrieval and response plans.

There is now, and will continue to be, high uncertainty in the contribution to overall risk by each of the sources of contaminants of concern, including new leakage during sluicing. Nevertheless, the range of preliminary leakage thresholds described in Cruse et al. (1995) serves as a reasonable basis for the potential range of LDMM leak detection sensitivity for individual tanks. Final leakage thresholds for individual tanks could easily vary from preliminary thresholds by one to two orders of magnitude depending on impacts of new characterization data, different modeling assumptions, and the interrelations of risks from nearby sources. Therefore, these individual tank thresholds will require reassessment as retrieval proceeds in each tank farm and as the levels of residual risk in waste sources that will not be retrieved become better quantified.

1.3.6 Leakage Detection

During retrieval, leak detection information will contribute to decision-making regarding continuing or stopping sluicing. Leakage detection can play an immediate and significant role in achieving the goal of minimal achievable leakage. Leak detection data that are reliable and provided in a timely fashion (i.e., within the retrieval operational time frame and at intervals that will support operational decisions) will be advantageous. During retrieval, leak detection information will contribute to operational decisions to determine if sluicing should be stopped or not. Lower leak detection levels and timely leak detection information will result in better operational decisions.

1.3.7 Leakage Monitoring

Monitoring for leakage includes: (1) surveilling possible leakage, and/or (2) concurring whether or not leakage has occurred. Leakage monitors are devices or methods that typically can be applied outside the tank. Monitoring will be of little or no value during a sluicing campaign to support operational go/no-go decisions because information will not be provided in time for taking response actions.

The LDMM devices and methods that do not fulfill the quantitative and timeliness requirements to be classed as leakage detectors can generally be considered as leakage monitors. A candidate leakage detection tool or method may first be developed as a monitor. As the tool or method is refined, developed, tested, evaluated, and proven to be reliable, it may also qualify as a detection device.

Leak monitoring outside the tank produces semi-quantitative or qualitative data. Leakage plume monitoring will also be used as a pre- and post-sluicing tool to provide general tank perimeter surveillance and to confirm whether or not leakage has occurred from a tank.

1.3.8 Leakage Mitigation

Leakage mitigation entails all actions undertaken at any time prior to, during, or after sluicing, to eliminate the possibility of leakage or reduce leakage if it does occur. Effective mitigation devices or actions will be made available and used throughout the retrieval effort. At present, only specific operational procedures and retrieval devices have been shown to provide the potential for leakage mitigation.

1.3.9 LDMM Technology Availability

An available LDMM technology is one that is ready for use. "Availability" also implies that little, if any, additional development, demonstration, evaluation, or implementation effort is required to obtain meaningful, reliable information as soon as the device or method is installed. Availability usually means off-the-shelf and ready for deployment. Availability cannot be claimed if a device or method is not also deployable. In order to qualify as available, an LDMM technology or method should have a record of successful performance in the application for which it was designed. A history of use is critical to ensure that the frequency of false positive indications is minimal and acceptable. The accuracy of LDMM devices must be well understood to provide the statistical basis necessary for interpreting instrument readings.

1.3.10 LDMM Technology Deployability

An LDMM technology, device, or method that cannot be placed into service while ensuring desired LDMM operational characteristics is considered to be not deployable. The need for LDMM deployability has raised the requirement for companion deployment technology to the same level as the fundamental LDMM technology. Most LDMM tools will require a companion deployment element. An effort to develop a new LDMM tool is not complete without including a means for deployment. The method of deployment must be considered simultaneously with tool development to ensure that the method does not interfere with the operation of the tool. The tool must be designed to withstand the conditions needed for its deployment. Materials of construction, quality of the installed instrumentation signal, and difficulty of maintainability after emplacement should also be considered when developing or selecting a deployment technology.

1.3.11 LDMM Technology Reliability

A technology must be reliable in terms of requiring minimal maintenance and providing trustworthiness of its results (i.e., a statistical basis must be available for interpreting results, and a means for calibrating the instrumentation should exist when significant drift may occur).

1.3.12 Leakage Detection Regardless of Leak Location

It is important that a leakage detection system provide the ability to identify leakage no matter where in the soil it is occurring. This requirement can be met using in-tank leakage detection technology. An external leakage detection technology must interrogate the full soil mass immediately around and beneath an SST. The leakage detection and monitoring zones are shown in Figure 1-2.

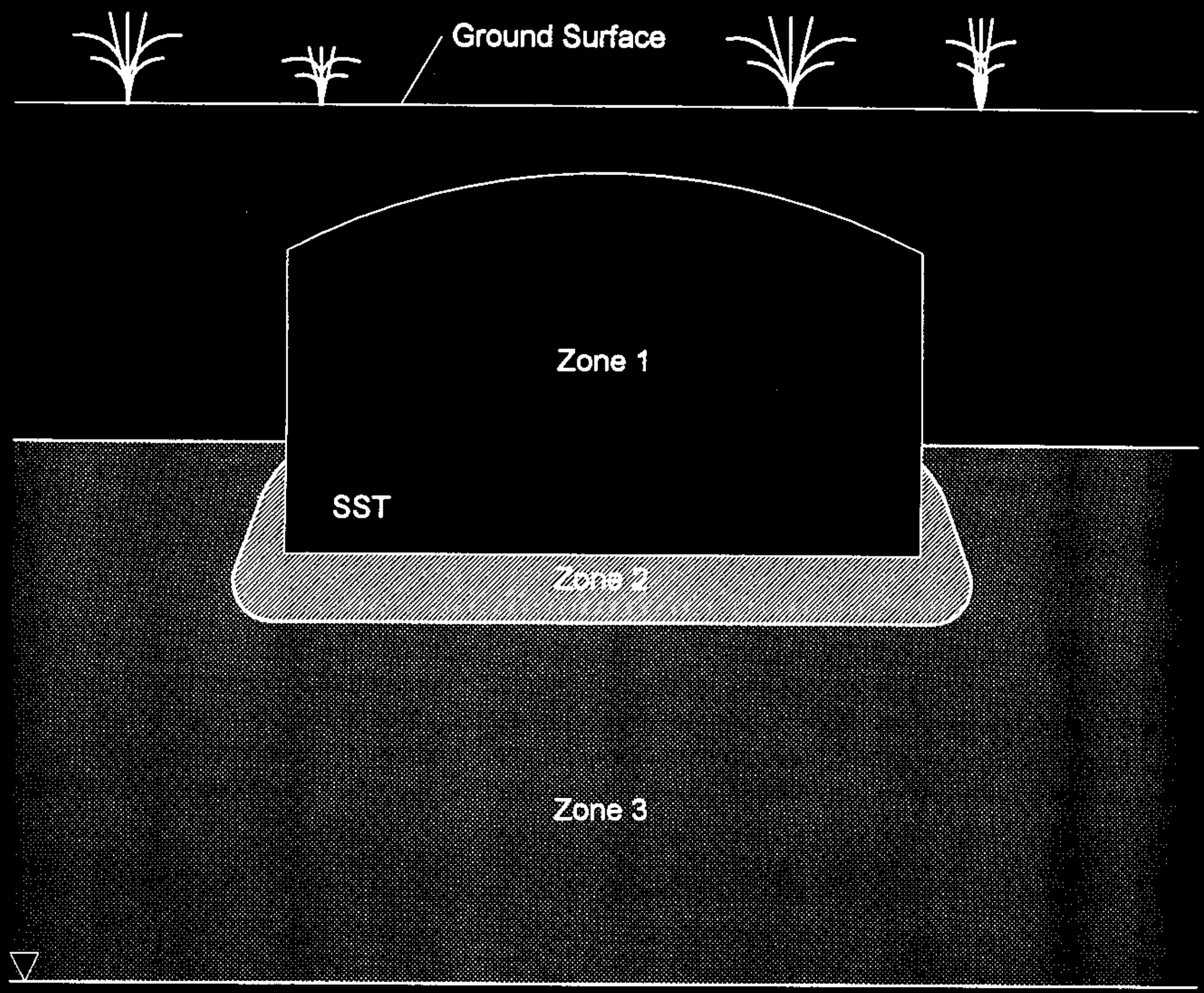
1.3.13 Timely Leakage Detection

Leakage detection time is the length of time between when the leakage occurs and the time that the detecting device or method registers the event and relates it to workers who interpret its meaning. The most valuable leak detector will be the one that provides instantaneous indication when leakage has started. No such device or method currently exists.

A leakage detection device or method must provide information within the time frame when any possible response to the leak will have a benefit to mitigating or reducing the volume of leakage. A device that provides high quality data about a leakage event, but requires months to obtain and interpret the data, is of no value if the retrieval action will last for only two weeks. The leakage detection time must fall within a fraction of the overall time frame for the retrieval campaign, e.g., before one-quarter of the total waste volume is retrieved.

1.3.14 Leakage Size, Volume, and Rate

Leakage size is a measure of the volumetric extent of the leakage plume. The leakage size will always be larger than the volume of the leakage because leakage fills soil pores but does not displace the soil. Leakage of several hundred gallons can create a plume with a volume of several hundred cubic yards or more in the vadose zone. Leakage rate and



Zone 1	In-Tank Leakage Detection
Zone 2	External Leakage Detection
Zone 3	External Leakage Plume Monitoring

Figure 1-2. Leakage Detection and Monitoring Zones.

volume data can be combined with knowledge of the surrounding soil characteristics to estimate plume size.

It is important to note that only limited control of leakage volume, rate, and its eventual size is possible during the act of sluicing. Once leakage is underway, response is limited (as discussed in Section 4.3) to (1) continuing, (2) continuing with additional controls, or (3) stopping the retrieval operation. An appropriate response is selected to minimize adverse impacts to the environment. The effort to minimize leakage volume, rate, size, and corresponding risks is at the center of Tri-Party Agreement goals and stakeholder values.

In most of the SSTs that are leaking or assumed to be leaking, the volume of existing leakage exceeds the amount of leakage that would be allowed when considering LTVs. The development of preliminary LTVs was based on the assumption that about 208,000 L (55,000 gal) of leakage had already occurred in each tank farm and that 99% of the waste in the tanks would be retrieved. The LDMM strategy proposed by this document includes striving for the minimum achievable leakage while remaining at or below LTVs. The LTVs for individual tanks may change depending on factors previously discussed.

1.3.15 Leakage Direction

Information on the direction of a leakage plume contributes to decision-making on how best to achieve closure of a tank farm and nearby waste sites. Knowledge of the direction of lateral spread of leakage may help ensure the safe installation of external LDMM technologies around adjacent tanks. Longer-term monitoring following a retrieval action may be necessary to establish the direction of leakage.

1.4 FACTORS IMPACTING USE OF LDMM

Several factors have been identified that impact the applicability of LDMM to support SST waste retrieval operations. These include (1) programmatic factors (those under the control of, or requiring decisions by, the TWRS retrieval program), (2) leakage factors (uncontrollable factors that define tank leakage), and (3) other site factors (uncontrollable factors not directly related to tank leakage). These factors are described in the following sections.

1.4.1 Programmatic Factors

Programmatic factors are factors that are under the control of the TWRS retrieval program or can be influenced by the program. The programmatic factors are listed below and described in the following sections.

- Waste retrieval method
- Operational response (leakage mitigation) strategy
- Tank closure strategy.

1.4.1.1 Waste Retrieval Method. The waste retrieval method may impact the selection or appropriate responses to tank leakage. Subsurface barriers do not appear to be cost-effective or normally necessary for leakage mitigation when retrieving waste using past-practice sluicing (Treat et al. 1995).

A conceptual waste retrieval and leakage mitigation approach proposed in this document uses the waste solution saturated in dissolved salt and/or containing suspended fine sludge particles as the sluicing liquid. This approach may prevent the dissolution of salt crystals that may be plugging leaks and may also help to seal cracks in the tank steel and concrete by filling in the flow pathways with sludge particles. If this concept proves to be successful, it may be possible to sluice most of the tanks, including some previously leaking tanks, without causing significant new leakage.

1.4.1.2 Operational Response (Leakage Mitigation) Strategy. An effective LDMM system must not only be capable of detecting leakage before it would cause unacceptable risks, but it must do so in time to initiate and complete actions to stop the leak and prevent unacceptable risk levels. However, signaling leakage has no value if there is no available or planned operational response (leakage mitigation).

Considerable time may pass before the occurrence of leakage is confirmed depending on the magnitude and location of the leakage plume relative to LDMM sensors. If a high rate of leakage is inferred using LDMM, the preferred operational response may be different than in the case of a low rate of leakage. For example, the appropriate response for a high leakage rate may be to pump out the tank as quickly as possible and rely on subsurface barriers, mechanical retrieval, robotic sluicing, or some other alternative to complete cleanout of the tank. In the case of a low rate of leakage, or where the LTV is high, the appropriate action may be to continue sluicing at the highest rate possible and use LDMM to confirm that the leakage does not exceed the LTV. There is also the possibility that the leakage volume will remain below the detection level or that very large and rapid leakage will occur at a rate that precludes usefulness of all available operational response. There are no effective operational responses for these cases.

1.4.1.3 Tank Closure Strategy. Knowledge of the total masses and curies of the constituents of concern in the soil from past and new leakage may be required to obtain a permit to close a tank farm or to make decisions on remediating contaminated soil. The combined risks associated with the leaked waste and risks from other sources will likely be considered in the permit application. The potential for successfully mitigating risk using any and all available methods may also be a factor in obtaining a closure permit.

Current information on the potential effectiveness of LDMM technologies may be suitable as input to a sufficiently accurate risk assessment for a closure permit application.

The use of LDMM for detecting and preventing the occurrence of an unacceptable level of soil contamination may serve to avoid the need to exhume certain tanks and contaminated soil in order to meet closure requirements. Preliminary costs associated with exhumation and treatment of tanks and contaminated soil are estimated to be very high (Boomer et al. 1993). Thus, the successful use of LDMM technologies could prove to be a cost-effective technique for minimizing the high costs of closing certain tank farms.

A hypothetical example of the complex interaction of tank closure with other factors involves a previously leaking tank. A leak mitigation response such as using robotic sluicing may not be justified due to high cost and worker risk associated with robotic sluicing. A better approach may be to use a proven, sensitive LDMM technology with past-practice sluicing and accept the risk that excessive leakage could occur, resulting in the need to cease sluicing. Cleanout would be finished using a more expensive method that would likely pose higher risks to workers.

Interrelationships between LDMM technologies and tank closure are not well defined, since final decisions on closure have not been made. If contaminated soils were to be exhumed, then it could be argued that heroic measures to minimize or eliminate additional leakage during sluicing would not be justified. However, the opposite argument (i.e., if contaminated soils are to be exhumed or treated in place, then additional leakage may only compound the problem and therefore should be avoided) may be equally defendable. The strength of either argument may be affected by the degree of existing contamination versus the degree of additional contamination that might result from leakage during sluicing. Additional closure system engineering development and analysis must be done before these complex interrelationships can be understood sufficiently well to support final decisions on deployment of LDMM technologies.

1.4.2 Leakage Factors

Leakage factors are factors that cannot be controlled. Leakage factors define tank leakage in terms of timing, rate, volume, location, and contaminant concentrations as discussed below.

1.4.2.1 Leakage Timing. The timing of leakage during the retrieval sequence can impact the selection of an appropriate leakage mitigation response. For example, if leakage occurs early in the sluicing process, a close-coupled subsurface barrier may be installed and, allow continuation of sluicing. If a leak occurs in the middle of the retrieval process, a different retrieval method such as mechanical retrieval may be used; and if a leak occurs near the end of the retrieval process, the response may be to complete retrieval without pausing.

1.4.2.2 Leakage Rate. The required sensitivity of LDMM technologies may be greatly impacted by the rate of leakage. No technology currently exists to measure the rate of leakage directly.

1.4.2.3 Leakage Volume. Some leak detection methods under consideration are capable of measuring or inferring leakage volume. The masses and curies of constituents of concern leaked in these cases can be estimated if the composition of the leaked solution is known. If the leak occurs at the base of the tank and leakage is occurring early in the sluicing cycle, the concentrations found in samples of the tanks salt well liquor may be the best indicators of the concentrations of the leakage (salt well liquor is pumped from the base of the tank). If the leakage is occurring high on the wall of the tank or occurs very late in the sluicing cycle when the tank bottom is exposed, the concentrations of decanted sluicing solution may be the best indicators of leakage concentrations.

1.4.2.4 Leakage Location. Some LDMM technologies are sensitive to leak location. This is true of LDMM systems located external to the tank. Certain external LDMM systems, especially those that detect radiation or chemical species may not "see" the leakage plume unless they are touching or in close contact with the LDMM sensors. Blind spots may occur when probes are widely spaced or when they are not installed beneath the tank because of high installation costs and/or unacceptably high worker risk. When sensors are not installed under the tank, large leaks from near the middle of the bottom of the tank may not be detectable.

1.4.2.5 Leakage Contaminant Concentrations. Concentrations of constituents of concern in individual tanks will also be highly variable due to factors such as differing waste history, pH, and temperature. External LDMM methods that rely on measurement or inference of masses or curies of a limited set of constituents of concern in the leakage plume may be amenable to estimation of the remaining constituents of concern by simple ratioing, if their relative concentrations inside the tank are known.

1.4.3 Other Site Factors

Other site factors include those uncontrollable factors not directly related to new leakage that will impact the deployment, implementation, or operation of LDMM technologies. Other site factors include installation constraints, site geology, and previous leakage as described in the following sections.

1.4.3.1 Installation Constraints. The ability to install LDMM technologies is subject to constraints such as the presence of aboveground and underground piping around the SSTs, weight limitations on SST domes, close proximity of other SSTs, and radionuclide-contaminated soils. All of these can limit the number and location of sensors that can be placed in the soils around an SST.

1.4.3.2 Site Geology. The effectiveness of LDMM technologies may depend on the characteristics of the construction fill and the native soil beneath a given tank farm. These characteristics include vadose zone moisture content, soil permeability, and the presence of layered interbeds or clastic dikes. These can impact how leakage moves through the subsurface (rate/direction), the shape of the resulting plume, and limit the types of applicable LDMM technologies and deployment methods.

1.4.3.3 Pre-Existing Leakage Plumes. The existence of leakage plumes from past releases can reduce the effectiveness of external LDMM technologies by increasing the background signal that the technology senses. Past leakage plumes may also contribute substantially to worker risks when boring is required to install LDMM devices.

2.0 IDENTIFICATION AND SCREENING OF LDMM TECHNOLOGIES

A previous study by Lewis et al. (1995) identified and screened candidate leakage detection and monitoring technologies that could be applied to SST waste retrieval. This study recommended that six technologies be considered for leakage detection and monitoring applications: (1) mass balance, (2) tracer gas testing, (3) electrical resistivity tomography (ERT), (4) neutron activation logging, (5) gamma-ray logging, and (6) time domain reflectometry (TDR). These technologies, plus six pre-existing detection capability (leak detection pits) are described in Sections 2.1 through 2.6. The two recommended borehole geophysical logging technologies, neutron activation and gamma logging, described in Lewis et al. (1995) are combined in Section 2.5.

A previous trade study by Treat et. al. (1995) evaluated tank leakage mitigation technologies including retrieval, subsurface barriers, soil flushing, and tank closure systems. An additional leakage mitigation technology (not evaluated by Treat et al. [1995]) is limited sluicing as described by Stuart et al. (1996). The following technologies were selected for leakage mitigation screening: (1) past-practice sluicing, (2) limited sluicing, (3) robotic sluicing, (4) mechanical retrieval, and (5) subsurface barriers. Discussion of the technologies is presented in Sections 2.7 through 2.11. Advantages and disadvantages of each technology are provided as a basis for screening.

2.1 MASS BALANCE USING LEVEL MEASUREMENT

The mass balance method of leakage detection and monitoring uses measurements of the liquid level and density in the tank to detect changes in the total mass of the waste contained within the overall retrieval system. A reduction in the mass is assumed to be due to leakage. The primary level and density instrument considered for this screening is the Enraf-Nonius 854 Advanced Technology Gauge (ENRAF). The ENRAF gauge is a liquid-level measurement device that consists of a weight (or displacer) at the end of a stainless steel wire. The gauge detects the density or change in the apparent weight of the displacer by buoyancy or by contact with a solid (Schofield 1994). The ENRAF gauge is currently used to collect surface-level readings on 16 of the 149 SSTs, including Tank 241-C-106 (Lewis et al. 1995).

The ENRAF gauge is designed to stay in contact with the tank waste surface or be partially submerged; this is a significant advantage over the older Food Instrument Corporation (FIC) gauge that utilized conductivity to measure tank waste levels. The FIC gauges have been utilized extensively in the past in Hanford Site tanks. The ENRAF gauge is mounted aboveground on tank risers. The only portion of the gauge that extends into the tank is the steel tape and plummet. The "bobbing" action of the older FIC gauges is thought to have been the reason that salt crystals periodically built up on the plummet and caused erroneous readings. Because the ENRAF gauge does not "bob," salt buildup will not be as significant.

The advantage of mass balance as a leakage detection and monitoring technology is the overall acceptance by the compliance agencies as an approved inventory control measure. The primary disadvantage is the loss of measurement control during retrieval operations when liquid is being added to or pumped from the tank.

2.2 TRACER GAS

Tracer gas can potentially detect leaks from SSTs by measuring for the presence of the tracer gas in the soil surrounding the tanks. This technology is the result of combining two mature technologies: tank or pipe integrity testing and tracer gas. Tracer gas testing is performed by mixing an inert, volatile chemical concentrate (i.e., a tracer) with a product inside a tank or pipe. The tracer would be added to the tank sluice liquid in very low concentrations (usually a few parts per million). The highly volatile tracer would distribute itself throughout the tank, both in the waste and vapor phase above the waste. If leakage occurs, the tracer would diffuse from the liquid and disperse into the surrounding soil. The vapor-phase tracer would be collected for analysis using a soil vapor extraction system.

The tracer must be specifically selected so that it is compatible with the liquids inside the tank but unique to the tank contents and outside environment. The tracer should produce no adverse impact on the physical properties of the tank waste. Low toxicity, nonhazardous, nonbiodegradable, and nonflammable tracers would be used for leakage detection (Lewis et al. 1995).

The advantages of tracer gas testing are high analytical sensitivity, usefulness during retrieval, and ability to detect gas using relatively few sensors. The disadvantages are potential for delayed response when gas passes through semi-permeable zones being monitored, and the potential release of gas through cracks or holes in the steel liner above the liquid level, thereby providing a false indication of leakage.

2.3 LEAKAGE DETECTION PITS

Leak detection pits are designed to collect any leakage that occurs between the tank steel and concrete. Any leakage that occurs will migrate along channels in the concrete foundation of the tanks. Four tanks in the AX Tank Farm are equipped with pits to monitor leakage. Radiation detectors, level monitors, and specific gravity instruments are located in the bottom of each pit to detect tank leakage.

The advantage of leakage detection pits is early detection of leakage. The disadvantage is that there are a limited number of tanks currently equipped with leak detection pits.

2.4 ELECTRICAL RESISTANCE TOMOGRAPHY

Electrical resistance tomography is an innovative leakage detection technology that measures changes in direct current (dc) resistivity of soil. The measurement is made with pairs of electrodes placed into the subsurface, each in electrical contact with the soil formation. A known current is passed between two electrodes and the resulting voltage difference is measured between other pairs of electrodes. Numerical techniques are used to calculate the resistivity distribution in the vicinity of the boreholes. Software can be used to construct a two- or three-dimensional map, or tomograph, of the subsurface electrical resistivity/readings.

Because most minerals are insulators, dc current in the subsurface is typically conducted through water in the pore space of the soil. The resistivity of the subsurface soils is a function of (1) resistivity of the pore water, (2) amount of pore water present, and (3) pore structure geometry. For leakage detection/monitoring, the system will respond primarily to changes that occur in the amount of water present in the soil (Lewis et al. 1995).

The advantage of ERT is that it is capable of identifying leakage during retrieval. In addition, the tomographic images provide two- and three-dimensional plots of the leak volume and direction of movement. This enhances ability to quantify the magnitude of the leakage and supports decisions regarding safe installation of boreholes and how best to close the tank farm. The disadvantage is the potential for electrical interference from buried metallic objects such as tank walls, piping, and operating machinery.

2.5 BOREHOLE GEOPHYSICAL LOGGING

Two existing borehole geophysical logging technologies were evaluated and recommended by Lewis et al. (1995) as technologies that could support leakage detection and monitoring: neutron activation logging and gamma-ray logging. These technologies are described in the following sections. Geophysical logging systems typically employ a logging truck, a support crew, and a standard time interval for borehole characterization.

2.5.1 Neutron Activation Logging

Neutron activation logging systems can be utilized to monitor tank leakage plumes and plume movement by determining the concentration of hydrogen from moisture in the soil by measuring the response to neutron back scatter and measuring the changes in the energy levels. Neutron activation provides a technique to measure moisture content and changes with time.

The advantage of neutron activation logging is that it is easily deployed and can provide a high level of precision for moisture measurements. The disadvantages are that the monitoring is not continuous and the moisture must be near the borehole to be detected. Thus, a hundred boreholes along tank walls and beneath the tank base may be required to create a sensitive leakage detection system.

2.5.2 Gamma-Ray Logging

Gamma-ray logging systems can be utilized to monitor tank leakage plumes and plume movement by measuring the radioactivity emitted from waste that has leaked in the soil. The number and energies of gamma rays emitted are distinctive of the different radionuclides in the waste. Gross gamma detection systems measure the total gamma-ray activity but do not distinguish among gamma-ray energies of different radionuclides. Spectral gamma systems measure both the numbers of gamma rays and the energy level of each, permitting a determination of the concentrations of both naturally occurring and manufactured radionuclides.

There are approximately 780 vadose zone monitoring wells in the vicinity of Hanford Site SSTs. These "dry wells" have been utilized by the operating contractors at the Hanford Site for leak detection and plume tracking. These wells have been monitored utilizing gross gamma detection systems to measure and monitor gamma radiation in the soils surrounding the tanks. The ability to detect leakage is dependent on the radionuclides in the leakage plume. The current sensitivity and success of this system has decreased with the decay of activity of the radionuclides in the soil. An alternative system has been deployed and is currently being evaluated. This system is a spectral gamma logging system and is more sensitive by several orders of magnitude.

The advantages of spectral gamma-ray borehole logging are that it can be used to detect leakage, identify the leak source, and track the leakage plume. The disadvantages are that the monitoring is not continuous and the radioactivity must be near the borehole to be detected. One hundred boreholes along tank walls and beneath its base may be required for a sensitive leakage detection system.

2.6 TIME DOMAIN REFLECTOMETRY

Time-domain reflectometry is an established technology for monitoring moisture movement in shallow soils. It can potentially be used to monitor SST tank leakage to the soil in two steps: (1) measuring the propagation velocity of an electromagnetic pulse along a transmission line and (2) converting this measurement to an estimate of soil moisture content. The key to this technology is the relative difference in the dielectric constant of most dry geologic materials (approximately 3 to 5) compared to the dielectric constant of water (approximately 80). Precision Moisture Instruments, Inc., produces a 2-m-long (6.6-ft-long) TDR probe that can be driven into the ground surface; this probe has been demonstrated at the Hanford Site as part of the Hanford Protective Barriers Program (Lewis et al. 1995).

An advantage of the TDR system is that, when properly deployed, it can be used for confirmation of leaks. A disadvantage is a low distance range of sensitivity. Hundreds of TDR probes may be required to ensure sensitive leakage detection.

2.7 PAST-PRACTICE SLUICING

Past-practice sluicing was conducted in two waste retrieval campaigns: (1) from 1952 to 1957, as part of a system to recover uranium from the waste tanks, and (2) from 1962 to 1978, as part of a system to recover strontium. The retrieval techniques utilized sluicing and slurry pumping. In general the technique was successful, but was plagued with equipment failures. Optimized past-practice sluicing would consist of improved and updated retrieval and sluicing techniques which incorporate current administrative, radiological, and regulatory controls. Technical improvements include advanced nozzle designs, improved pumping systems, recirculation of the supernatant, and improved heating, ventilating, and air conditioning (HVAC) systems.

Removing the waste from the tanks by past-practice sluicing or other retrieval method would mitigate the risk to the groundwater. An advantage of optimized past-practice sluicing is better utilization of the existing TWRS system and work force. The disadvantage is limited control of new leakage.

2.8 LIMITED SLUICING

Limited sluicing is a waste mitigation technique proposed in *Operational Tank Leak Detection and Minimization During Retrieval* (Stuart et al. 1996). A layer of sludge/saltcake would be maintained on the vertical walls of the tanks to avoid further damage to the tank shell and to help retain whatever natural seal exists. Optimized past-practice sluicing and a telescoping pump would be used. A high degree of control would be exercised over the flow and direction of the nozzle spray when sluicing near the tank walls. Improved video monitoring would be employed to track and verify progress.

The advantage of limited sluicing is that existing materials (waste sludge/saltcake) are left on the portions of the tank most vulnerable to leaks during most of the waste retrieval operation. The disadvantage is a need for more complex equipment and methods relative to past-practice sluicing.

2.9 ROBOTIC SLUICING

Robotic sluicing would employ a type of robotic armed-based retrieval system that was first investigated at the Hanford Site in the mid-1970s. The technology is under development, but has not been tested in an actual Hanford Site SST (Treat et al. 1995).

An attachment to the end of the robotic arm called an end effector would use high-pressure water jets for dislodging the waste. After the sludge is dislodged, the slurried mixture would be immediately vacuumed through a hose to an air separation system. Following separation the waste would proceed to a processing system.

The advantage of this system is that high pressure sluicing would be effective in cutting through hardened sludge. The disadvantage is that this system could potentially cut through corroded tank walls, which may cause new leakage.

2.10 MECHANICAL RETRIEVAL

Mechanical retrieval, designed for removal of solid waste and debris by mechanical means as opposed to hydraulic means, is one of the arm-based retrieval methods currently under consideration for use in the SSTs. It is one of several methods of retrieving waste from SSTs that have been investigated at the Hanford Site since the mid-1970s.

Mechanical retrieval would use a scoop-like end effector affixed to the end of the robotic arm for waste retrieval. The end effector would be capable of mechanically excavating the solid waste in the tank. A jack-hammer end effector may be necessary for breaking up the rock-like saltcake and heels 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 removed from the SST for further processing.

The primary advantage of mechanical retrieval is its likely effectiveness in cutting through a hardened sludge heel. Disadvantages include the likelihood of high maintenance and associated worker exposure, and reduced effectiveness in removing waste adhering to tank walls and equipment in comparison to sluicing.

2.11 SUBSURFACE BARRIERS

A range of subsurface barrier options are potentially applicable for use in leakage mitigation. Those deemed to be sufficiently well-developed to evaluate are low-permeability chemical barriers, freeze wall barriers, and circulating air barriers. None of these barriers has been successfully demonstrated in an operating environment similar to that of Hanford Site Tank Farms. Chemical barriers (close-coupled, box-shaped, and V-shaped), freeze wall barriers (V-shaped) and the circulating air barrier are discussed in the following sections.

2.11.1 Close-Coupled Chemical Barrier

Chemicals would be used to create a close-coupled barrier around the base and walls of individual tanks. Chemicals would be injected through vertical and horizontal pipes jacked or drilled into the soil around a tank and gel or solidify to create a water-tight barrier.

Mudless drilling methods would be required in the case of drilling to prevent plugging of soil pores, a condition that would interfere with subsequent chemical injections. It is assumed that the horizontal pipes would be installed from inside vertical 4.6-m (15-ft) diameter caissons, which would be installed in the open areas between tanks. Similar caissons have been installed in the A and SX Tank Farms (Raymond 1966).

The primary advantages of the close-coupled chemical barrier are: (1) the amount of injection piping and volume of injected chemical would be minimized relative to other barrier types because the injected chemical is designed to seal to the tank structural concrete rather than be located some distance away where the areal extent of the barrier is greater and (2) the volume of soil contaminated by leakage from new sluicing operations would be minimized because an effective close-coupled barrier would contain additional leakage from the tank, thereby preventing additional contamination of the soil. The primary disadvantages are: (1) soil contaminated from previous leaks may require flushing to remove contamination that would otherwise be incorporated into the injected barrier or contamination that may interfere with the chemical solidification process and (2) forces created by emplacing piping for chemical injection may compromise the integrity of the tanks.

2.11.2 Box-Shaped Chemical Barrier

The function of a box-shaped chemical barrier would be to create a low-permeability basin beneath the level of existing soil contamination in each tank farm. The base of this standoff barrier would slope slightly to promote runoff of leakage to a low point for collection. Without the slope, liquid waste would collect in subsurface depressions on the surface of the barrier. The resulting ponds of waste could not readily be detected. The potentially high number of ponds would complicate removal of collected liquid waste. The box-shaped chemical barrier would be created using both vertical and directional drilling techniques.

The primary advantages of the box-shaped chemical barrier are: (1) only one barrier system would be needed for each tank farm rather than one for each tank or leaking tank, (2) drilling to emplace the barrier-forming chemicals would not occur in contaminated soils, and (3) leakage would be contained and prevented from migrating to the groundwater. The primary disadvantages are: (1) long directional drill lengths would be required with little tolerance for directional deviation, and (2) the standoff barrier would not prevent or minimize new leakage.

2.11.3 V-Shaped Chemical Barrier

The V-shaped chemical barrier would be installed in the shape of a prism around an entire tank farm. The relatively steep slope of the barrier would promote subsurface runoff of leakage to the base of the barrier where it could be removed by pumping. The angled boreholes required to form the "V" would be created by slant drilling, a technology that has been demonstrated at the Hanford Site. The ends of the barrier would be vertical. Vertical drilling techniques that do not require drilling muds, such as sonic drilling, are required to form the vertical boreholes for injecting the barrier-forming chemical. The barrier would be formed by injecting chemicals into each borehole at the base of the casing while the casing is being withdrawn.

The primary advantages of the V-shaped chemical barrier are: (1) only one barrier system would be needed for each tank farm rather than one for each tank or leaking tank, (2) drilling to emplace the barrier-forming chemicals would not occur in contaminated soils, and (3) leakage would be contained and prevented from migrating to the groundwater. The straight drilling techniques employed in this technology would be more likely to achieve the hole-alignment objectives needed to ensure a continuously formed barrier than would the directional drilling techniques that would be used to emplace a box-shaped chemical barrier. The primary disadvantages are: (1) long directional drill lengths would be required with little tolerance for directional deviation, and (2) the standoff barrier would not prevent or minimize new leakage.

2.11.4 V-Shaped Freeze Wall Barrier

The V-shaped freeze wall barrier would be formed from ice instead of chemicals. The barrier would be constructed to the same drilled dimensions and with the same drilling technology used to create the V-shaped chemical barrier. If needed, drilling muds would be used to help fill the voids in highly permeable soil formations. The nondraining water contained in the drilling muds would help ensure that ice fills the soil pores.

In the freeze wall barrier design, freeze pipes would be installed in a V-shaped configuration around an entire tank farm. Each freeze pipe would include an internal pipe. Coolant would be pumped down the inside pipe and returned through the annulus. The coolant is assumed to be a salt brine cooled to -15 to -25 °C using a refrigeration system at the surface (KEH 1993). The addition of water to the soil may be required during freezing if the natural water content of the soil is insufficient to form an effective barrier.

The primary advantage of this type of barrier is the enhanced ability to detect and repair leaks and other flaws in the barrier. Flaws may be detectable by monitoring temperature and pressure within the space occupied by the barrier. Additional piping would be required to enable detection and repair of flaws. The primary disadvantages are the active nature of the barrier system and its high maintenance requirements. The chemical barriers, in contrast, are passive and require little or no maintenance. Another disadvantage of the freeze wall technology is the need for additional development of methods for adding water to highly conductive Hanford Site soils.

2.11.5 Circulating Air Barrier

A circulating air barrier would rely on evaporation of water from the soil, thereby limiting the ability of leakage to migrate through the vadose zone. The circulating air barrier would use circulation of warm dry air through the soil to remove the moisture from the soil. Leaked liquids will not readily flow through dried soil until the moisture level of the soil reaches its critical liquid saturation point (KEH 1993).

The circulating air barrier would be created by injecting warm dry air through an array of vertical boreholes drilled between tanks. The lower end of the pipe casing in each hole would be perforated or screened. Air would flow through the perforations, into the soil, and then into perforated extraction pipes. The extracted air would be treated to remove water, volatile organics, and entrained particulates and would then be reinjected.

The primary advantages of the circulating air barrier are: (1) the technology is relatively simple and (2) it would limit the spread of leakage and possibly the volume of contaminated soil. The disadvantages are: (1) contaminated water may be recovered in the extracted air dehydration system, (2) contaminated water would require treatment and disposal, and (3) the circulating air barrier, like the three standoff barriers previously discussed, would not prevent new leakage.

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3.0 SCREENING OF CURRENTLY AVAILABLE LDMM TECHNOLOGIES

There are a number of requirements for an effective LDMM system. These are provided in detail in Section 5. However, there are two primary requirements, availability and deployability, which initially establish the feasibility of the technologies. Technologies that meet these criteria are identified as currently available technologies. The following defines these primary requirements for an LDMM system:

- Availability. A technology, device, or method for LDMM must be proven and currently ready for use to be considered available. A currently available technology is one that requires little, if any, additional development, demonstration, evaluation, or implementation effort to obtain meaningful, reliable information as soon as the device or method is installed. Availability usually means off-the-shelf and ready for deployment.

- Deployability. A LDMM technology, device, or method should be placed into service with assurance that desired LDMM operational characteristics remain intact. If not, the approach is considered to be not deployable. A device that fulfills all other requirements must still be deployable to be of value. The device must be designed to withstand the conditions needed for its deployment. Materials of construction, quality of the installed instrumentation signal, and difficulty of maintainability after emplacement should also be considered when developing or selecting a deployment technology.

3.1 RESULT OF SCREENING

The technologies described in Section 2 were screened against the availability and deployability criteria to establish those that qualify as currently available technologies. Table 3-1 summarizes the results of the screening. *Mass balance* technology uses instruments that are commercially available and are currently deployed in some of the SSTs. *Detection pits* were built into the structure during construction of four SSTs (AX Tank Farm). The *detection pits* are considered available and deployable for these four SSTs but no others. *Borehole logging* is a technology that is currently used for vadose zone monitoring around the SSTs, thus it is available and deployable. *Past-practice sluicing* was previously used at the Hanford Site for retrieval of waste from SSTs. All other technologies are either in various stages of development or have not been demonstrated as deployable in or around the SSTs.

Table 3-1. Currently Available LDMM Technologies.

Technology	Available	Deployable
Leakage Detection and Monitoring		
Mass Balance	Yes	Yes
Detection Pits	Yes	Yes (four deployed)
Tracer Gas	No	Maybe
ERT	No	Maybe
Borehole Logging	Yes	Yes
TDR	Yes	Maybe
Leakage Mitigation		
Past-Practice Sluicing	Yes	Yes
Limited Sluicing	Maybe	Maybe
Robotic Sluicing	No	Maybe
Mechanical Retrieval	No	Maybe
Subsurface Barriers	Maybe	Maybe

Note: Technologies shown in italics are available and deployable.

3.2 DESCRIPTION OF BASELINE LDMM SYSTEM

All of the technologies that passed the screening, when used in conjunction, form the selected baseline LDMM system. The leakage detection component of the baseline system consists of internal liquid/waste level measurement devices (i.e., *mass balance*) and *detection pits* (where available). The leakage monitoring component consists of *borehole logging*. Operational, procedural, and administrative methods, and equipment design and availability, would be used to mitigate leakage during *past-practice sluicing*.

4.0 DESCRIPTION OF LDMM TECHNOLOGIES AND LEAKAGE ASSUMPTIONS

Leakage detection and monitoring technologies are described in Section 4.1, leakage mitigation technologies are described in Section 4.2, and assumptions made to define tank leakage to enable evaluation of the potential effectiveness of LDMM technologies are described in Section 4.3.

The descriptions of alternatives include the deployed LDMM system configuration and discussion of system operation, including the number and depth of wells placed around each SST, the frequency at which data are gathered, and assumptions made to estimate system performance.

4.1 LEAKAGE DETECTION AND MONITORING TECHNOLOGIES

Descriptions of leakage detection and monitoring technologies including: no action, mass balance, tracer gas testing, ERT (4,1 and 8,3 configurations), borehole logging, and TDR are provided in Sections 4.1.1 through 4.1.7.

A description is not provided for leak detection pits because this currently available technology is not evaluated further in this study. It is assumed that leak detection pits will be used only when the AX Tank Farm SSTs are retrieved. This technology is not deployable for any of the other SSTs.

4.1.1 No Action

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 or, in the event of a catastrophic leak, until it is obvious even without leakage detection technology that leakage has occurred. There would be no monitoring of potential leakage plumes.

The no action alternative is not considered feasible for use. It is included here as a common reference basis for comparison of the other technologies.

4.1.2 Mass Balance

The current baseline method of leak detection is mass balance using ENRAF gauges. This method would monitor the quantities of liquid into and out of the SST, and includes visual inspection of the interior of the tank for remaining waste. The mass balance system of leak detection is immediately deployable for all of the tanks. Remote cameras for inspection of the interior and measurement of liquid waste quantities would be provided by the selected

SST waste retrieval system. Stuart et al. (1996) describes the mass balance procedure as follows:

> Initial tank characterization data is necessary to define the mass of soluble and insoluble solids in the tank and receiving tanks based on the solids level, mass fraction of soluble and insoluble salts, and the porosity or liquid fraction of the solids. The mass of the liquid in both tanks must also be determined from the specific gravity of the liquid, tank level, and porosity of the solids. Once sluicing begins it is necessary to periodically pump all liquids down as low as possible in the tank being sluiced and perform an estimate of the solids content. It is currently recommended that this be done at the end of each batch sluice (approximately 16 hours). The solids are now likely to be in a more conical shape sloping towards the center, so a visual estimate is the only practical means of performing this at this time. Several observers could be used to perform this estimate to develop a statistical average (Delphi technique) to improve precision. After estimating the solids content in the tank being sluiced, liquid would then be added back to it until the level is raised above the highest point of the solids. The level, temperature, and specific gravity of the liquid is then measured in the tanks being sluiced to determine the mass present. In the receiving tank, to perform the mass balance it would be assumed that the soluble solids fraction that was transferred is now in solution and that a measurement of level, temperature, and specific gravity combined with the insoluble solids estimate would then be made to determine the total mass in the tank. Mass inputs (e.g., water additions) would also need to be closely gauged to maintain the mass balance. Based on the mass of inputs, temperature, specific gravity, mass of soluble and insoluble solids, and estimate of solids transferred the expected sum of the level of the two tanks is determined and compared to the actual sum of the level of the two tanks. If the measured level is outside of the expected (calculated) level by more than the accuracy of the method, then a leak is suspected.

For the purpose of evaluating mass balance as a leakage detection technology for waste retrieval from SSTs at the Hanford Site, the following assumptions were made.

- Mass balance methods require that the target tank be pumped of drainable liquid prior to making a visual estimate of the remaining waste. It was assumed that retrieval operations would be conducted around-the-clock, and that visual estimates can be made during scheduled stops in retrieval activities, resulting in a minimum impact to the retrieval schedule. It was assumed that visual estimates would occur daily.

- Visual estimates of remaining tank waste can be performed remotely. Camera operators would be located outside of the tank farm perimeters.

- The camera equipment and any other in-tank equipment necessary for the mass balance leak detection methods would not impede retrieval and has the capacity to remain in the tank during sluicing. It is assumed that the ENRAF gauge can be retracted into the riser during sluicing.

The mass balance leakage detection system is suitable for the detection and quantification of a leak and it is mature enough for immediate deployment; however, there are still some unknowns:

- The calculations involved and the imprecise method of estimating the remaining tank waste following a sluicing interval result in potentially large error bands. For these reasons, the minimum size of leakage that can be detected is uncertain.

- Mass balance methods would be utilized during sluicing stoppages. One leakage detection determination for each sluicing batch activity would be allowed, which is assumed to be one leak detection determination per day.

- The required in-tank equipment (i.e., cameras, thermocouple trees, and level/density instruments) may reduce the effectiveness of sluicing if not elevated to the tank dome or risers. If the equipment must be elevated during sluicing, additional costs and worker risks may be introduced beyond those assumed.

4.1.3 Tracer Gas

Tracer gas is a technology used primarily in the petroleum industry to assess the integrity of belowground and aboveground storage tanks. A suspected leaking tank is inoculated and pressurized with a suitable tracer by introducing the tracer into the tank in controlled amounts. The surrounding soils or groundwater beneath the tank are periodically sampled following inoculation and tested for the presence of the tracer. If the tracer is detected outside of the tank, a leak has occurred. The American Petroleum Institute has established procedures for the application of tracer gas tank integrity testing.

Tracers are carefully selected to satisfy several criteria: (1) the tracer must be compatible with the contents of the tank, (2) it must be suitable for the media to be sampled (i.e., it must be easily soluble for groundwater sampling or volatile for soil vapor sampling), (3) it must be detectable at very small quantities, (4) it should not have background levels previously present, and (5) it should be inert and nontoxic.

Using a tracer gas requires a soil vapor extraction system capable of inducing a slight vacuum in the soils beneath the tank and removing soil vapor for analysis. For the purpose of evaluating tracer gas as a leakage detection technology, the following assumptions are made.

- A suitable tracer or suite of tracers can be identified.
- An optimal wellfield configuration can be deployed within the tank farms.
- Deployment is feasible/possible.

The ideal tracer would enter into solution within the tank, and if leaked to the soil, would volatilize and change to a gaseous phase for extraction. A tracer that is highly volatile might reside in the tank head space and never enter the tank liquids in significant concentrations, resulting in the possibility of undetected leaks. Conversely, a tracer that is preferentially soluble might migrate from the tank via a leak, yet remain in the soil moisture and resist being stripped out by the soil vapor extraction system.

A number of wellfield configurations for leak detection via tracer gas testing are possible. The optimal configuration is a center extraction configuration, shown in Figure 4-1. This configuration would employ a single extraction interval centered beneath the base of the tank. Inducing a vacuum at this point would cause soil vapor flow from the surface down the walls and across the bottom of the tank to the extraction interval. An advantage to this configuration is that the tank would become enveloped in the soil gas flow and there is a relatively high degree of confidence that any tracer leaked into the soil would be captured and detected. The primary drawback to the center extraction configuration is that the extraction interval must be located beneath the tank, requiring the installation of a horizontal pipe below the base of the tank. This has been accomplished previously via a caisson, but is a significant installation challenge. The effort can be reduced somewhat by using a single caisson to install horizontal pipes under multiple tanks although the cost for this may be high.

A second configuration is a perimeter extraction configuration. Two possible implementations of this configuration are shown in Figures 4-2 and 4-3. The advantage of a perimeter extraction configuration is that the extraction wells are standard vertical boreholes. Disadvantages include the necessity of a surface cap to prevent air flow short circuiting and a somewhat lesser degree of confidence in tracer capture.

In general, tracer gas leak detection is suitable for qualitative detection only, and is not able to provide quantification or monitoring data. While tracer gas leak detection is potentially effective, there are issues of installation and tracer identification that would require further development.

4.1.4 Electrical Resistance Tomography (4,1 Configuration)

The ERT technology would employ new technology to map the resistivity around and below a tank over time. When leakage of tank liquids occurred, the electrical resistivity of the soils affected by the leak would measurably change, and electrical resistivity tomographs could be prepared to map the resistivity changes (Ramirez et al. 1995).

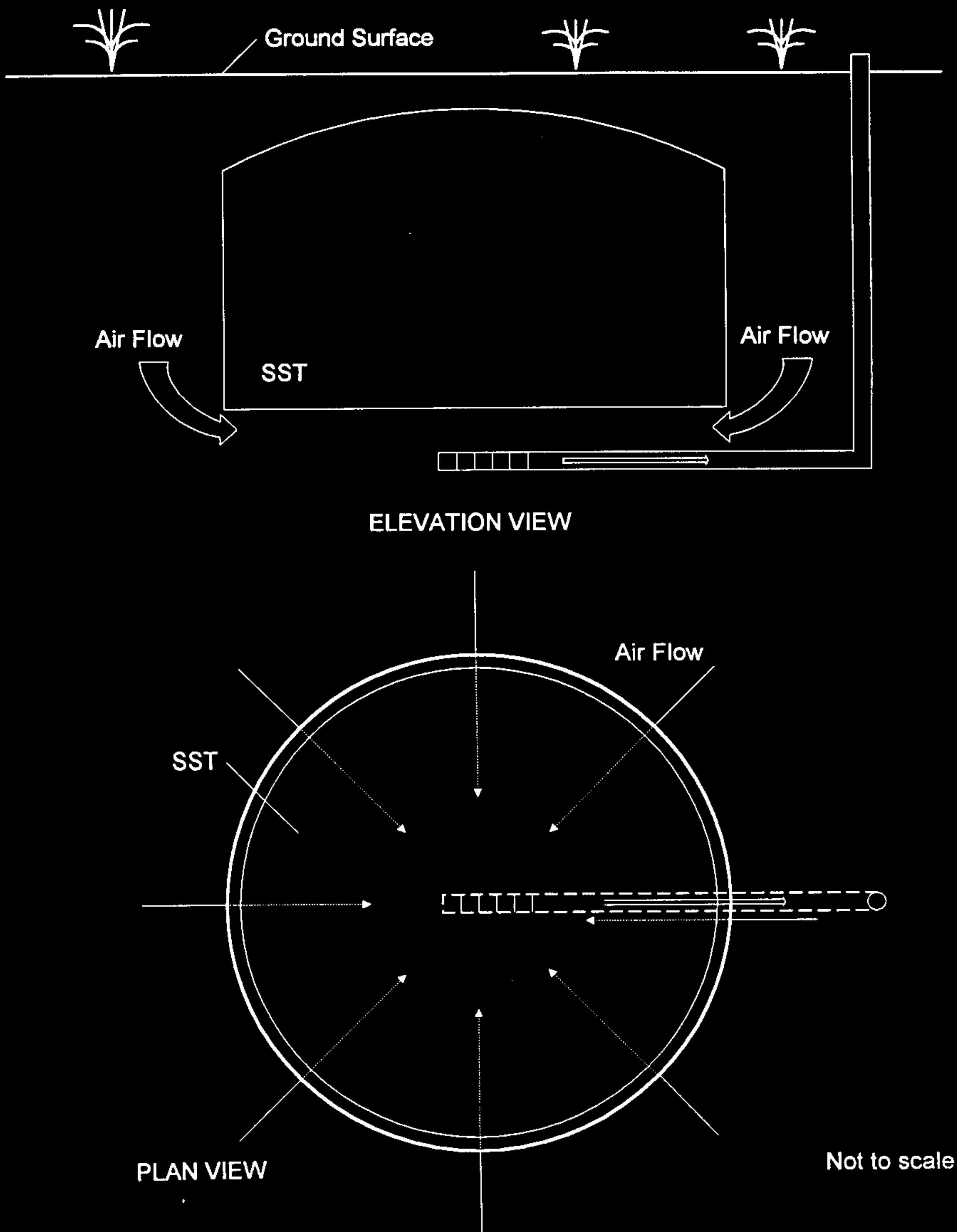

Figure 4-1. Tracer Gas Center Extraction.

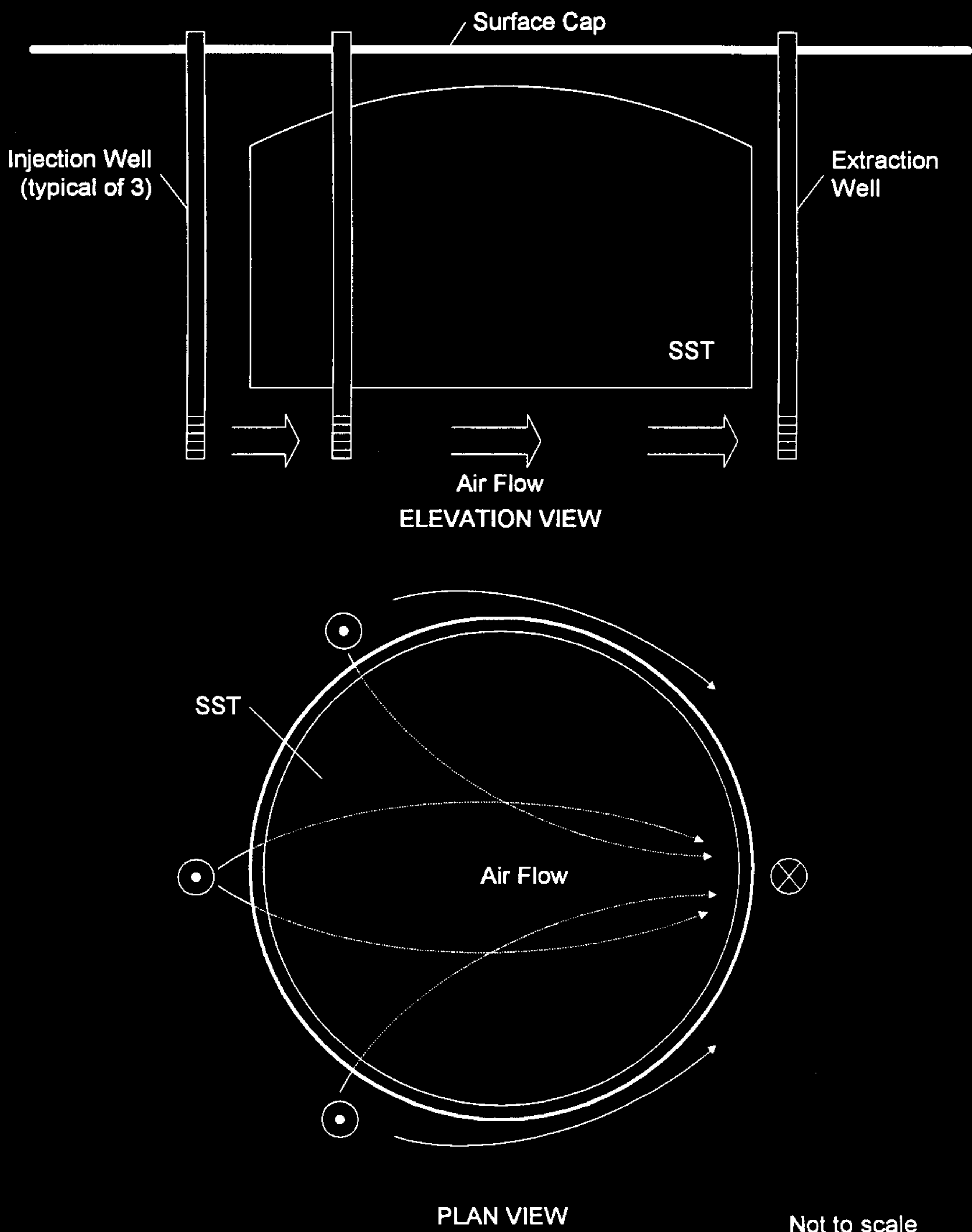

Figure 4-2. Tracer Gas Perimeter Extraction - Configuration 1.

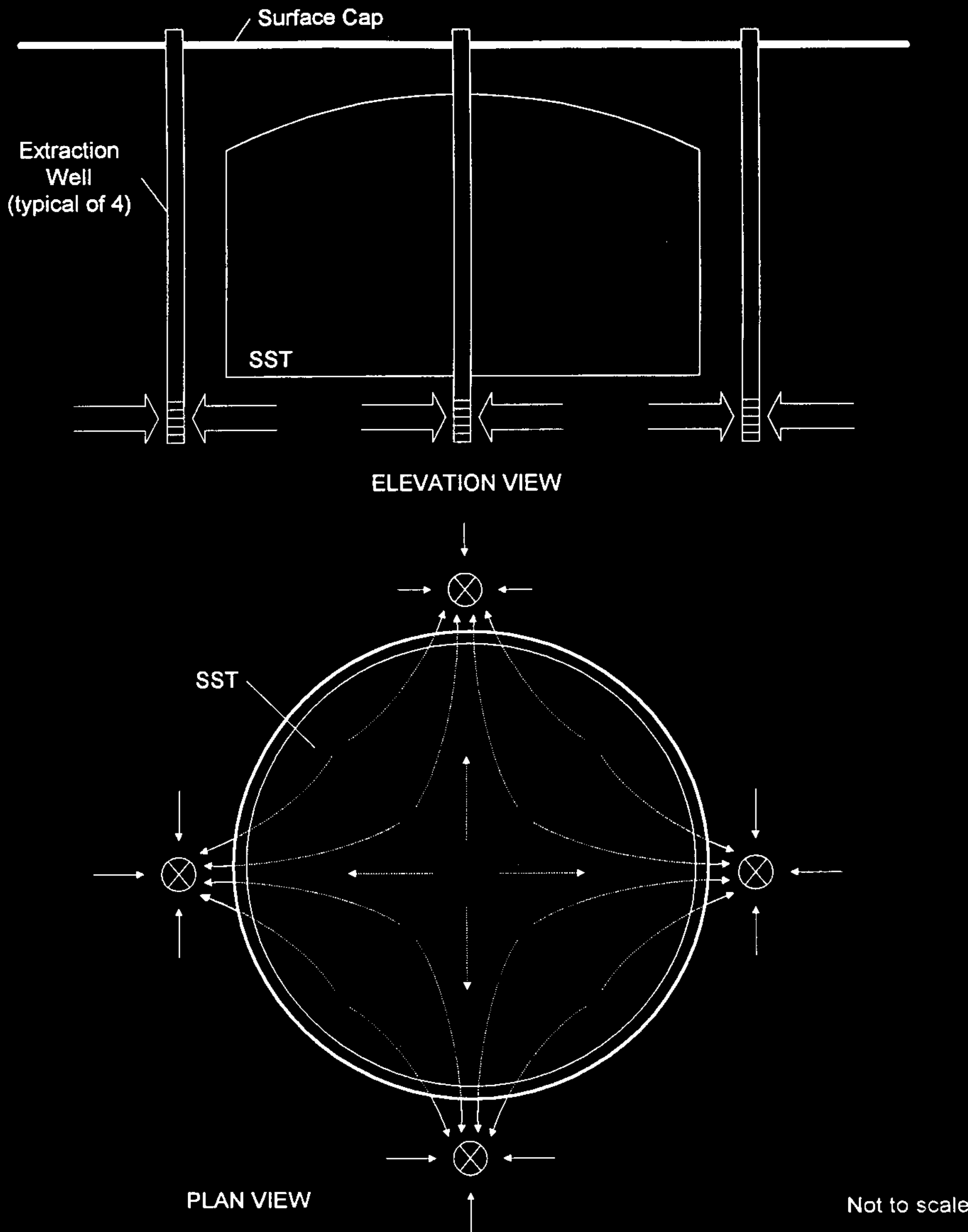

Figure 4-3. Tracer Gas Perimeter Extraction - Configuration 2.

An ERT survey would be performed using a number of vertical electrode arrays (VEAs), each with multiple, equally spread electrodes, deployed around the tank to an optimal depth. During a leak detection determination, the electrical resistance between each pair of probes would be measured. The data would be processed using electrical current data inversion algorithms. In the developmental stage, processing the data to form a two-dimensional tomograph currently takes about 20 minutes to complete on a Sun™ workstation (Lewis et al. 1995).

The 4,1 ERT configuration employs four ERT VEAs with one electrode per VEA, as shown in Figure 4-4. The probes would be located 4.6 m (15 ft) below the base of the tank, or about 15 m (50 ft) to 21 m (70 ft) below ground surface (bgs), depending on the SST size. Data acquisition would be performed remotely and no personnel within the tank farm would be required for a leak detection determination.

In this configuration, there are six distinct probe pairs (Figure 4-4); therefore, six measurements can be taken. The tomograph resulting from these measurements would map a two-dimensional horizontal slice at the probe depth covering the entire base of the tank. Since relatively few probes would be used, there would be gaps in the detection coverage beneath the tank, which will be reflected in the detection limit and data quality.

For the purpose of evaluating ERT in the 4,1 configuration as a leakage detection technology, the following assumptions were made.

- The optimum minimum depth of the probe is 4.6 m (15 ft) below the base of the tank. This is based on the experimental results described in Ramirez et al. (1995).
- Data acquisition can be performed remotely and can be automated.
- Deployment of ERT VEAs around SSTs to required depths is currently possible. Ongoing research/testing is evaluating the use of cone penetrometers (CPTs). A solid electrical interface with the soil would be required.
- An ERT probe located between two tanks can potentially support leak detection for both tanks. Installing probes in a grid that covers multiple tanks could reduce per tank costs.
- The ERT technology has been shown effective with symmetric or asymmetric probe locations. Symmetric locations are assumed but this would likely not be the case during operations due to obstacles within the tank farms. This would accommodate logistical VEA positioning problems during deployment.
- Multiple leak detection determinations would be processed in an eight-hour day, so a processing workstation can support more than one tank at a time.

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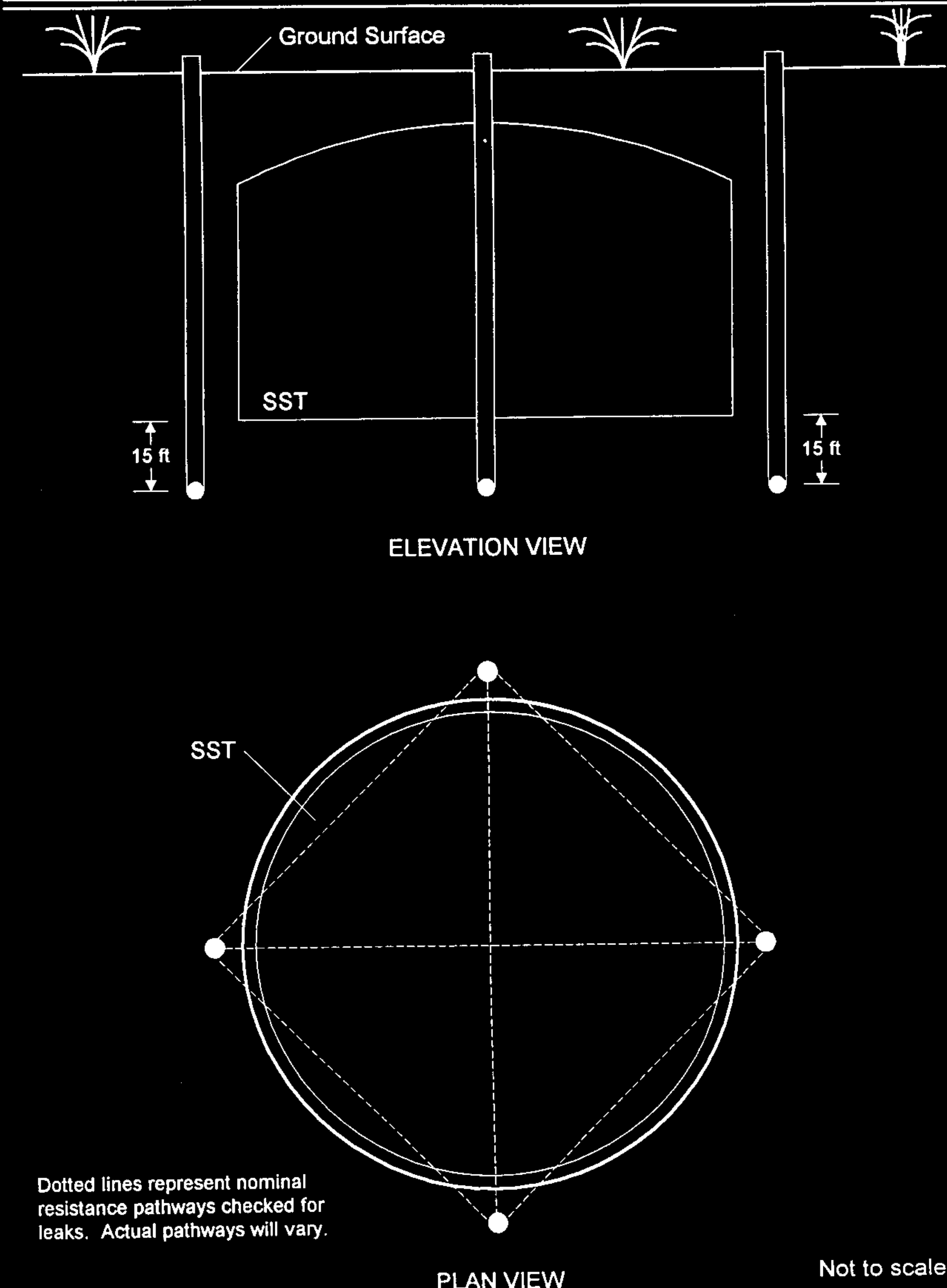

Figure 4-4. 4,1 ERT Typical Configuration.

The 4,1 ERT configuration may prove suitable for leakage detection; however, successful deployment will require further development. While it is assumed that tomographs can be generated from data acquired from an asymmetric probe grid, this has not been demonstrated. The presence of the tank is known to affect the resulting tomographs, limiting the probes to being located no closer than 3 m (15 ft) below the base of the tank. Development efforts could possibly reduce this distance, thereby reducing the detection limit of the technology.

4.1.5 Electrical Resistance Tomography (8,3 Configuration)

The 8,3 configuration of ERT would employ the same technology and equipment as the 4,1 ERT configuration (Section 4.1.4). As such, all of the same assumptions and qualifications apply.

The 8,3 ERT configuration, shown in Figure 4-5 would employ eight ERT VEAs with three electrical resistance electrodes per VEA, for a total of 24 probes. The probes would be located at depths of 3 m (10 ft), 4.5 m (15 ft), and 6 m (20 ft) below the base of the tank. There are potentially a total of 168 probe pairs, not including pairs with both probes located in the same CPT well. This creates a larger processing problem. In a pilot test that employed 16 boreholes with eight probes each (nearly 5,000 probe pairs), the processing time for a three-dimensional tomograph was six days (Ramirez et al. 1995). It is expected that 168 probe pairs can be processed in about four hours. Processing time is expected to decrease with further development of the algorithms and improvements in computing capability.

Advantages of using the 8,3 ERT configuration over the 4,1 configuration include improved coverage beneath the tank provided by the increased number of electrodes/VEAs, and the ability to create three-dimensional mappings. The 8,3 ERT configuration is suitable for quantitative detection and monitoring of tank leaks.

4.1.6 Borehole Logging

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 are displayed as a function of depth.

There are several types of borehole logging methods. While they differ in the manner in which they obtain information, each is limited to interrogating soils immediately adjacent (within a few feet) of the borehole as shown in Figure 4-6 (Lewis et al. 1995).

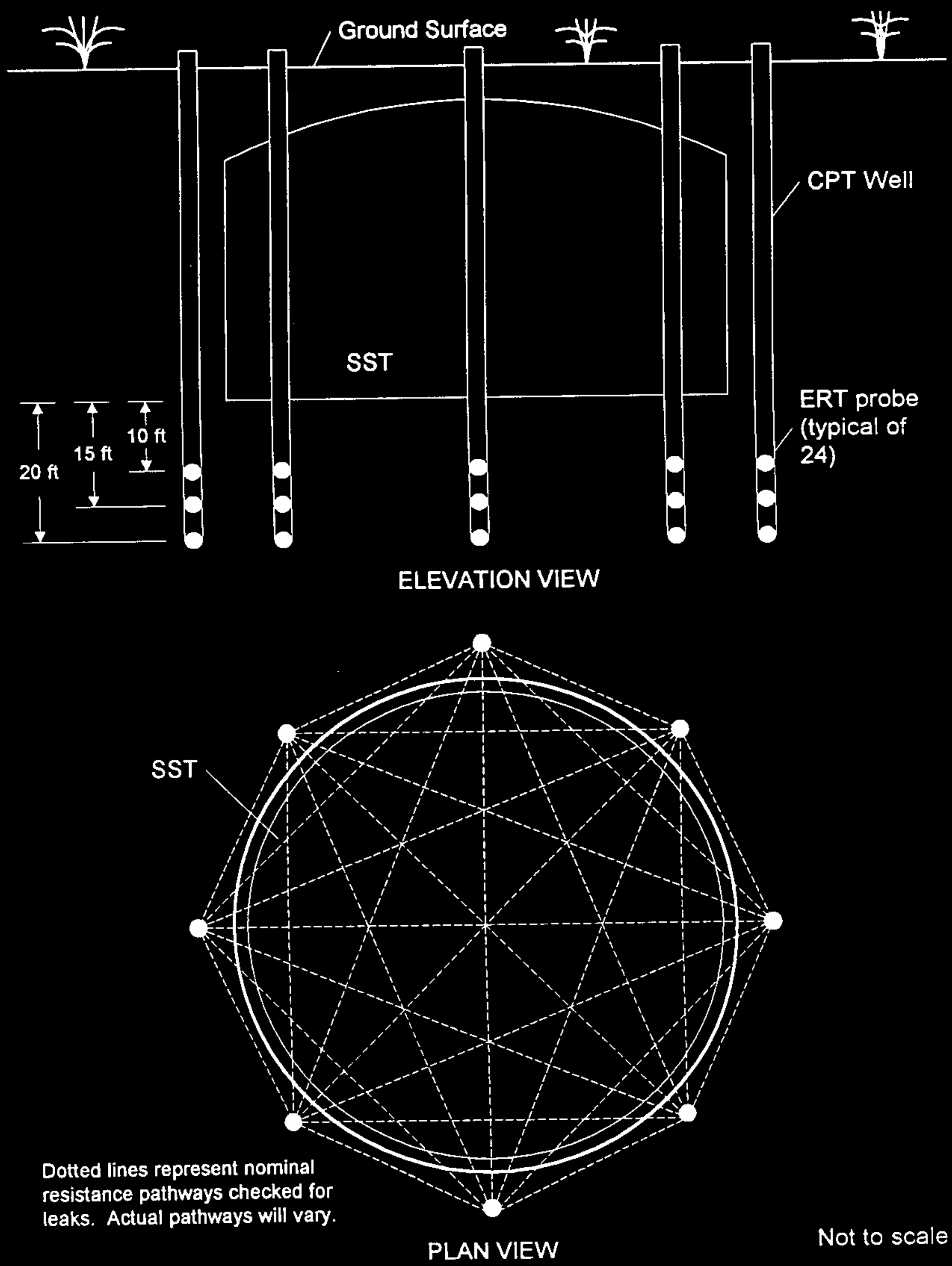

Figure 4-5. 8,3 ERT Typical Configuration.

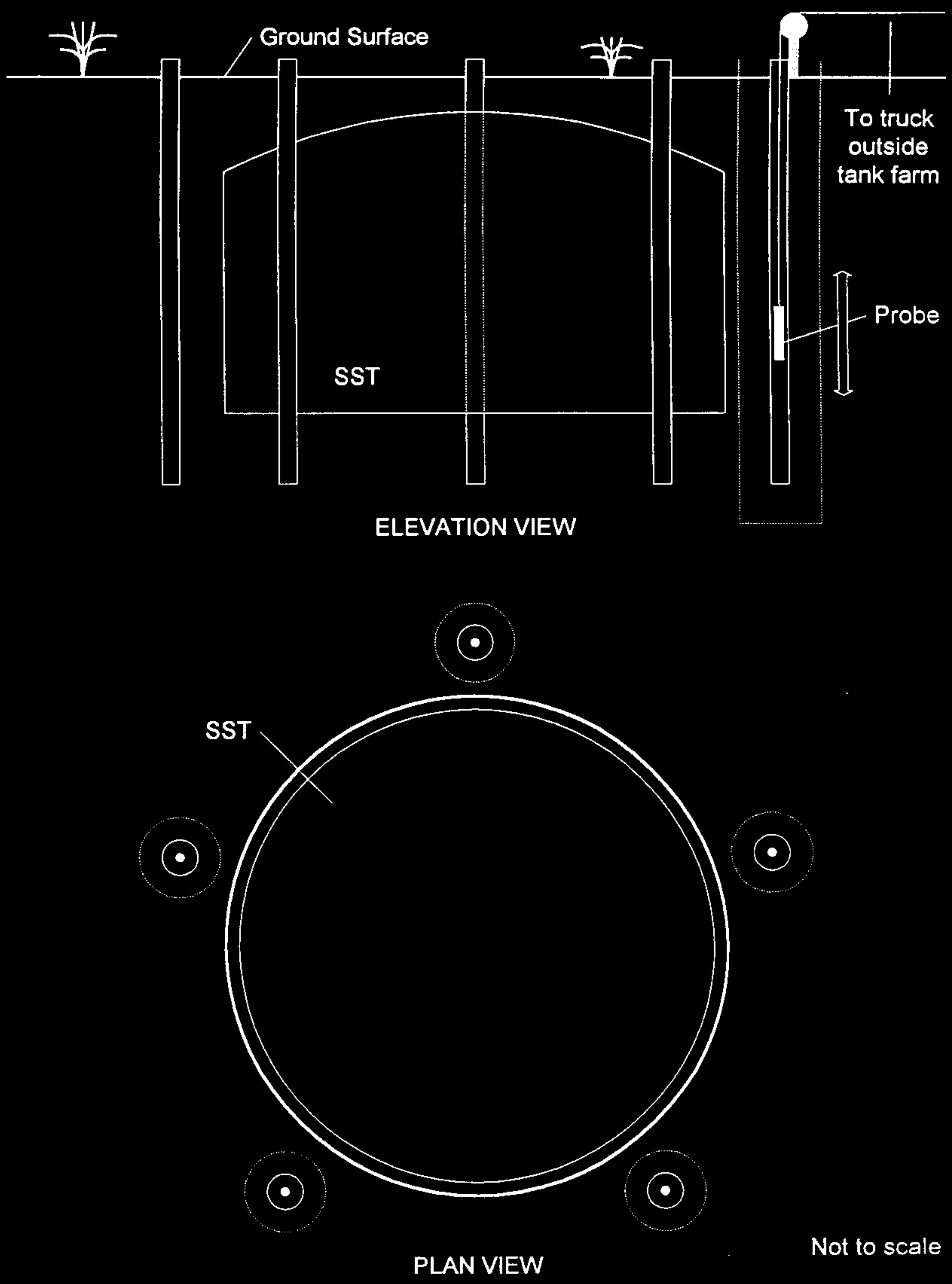

Figure 4-6. Borehole Logging.

For the purpose of evaluating borehole logging as a leakage plume monitoring technology, the following assumptions are made.

- Existing boreholes in the tank farms can be used. There are an average of five boreholes per tank throughout the tank farm system. The average distance from the edge of a tank to a borehole is 3 m (10 ft).

- Logging cables can be of sufficient length to allow the logging truck to remain outside of the tank farm; however, in-farm labor would be required to deploy the instrumentation.

Borehole logging is typically implemented at the Hanford Site via an independent vendor. The vendor provides the measuring device, logging truck, and technical support. It takes about three hours to set up, log, and shutdown a single well (Lewis et al. 1995).

Borehole logging is suitable for leakage plume monitoring, and has been utilized for this purpose in the tank farms. It is a mature technology that can be immediately deployed and is currently in use.

4.1.7 Time Domain Reflectometry

For use as SST leakage monitors, TDR would have to be deployed at the Hanford Site by drilling or in CPTs. Each probe must be placed into the soil at its predetermined detection location with a strong soil interface. Probes have been pushed into Hanford Site soils to depths of approximately 6 ft, and it is unlikely that a probe could be pushed to the required depth of 12 to 15 m (40 to 50 ft) bgs for TDR. The CPTs could potentially be utilized to form a borehole within 6 ft of the desired location and the TDR probe could be pushed beyond the base of the CPT well into position (Lewis et al. 1995).

For the purpose of evaluating TDR as a leakage monitoring technology, the following assumptions were made.

- CPTs would be a viable, feasible means of deployment

- TDR would deploy five probes evenly spaced around the perimeter of the tank (Figure 4-7).

- Data acquisition and processing would be performed remotely. After system installation, there would be no need for labor within the tank farms, except for possible system maintenance and repair.

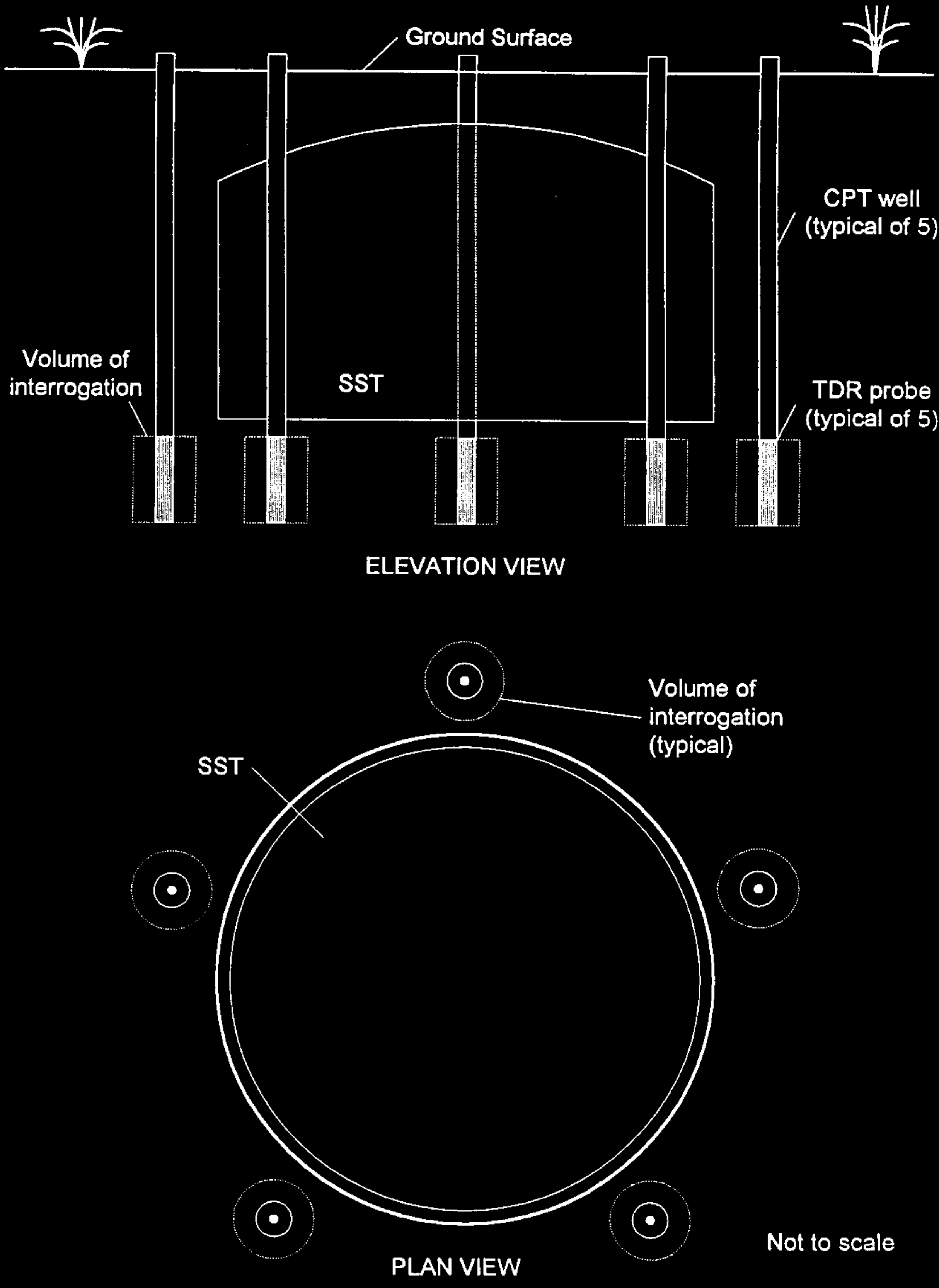

Figure 4-7. Five Point TDR.

- Each TDR probe would require its own CPT well for installation. In the event that multiple probes are desired in a vertical column, it is recommended that all probes not be placed with a single CPT well because the probes positioned within the CPT well would have a poor interface to the soil.

The TDR technology has been demonstrated and tested under limited conditions at the Hanford Site and appears suitable for leakage monitoring. Implementation of the TDR technology would require deployment of the subsurface probes and a data acquisition system. While the deployment of the probes was assumed to be symmetrical around the tank, as shown in Figure 4-7, this would likely be difficult to achieve. Surface and underground piping or instrumentation would limit the areas in which a CPT well and TDR probe could be deployed. Once installed, the TDR probes would continuously log data for remote processing. Leakage monitoring determinations could be made virtually as often as desired, with very little processing delay.

4.2 LEAKAGE MITIGATION TECHNOLOGIES

This section provides detailed descriptions of leakage mitigation technologies.

4.2.1 Past-Practice Sluicing

As identified in Section 2, past-practice sluicing was conducted during two waste retrieval campaigns. The first campaign, conducted from 1952 to 1957, was used as a part of a system to recover uranium from the waste tanks; the second occurred between 1962 to 1978 for recovery of ^{90}Sr. The retrieval techniques utilized sluicing and slurry pumping. In general the technique was successful, but was plagued with equipment failures.

Several technical enhancements are planned to optimize the effectiveness of past-practice sluicing. The optimized system may remove the waste from the tank faster and more reliably than the old system, resulting in lower leakage. Optimized past-practice sluicing will be the baseline technology for retrieval. The following was assumed for the optimized technology:

- Technological improvements
  - Advanced nozzle designs
  - Improved pumping systems
  - Improved HVAC systems
- Enhanced sluicer designs
- Supernatant recirculation.

The optimized past-practice sluicing technology is both available and deployable. A demonstration of this technology has been scheduled for a Hanford Site SST.

4.2.2 Limited Sluicing

Although limited sluicing is not considered currently available, it has potential application in those tanks of suspect integrity and with higher percentages of residual saltcake. The advantage of limited sluicing is that, to the extent possible, existing sludge and saltcake are left on the portions of the tank most vulnerable to leaks during most of the waste retrieval operation.

The following description of the limited sluicing retrieval sequence is taken from Stuart et. al. (1996).

First, a compatible liquid is added to the tank to establish a consistent waste level from which to calculate the tank waste volume. This creates a situation in which a very accurate waste volume baseline is established and very small changes in volume can be detected.

Next, waste is removed near the center of the tank where the retrieval pump is located and a sump to provide suction head for the pump can be established without the sluicing liquid coming in contact with the tank walls. Waste removal continues by limited sluicing (i.e., close control of the sluicing nozzle location) and maintenance of a restricted zone within 1 to 2 ft of the tank wall, bottom, and knuckle region. The actual thickness of this zone will be a function of the stability of the waste. A minimal liquid level should be maintained (i.e., only enough to meet NPSH required) to further minimize the potential for a leak and the amount that could leak.

Once all waste outside of the restricted zone is removed, the next phase is to remove all waste along the wall above the knuckle region. It will be possible at this point to maintain the liquid level well below the working point so that only a minimal amount of leakage could occur if a liner breech is located. Again, limited sluicing is used and a minimal liquid level is maintained.

Once all waste from the wall above the knuckle region is removed, the next phase is to remove all waste along the bottom of the tank. This is a region where the probability of a leak is somewhat lower. Waste should be removed from the center of the tank outward while utilizing limited sluicing and maintaining a minimal liquid level.

Once all waste from the tank bottom has been removed, the last phase is to remove all remaining waste from the knuckle region. As always, limited sluicing while maintaining a minimal liquid level should be used.

4.2.3 Robotic Sluicing

The robotic sluicing technology is not currently available for deployment. The technology is under development, but has not been tested in an actual Hanford Site SST.

As shown in Figure 4-8 the system is a robotic-armed sluicing and retrieval machine. An attachment to the end of the robotic arm, called an end effector, would use high-pressure water jets for dislodging the waste. After the waste (sludge) is dislodged, the slurried mixture would be immediately vacuumed through a hose to an air separation system. Following separation the waste would proceed to a processing system.

The robotic arm would be suspended from a bridge-mounted confinement structure. The bridge-mounted confinement structure would be fabricated from I-beams bolted together, and stand 31.1 m (102 ft) long, 10.4 m (34 ft) wide, and 5.2 m (17 ft) high. The arm would position the high-pressure jets that dislodge the waste with a reach of 18.3 m (60 ft) deep and 5.2 m (17 ft) laterally. The jets would be contained within a shroud connected to an air conveyance hose. The air- and water-entrained solids vacuumed through the air conveyance hose would be sent to an air conveyance module.

The air conveyance module would be housed within a composite concrete and steel building located on a bridge-mounted confinement structure. It would be connected to the SST via the air conveyance hose. Air, waste fluid, solid waste, and debris (of acceptable size) would flow through the hose to the air conveyance module. The air stream would pass through a cyclone where the heavier waste particles would be separated and routed to an accumulation tank. The remaining air stream would be stripped of remaining moisture, heated, and then largely recycled through the air conveyance system. The robotic sluicing system would include other systems to support the primary retrieval components, including maintenance and decontamination capability, air filtration, and circulation.

The high-pressure sluicing system should be effective in cutting through hardened sludge heels, but may also cut through corroded tank walls, which may cause new leaks (Treat et al. 1995).

4.2.4 Mechanical Retrieval

The mechanical retrieval technology is currently not available. Mechanical retrieval would use a scoop-like end effector affixed to the end of the robotic arm for waste retrieval (Figure 4-9). The end effector would be capable of mechanically excavating the solid waste in the tank. A jack-hammer 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 removed from the SST for further processing.

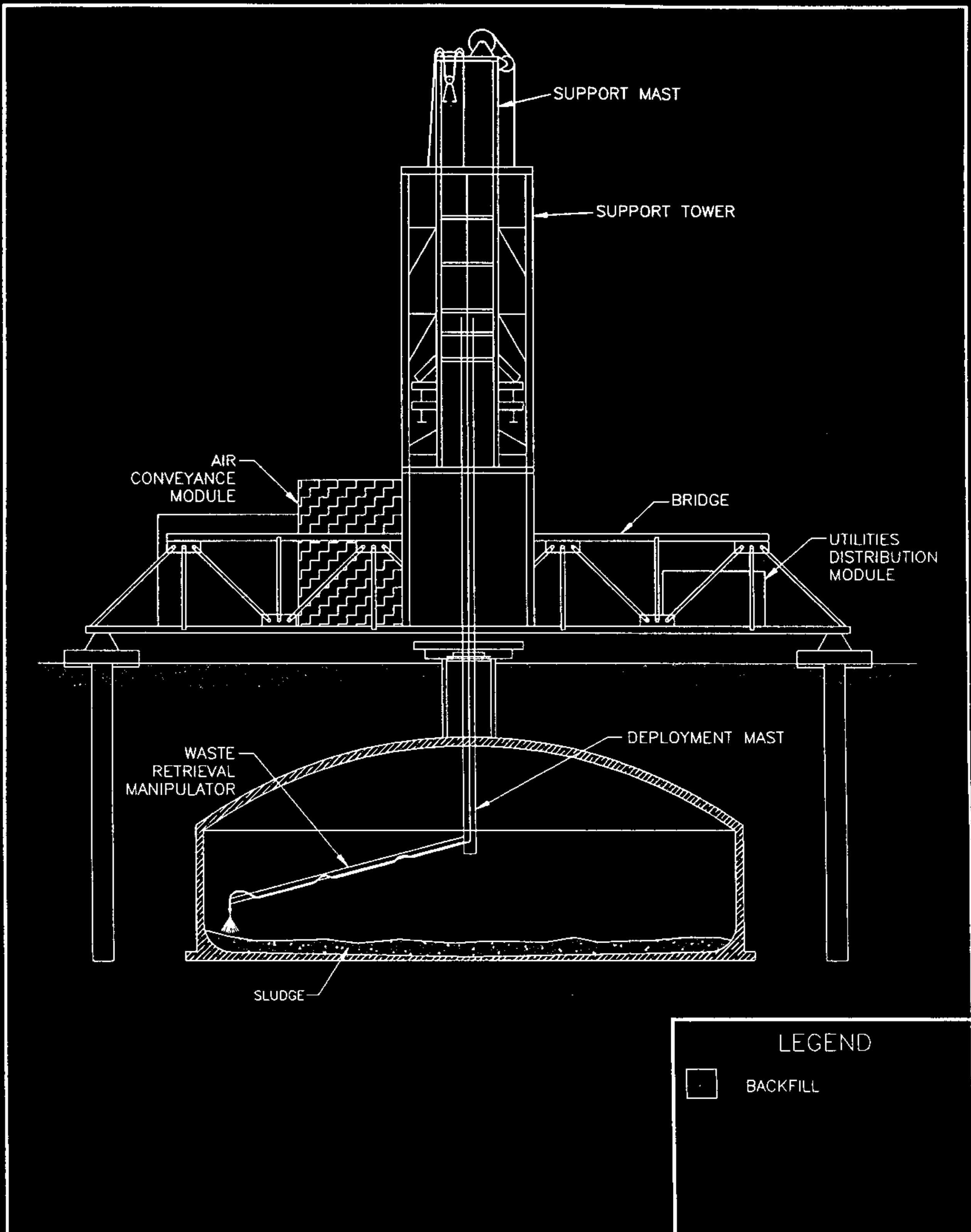

Figure 4-8. Robotic Sluicing.

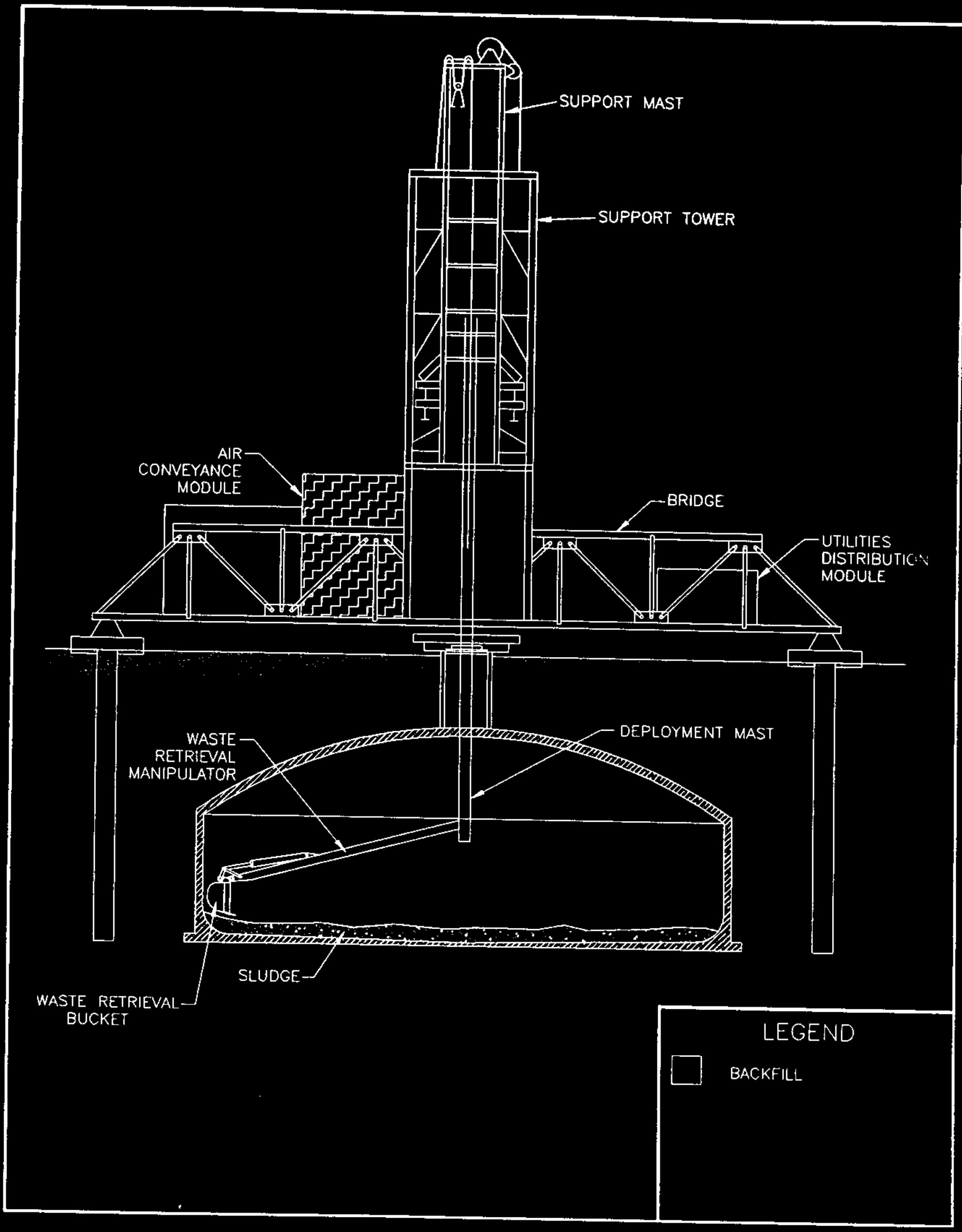

Figure 4-9. Mechanical Retrieval.

The robotic arm would be suspended from a bridge-mounted confinement structure above the SST. It would be similar to the robotic arm used in robotic sluicing. The structure would include a deployment mast for mounting and aligning the robotic arm in the SST. The robotic arm would be deployable to a depth of 18.3 m (60 ft), its horizontal reach would be 5.2 m (17 ft), and it would have the capability of lifting 3 tons. It would be equipped with six split buckets, with two shovels each to collect the waste. The arm would deliver the waste to an in-tank transfer system that would consist of a bucket on a separate trolley that could be maneuvered independently of the robotic arm.

4.2.5 Subsurface Barriers

A range of subsurface barrier technologies are potentially available to mitigate leakage from SSTs. Those deemed to be sufficiently well-developed and potentially feasible for the intended application are presented in the following sections.

4.2.5.1 Close-Coupled Chemical Barrier. Chemicals used to create the close-coupled barrier would be injected through vertical and horizontal pipes jacked or drilled into the soil (Figure 4-10). The chemicals would cause the injected fluid to solidify, thus forming a barrier. Mudless drilling methods would be required to prevent plugging of soil pores, a condition that would interfere with subsequent chemical injections. It is assumed that the horizontal pipes would be installed from inside vertical 4.6-m (15-ft) diameter caissons, which would be installed in the open areas between tanks. The horizontal pipes could also be installed using coffered trenches. The caissons, if used, would be constructed from sections of culvert pipe that would be lowered in 3.1-m (10-ft) sections into a progressively deeper hole formed by a bucket excavator. Similar caissons have been installed in the A and SX Tank Farms (Raymond 1966). The annular space between the culvert pipe and soil would require grouting to provide structural stability for horizontal pipe jacking. The horizontal pipes could be used to convey flushing solution to the soil.

The horizontal injection pipes would be installed in two separate planes beneath the tanks (Figure 4-11). The horizontal pipes would be perforated to allow the barrier-forming chemical to be injected into the soil. Chemicals would be injected through the lower array of pipes first. The injected chemicals would be designed to penetrate a radial distance of about 0.75 to 1.5 m (2.5 to 5.0 ft) and begin to gel in about two hours. The resulting barrier columns would be designed to overlap, thereby forming a barrier plane. Injection through the upper array of pipes would occur several days later, when the lower barrier plane had fully gelled. Chemicals would be injected through the upper array of pipes under slightly higher pressures than through the lower array to promote full penetration of soil in contact with the tank's structural concrete.

A similar approach would be used at the tank walls. Injection pipes would be jacked or drilled vertically from the surface to the base of the tank footings. Chemicals would be injected through the end of the pipe at this level to tie into the barrier emplaced beneath the tank. Injections would then progressively be made by working upward from the base of the

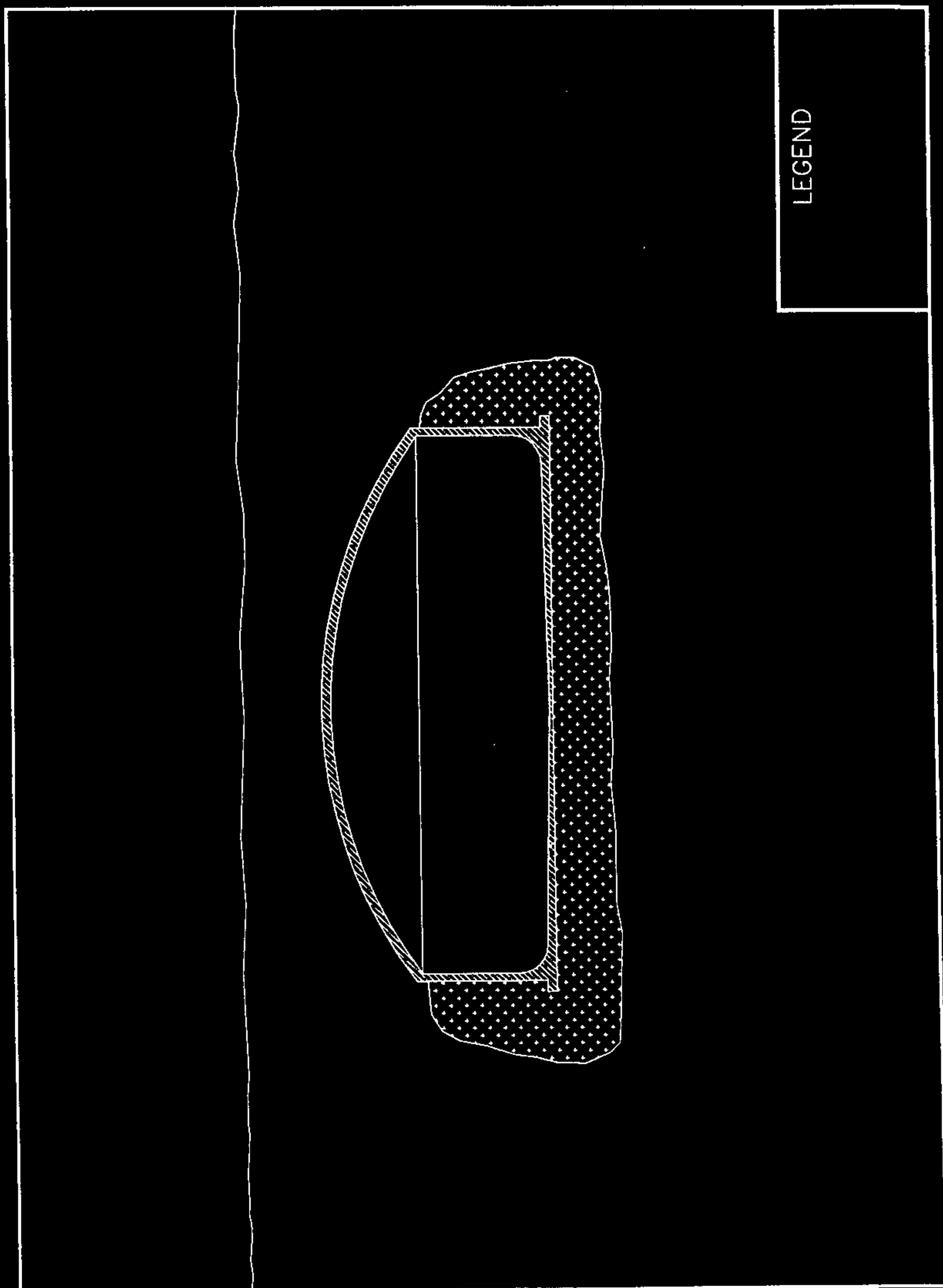

Figure 4-10. Close-Coupled Chemical Barrier.

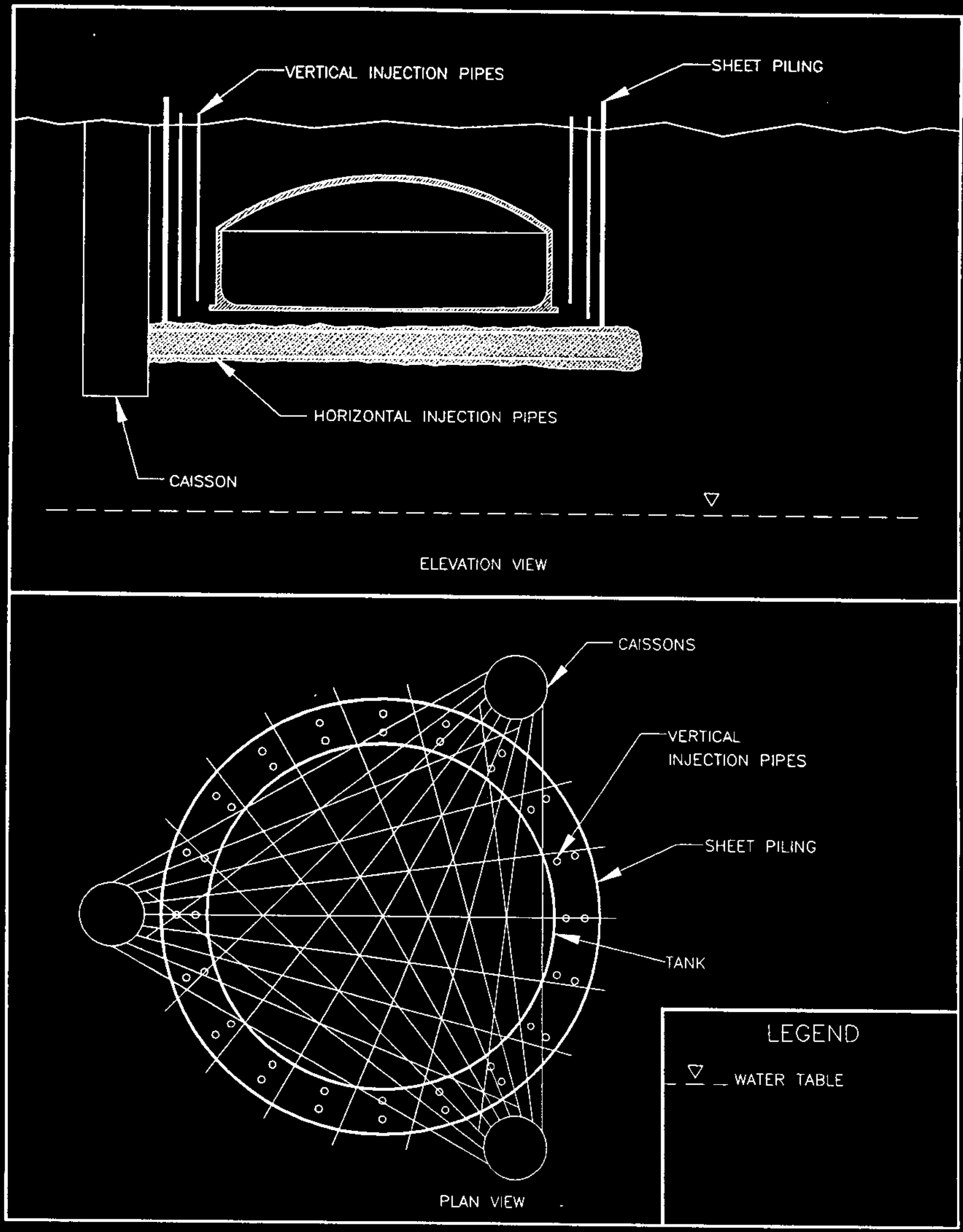

Figure 4-11. Chemical Injection Piping for Close-Coupled Barrier.

tank wall until a sealed, close-coupled barrier about 3 m (10 ft) thick is created around the tank. This technology is not currently available for deployment.

4.2.5.2 Box-Shaped Chemical Barrier. The function of the box-shaped chemical barrier would be to create a low-permeability basin beneath the level of existing soil contamination (Figure 4-12). The base of this standoff barrier would slope slightly to promote runoff to a low point for collection. Without the slope, liquid waste would collect in subsurface depressions on the surface of the barrier. The resulting ponds of waste could not readily be detected. The potentially high number of ponds would complicate removal of collected liquid waste.

The box-shaped chemical barrier would be created using both vertical and directional drilling techniques. The use of directional drilling avoids the need to excavate soil to a depth of 30.5 m (100 ft) or more in order to provide access for horizontal drilling beneath existing leak plumes. Directional drilling must be perfected for Hanford Site conditions if parallel horizontal boreholes are to be constructed beneath the Hanford Site tank farms (KEH 1993). This type of drilling would begin outside the boundary of the tank farm, with the initial drill angle at 45° to 70° from vertical. As drilling progresses, the borehole would be gradually curved until the desired slope of the barrier floor is achieved. Mudless drilling methods must be used to prevent plugging of the soil pores with fine particulates. Soil pores that are plugged would prevent flow of barrier-forming chemicals into the soil.

Each borehole would be cased with an open-ended pipe. The barrier-forming chemicals would be injected through the end of the pipe as it is withdrawn from the hole. Alternatively, the chemicals could be delivered through sleeve-port piping. A cylindrical barrier section, centered around each borehole, would be created by each of these methods, assuming the barrier-forming chemicals flowed evenly into the ground. The presence of lenses, clastic dikes, and other soil heterogeneities would cause uneven flow. The boreholes would be sufficiently close to ensure that the cylinders would overlap and form a continuous barrier floor. The boreholes were assumed to be spaced 3.1 m (10 ft) apart, a distance that would result in an average barrier thickness of 3.4 m (11 ft) and a minimum thickness of 1.8 m (6 ft) under a set of hypothetical Hanford Site soil conditions (KEH 1993). Actual Hanford Site soils are heterogeneous and closer spacing of boreholes may be required if zones of soils with low permeabilities are present as expected in some tank farms. Low permeability would limit the penetration distance of chemicals in the soil.

After the horizontal member of the barrier is formed, vertical boreholes would be drilled and cased to intersect the horizontal member. The vertical casings would be withdrawn as injection of the chemical proceeds. The resultant vertical members of the barriers are assumed to adequately seal to the horizontal member, thus creating a catchment basin for tank leaks and/or for flush water if soil flushing is used. This technology is not currently deployable.

4.2.5.3 V-Shaped Chemical Barrier. The V-shaped chemical barrier would be installed in a standoff configuration as shown in Figure 4-13. The relatively steep slope of the barrier

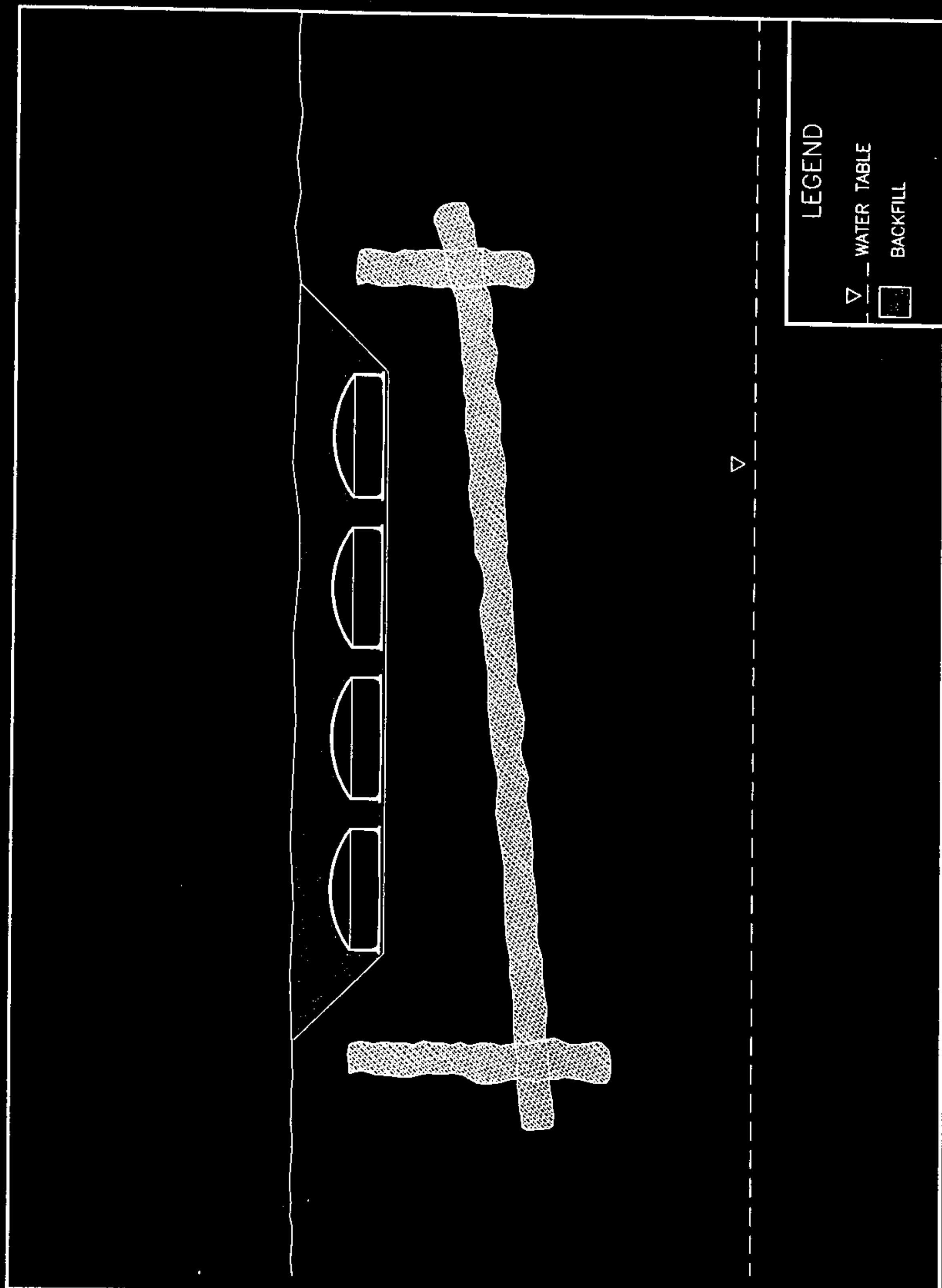

Figure 4-12. Box-Shaped Chemical Barrier.

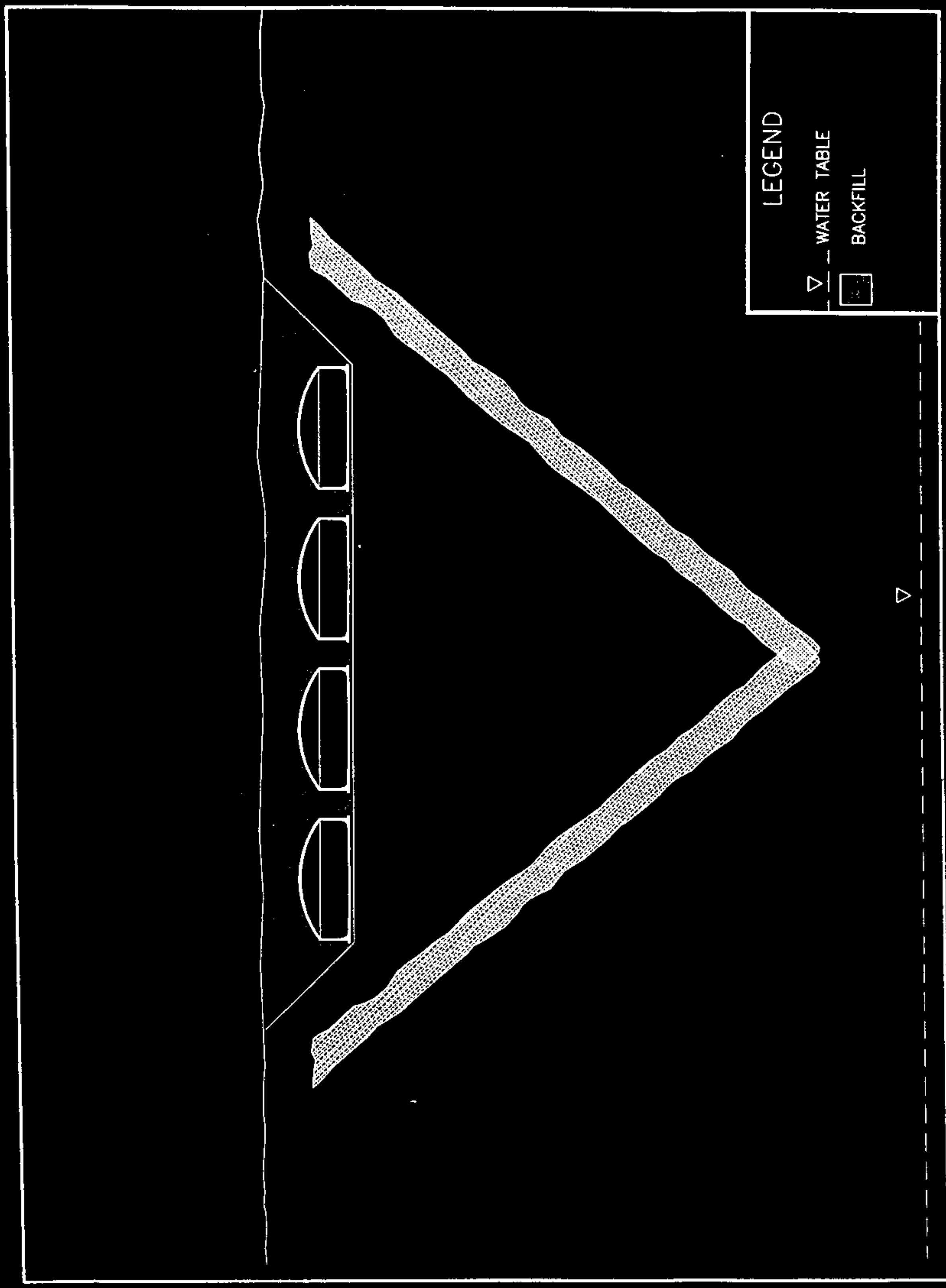

Figure 4-13. V-Shaped Barrier.

would promote subsurface runoff of leaked liquid waste or flush water to the base of the barrier where it could be removed by pumping. The angled boreholes required to form the "V" would be created by slant drilling, a technology that has been demonstrated at the Hanford Site. The ends of the barrier not shown in Figure 4-13 would be vertical. Vertical drilling techniques that do not require drilling muds, such as sonic drilling, are required to form the vertical boreholes for injecting the barrier-forming chemical. The barrier would be formed by injecting chemicals in each borehole at the base of the casing while the casing is being withdrawn. This technology is not currently deployable.

4.2.5.4 V-Shaped Freeze Wall Barrier. The V-shaped freeze wall barrier would be formed from ice instead of chemicals. The barrier would be constructed to the same drilled dimensions and with the same drilling technology used to create the V-shaped chemical barrier. If needed, drilling muds would be used to help fill the voids in highly permeable soil formations. The nondraining water contained in the drilling muds would help ensure that ice fills the soil pores.

In the freeze wall barrier design, freeze pipes would be installed in a V-shaped configuration around and beneath the tanks. Each freeze pipe would include an internal pipe. Coolant would be pumped down the inside pipe and returned through the annulus. The coolant is assumed to be a salt brine cooled to -15 to -25 °C using a refrigeration system at the surface (KEH 1993). The addition of water to the soil may be required during freezing if the natural water content of the soil is insufficient to form an effective barrier. As with the previous technologies, the V-shaped freeze wall barrier is not currently available nor deployable for this application.

4.2.5.5 Circulating Air Barrier. A circulating air barrier would rely on evaporation of water from the soil, thereby limiting the ability of a leak to migrate through the vadose zone. The circulating air barrier would use circulation of warm dry air through the soil to remove the moisture from the soil (Figure 4-14). Leaked liquids will not readily flow through dried soil until the moisture level of the soil reaches its critical liquid saturation point (KEH 1993). The critical saturation point depends on the physical properties of the soil. This point may exceed 30% by volume water for fine-grained soils and may be less than 2% by volume water for gravels. The critical saturation point for Hanford Site soils ranges from about 5% to 25% due to the heterogenous nature of the soils. Thus, the dried soil will vary in capacity to absorb leaked waste.

The flow of dry air through the soil while a leak is occurring would also dehydrate the leaked waste by evaporation of water. As evaporation proceeds, the solubility limits of dissolved constituents would eventually be exceeded and precipitates would form in the soil pores. The precipitates may be effective in blocking additional flow.

The circulating air barrier would be created by injecting warm dry air through an array of vertical boreholes drilled between tanks. The lower end of the pipe casing in each hole would be perforated or screened. Air would flow through the perforations, into the

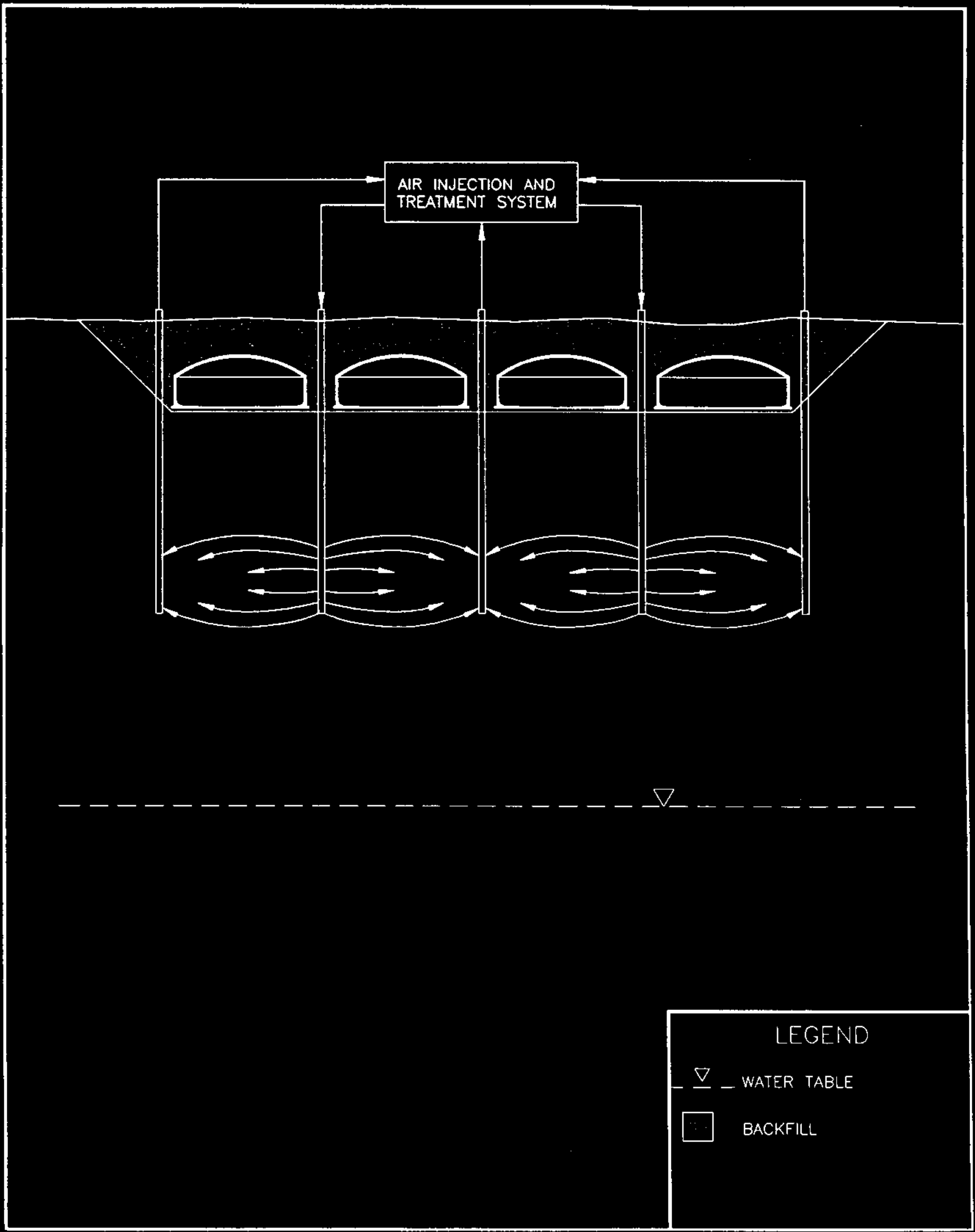

Figure 4-14. Circulating Air Barrier.

soil, and then into perforated extraction pipes. The extracted air would be treated to remove water, volatile organics, and entrained particulates and would then be reinjected.

The integrity of the circulating air barrier would be inferred by measuring the humidity of the extracted air. A sufficiently low humidity would indicate that the soil is dry enough to absorb a design-basis leak. Well pressures and injected air flow rates would provide other indications of the integrity of the barrier. Dry wells may also be installed under tanks using slant drilling as a means of obtaining pressure, temperature, and humidity data at points between the injection and extraction wells. The loss of injected air through highly permeable soil to the surface of the ground could be minimized by capping the tank farm area with an impermeable plastic membrane or layer of clay. This technology is potentially available and deployable, but its effectiveness remains to be proven.

4.3 ASSUMED TANK LEAKAGE FACTORS

The four leakage factors described in Section 1.4.2 must be further defined to permit assessment of the leakage detection limit and the public risk posed by leakage. These parameters are used as the primary basis for establishing and comparing the effectiveness of LDMM technologies. The four leakage factors include: (1) the shape of the leakage plume, (2) the type of leakage release, (3) the location of the leakage, and (4) the concentration of constituents of concern. The assumptions for each factor are shown in Table 4-1 and are discussed below.

Table 4-1. Leakage Factors Evaluated.

Leak Factors	Assumed Range Of Characteristics
Leakage shape	Sphere and oblate ellipsoid
Leakage type	Point release and distributed release
Leakage location	Construction joint
Leakage concentrations	Average of all SST wastes

The shape of the plume resulting from an SST leak is a complex function of the leakage rate, leakage size, and the subsurface soil properties; however, generalized plume shapes can be assumed. Leakage that occurs in areas in which the local stratigraphy is generally sandy and somewhat homogeneous will result in plumes with a spherical shape. Leakage that occurs in areas where the local stratigraphy consists of layered soils will produce leakage plumes that tend to follow these bedding planes, resulting in plumes shaped as oblate ellipsoids. Both plume shapes were evaluated. It was assumed that oblate ellipsoids would be formed with the depth axes equal to ½ the lateral axes. Leakage resulting from a linear source at the tank base was assumed to take the shape of an arc of a toroid. These assumptions are similar to those made in Lowe et al. (1993). The assumed leakage shapes are shown in Figures 4-15 and 4-16.

Three general tank leakage locations were postulated. (1) on the side of the tank liner with flow out through the construction joint in the concrete encasement, (2) at the center of the tank bottom, and (3) on the side of the tank liner with flow out through the wall of the concrete encasement. The first of these locations was considered most likely (Lowe et al. 1993) and was evaluated.

The concentrations of the contaminants of concern (COCs) were assumed to be equal to the average concentrations for all SSTs as described in Treat et al. (1995).

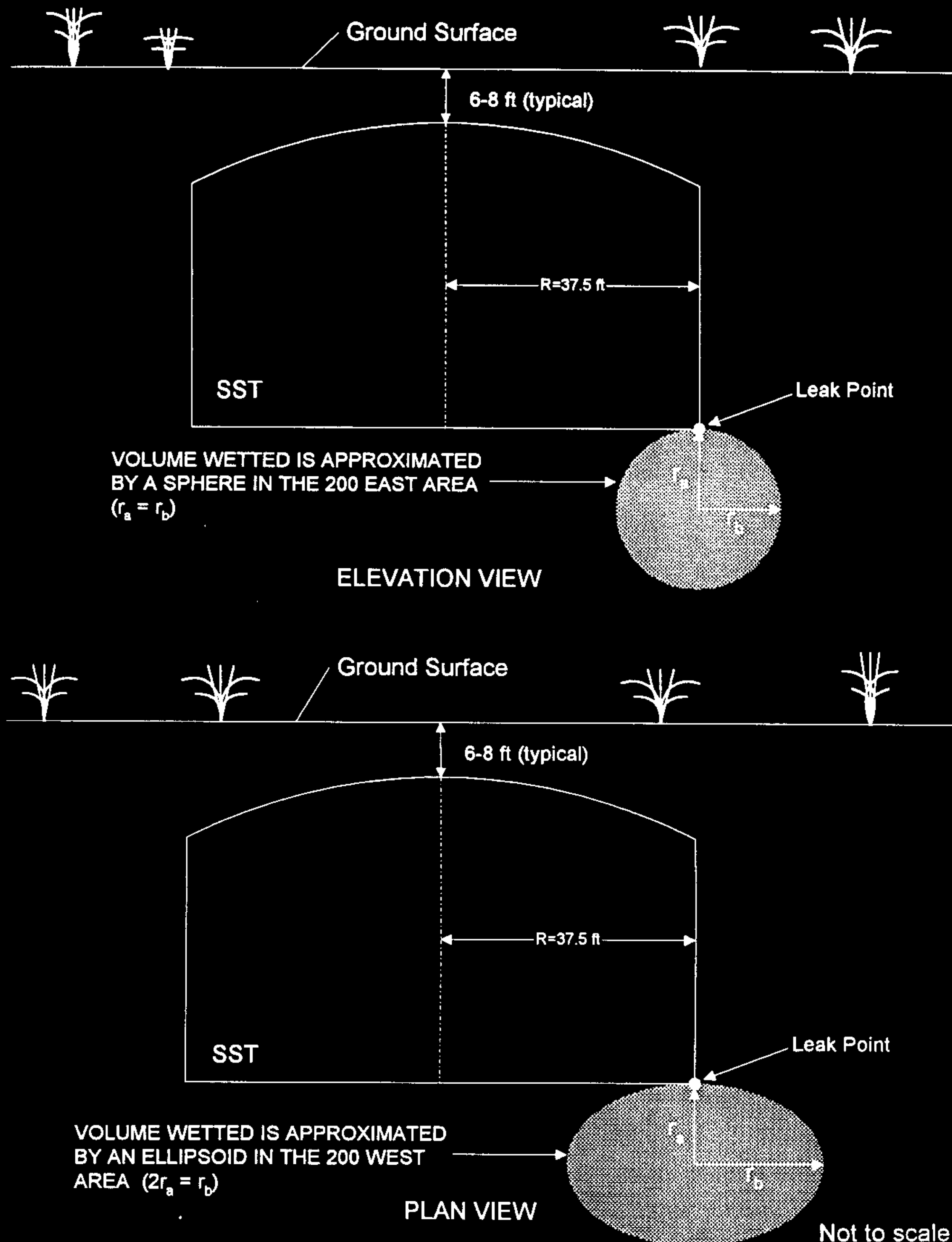

Figure 4-15. Geometric Relationship of Leakage - Plume Shape.

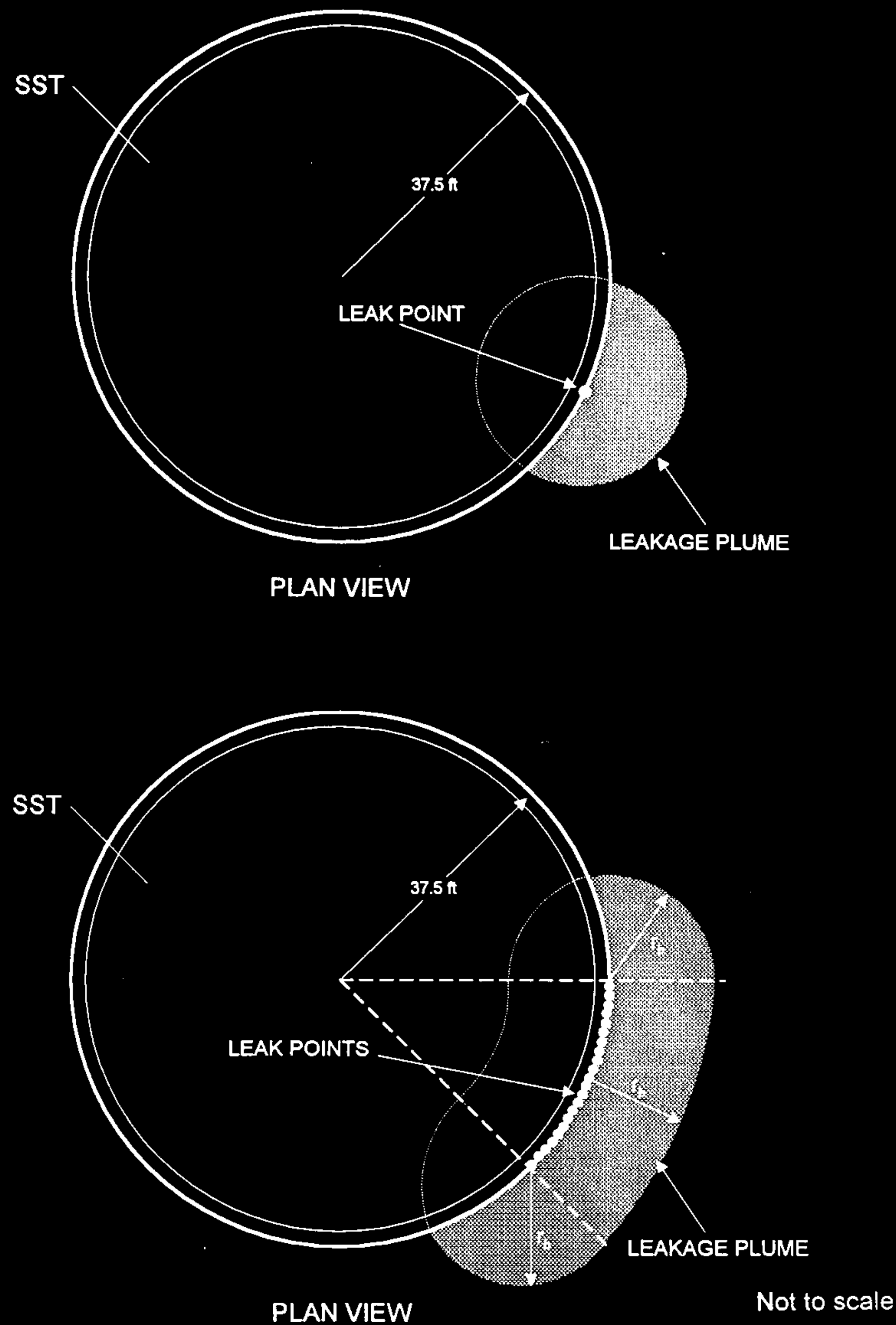

Figure 4-16. Geometric Relationship of Leakage - Type of Source.

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5.0 DECISION CRITERIA

The decision criteria used to evaluate LDMM technologies to support SST waste retrieval include the functional requirements identified in Cruse et al. (1995) and Foster Wheeler (1996) and performance measures described in this section.

5.1 FUNCTIONAL REQUIREMENTS

Leakage detection, monitoring, and mitigation generally applies to three zones of influence in the environment surrounding a given SST tank farm: (1) near-field, (2) unsaturated, and (3) groundwater. Figure 5-1 shows the three zones of influence. Due to the short time required for sluicing relative to leakage migration rates, only the near-field zone requirements for LDMM are addressed.

The near-field zone is a cylindrical volume with a vertical centerline corresponding to the tank vertical centerline. This zone includes the internal tank volume, the liner, the concrete shell, and extends from the exterior surfaces of the tank and/or ancillary equipment structures radially outward to include the existing drywells. The top of the cylinder is at grade level and the bottom extends downward to include any backfilled soil, lateral drywells, or leak detection pits. The tank bottoms are about 15 m (50 ft) to 21 m (70 ft) belowgrade. Allowing another 8 m (25 ft) to encompass any laterals or leak detection pits gives a value of 23 m (75 ft) to 29 m (95 ft) belowgrade for the bottom of the near-field zone. The diameter of the cylinder formed by the tank plus the volume needed to encompass the nearest drywells is typically 30 m (90 ft).

Functions and requirements for SST leakage detection and monitoring are identified in *Functions and Requirements for Hanford Single-Shell Tank Leakage Detection and Monitoring* (Cruse et al. 1995 and Foster Wheeler 1996). A function defines what a system or subsystem must accomplish to meet the overall mission; a requirement is a qualitative or quantitative statement of how well a function must be performed. The following sections discuss the functional requirements applicable to this study.

5.1.1 Detection Level

Existing, demonstrated detection technologies with known minimum detection limits shall be used. Only technologies that are available and deployable within the SST farm environment can be implemented. The technologies must be demonstrated to provide reliable data with a known minimum detection limit and provide leakage detection, volume, and rate information regardless of leak location. The technology must provide data within a time frame that allows for operational response to a detected leak.

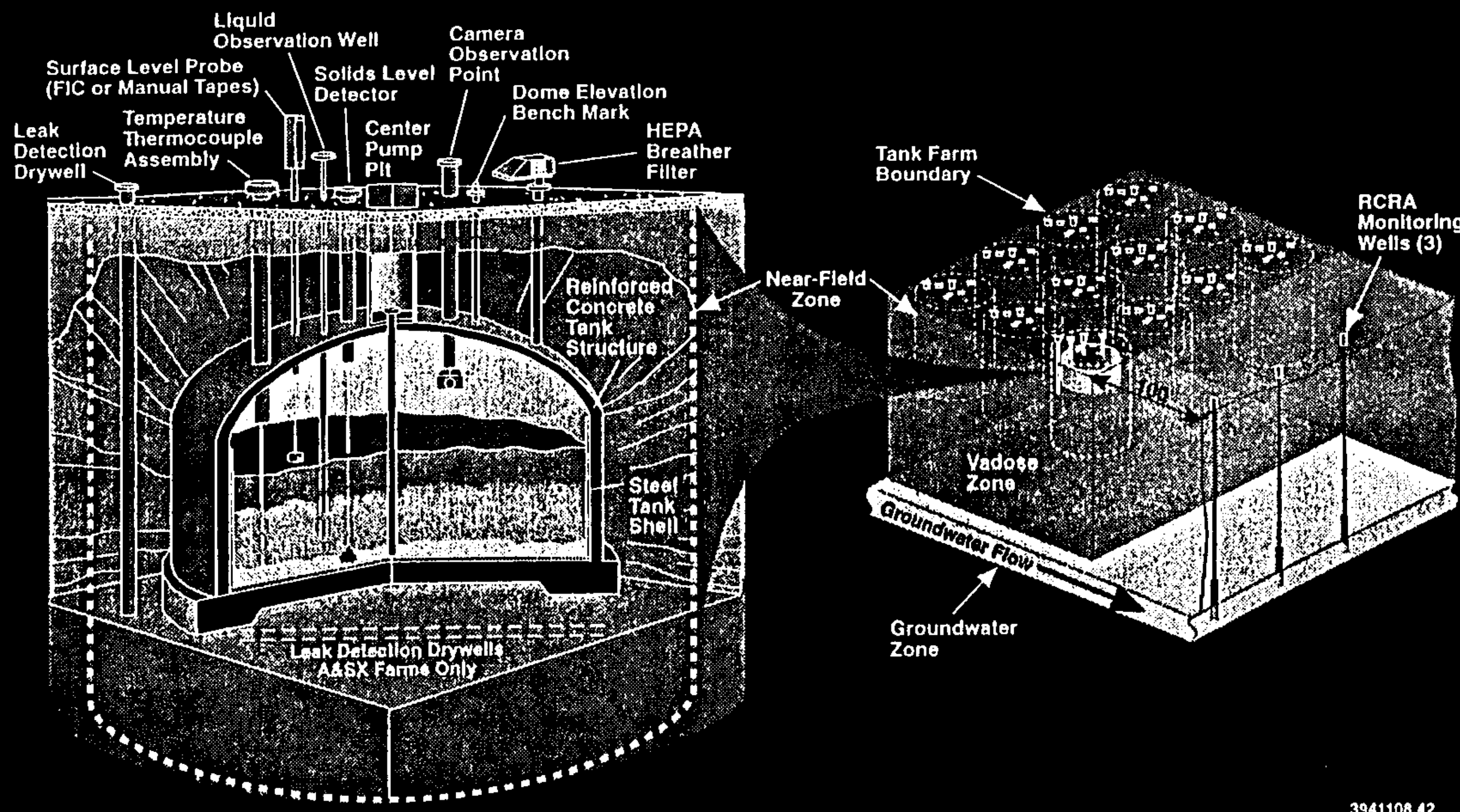

Figure 5-1. SST Leakage Detection and Monitoring Zones.

5.1.2 Monitoring

Existing, demonstrated monitoring technologies that can locate and monitor leakage plumes shall be used. Only technologies that are available and deployable within the SST farm environment can be implemented. The technologies must be demonstrated to provide reliable data about leakage plume location and movement external to the SST for time periods during and after SST waste retrieval.

5.1.3 Mitigation

Existing, demonstrated mitigation technologies that can minimize further SST waste leakage shall be used. Only technologies that are available and deployable within the SST farm environment can be implemented. The technologies must be demonstrated to provide reliable minimization of the leakage amount and/or environmental impact of waste leakage.

5.1.4 Public Health and Worker Safety

Public health and worker safety shall be ensured during all phases of the LDMM system life-cycle. Safety will be a key consideration in evaluating proposed enhancements or alternatives to the baseline SST leakage detection and monitoring systems.

5.1.5 Environmental Impact

Proposed alternatives to the baseline SST LDMM system should enhance ability to limit leakage and risk to the environment as necessary to ensure that related conditions of the tank farm closure permit are met.

5.1.6 Impact On Other TWRS Functions

Enhancements or alternatives proposed for SST LDMM should be supportive of and not impair SST waste tank safety, storage, retrieval, and closure readiness activities.

5.2 PERFORMANCE MEASURES

A successful LDMM system must be available and deployable. Unless both these requirements are met, the LDMM system is not feasible.

The ideal LDMM system would feature absolute reliability and repeatability; would be able to detect a single molecule of leakage; would provide an instantaneous signal when leakage begins; and would be able to precisely provide the rate of leakage, the location of the leak site, the physical parameters of the leakage plumes and identify the COCs in the leakage. The attributes of this ideal system were translated to a set of realistic requirements and performance criteria. The following list defines these requirements and criteria.

- **Available** - A technology must be available in order to be used for near-term LDMM.
- **Deployable** - In order for a technology to be useful, it must be possible to install the technology with assurance that all operational requirement will be met.
- **Reliable** - A technology must be reliable, both in the sense of minimal maintenance and in the trustworthiness of its results.
- **Detection Regardless of Leak Location** - The ability to detect leakage should not be dependent upon the location of the leak. Therefore leakage detection methods must be internal (i.e, within the tank) or interrogate the appropriate soil mass directly beneath and around an SST.
- **Timely Detection** - Leakage detection information is required at several points within the overall time frame of sluicing operations to support daily operational decisions on whether to continue or cease sluicing.
- **Plume Location/Direction** - Leakage monitoring must include plume location and migration direction. Information on the direction of a leakage plume contributes to the process of risk-based decision-making regarding how best to close the tank farm.
- **Leakage Rate** - The rate of leakage helps define the appropriate operational response to a leak.
- **Leakage Volume** - The actual volume leaked is critical for selecting appropriate operational responses and future actions, if any, required to close the tank farm.
- **Leakage Constituents** - The composition of COCs in leakage is critical for estimating the risk associated with the leakage and selecting the appropriate operational response.
- **Lowest Detectable Leakage** - The leakage detection technology must be capable of detecting and qualifying leakage from any location around the tank at sensitivities necessary to ensure protection of the environment.
- **Minimize Further Leakage** - Leakage mitigation technology should be able to minimize the amount and environmental impact of leakage.

- **Effluent Treatment.** Treatment of any effluents generated by LDMM systems is undesirable and should be minimized.

- **Secondary Waste Generation.** The generation of secondary waste should be minimized.

The criteria defined above can be categorized as requirements or ranking variables. Requirements are those criteria that must be met and preferably exceeded for the technology to have value for leakage detection or leakage monitoring. Ranking variables reflect criteria without mandatory requirements. Table 5-1 shows which criteria are considered requirements and ranking variables for LDMM.

Table 5-1. Leakage Detection, Monitoring, and Mitigation Criteria.

CRITERIA	Leakage Detection		Leakage Monitoring		Leakage Mitigation	
	Requirement	Ranking Variable	Requirement	Ranking Variable	Requirement	Ranking Variable
Available	✓		✓		✓	
Deployable	✓		✓		✓	
Reliable	✓		✓		✓	
Detection Regardless of Leak Location	✓					
Timely Detection	✓					
Plume Location/Direction			✓			
Leakage Rate	✓			✓		
Leakage Volume	✓			✓		
Leakage Constituents				✓		
Lowest Detectable Leak		✓				
Minimize Further Leakage					✓	
Effluent Treatment		✓		✓		✓
Secondary Waste Generation		✓		✓		✓

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6.0 ANALYSIS OF ALTERNATIVES FOR LEAKAGE DETECTION

Leakage detection technologies described in Section 4.1 were evaluated based on the leakage detection performance measures described in Section 5.2. The approach to evaluating the performance measures, the results of the analysis, and the cost-benefit of each technology are provided in Sections 6.1, 6.2, and 6.3, respectively.

6.1 LEAKAGE DETECTION COST/RISK EVALUATION APPROACH

The approach taken to assess the leakage detection technologies against the seven performance measures (cost, schedule, operability, health and safety, environmental acceptability, technical maturity, and complexity of interfaces) are described in the following sections.

6.1.1 Costing Methodology

The costing methodology enables a rough cost estimate for each leakage detection technology. The technologies include: no action, mass balance, tracer gas, ERT in the 4,1 and 8,3 configurations, borehole logging, and TDR.

The estimated costs were developed using available published information and best engineering judgement. Cost data were derived primarily from Lewis et al. (1995) and personal communications with qualified knowledgeable persons. The costs were developed on a programmatic basis, with tank farm and tank costs summed into total programmatic costs for leakage detection. The programmatic costs are expressed as total net present worth (TNPW) values. Actual tank or tank farm information was used when appropriate; a hypothetical tank farm consisting of 12 tanks was used when estimating public health risk. Costs were evaluated in five major stages of the technology life cycle: development, preparation, installation, operation, and decommissioning.

6.1.1.1 Development. Developmental costs were determined by first identifying the leakage detection technology developments required before the technology can be considered available; necessary deployment technology developments were identified and costed as well. Mass balance, borehole logging, and TDR technologies were considered to require no further development, and thus have no associated developmental costs. Tracer gas and ERT technologies require further development as described in Section 4.1.

6.1.1.2 Preparation. Preparation costs are costs that must be expended following full development of a technology and prior to its actual installation. The only preparation costs identified were related to planning and permitting. Permit requirements of a technology were identified and the associated costs were estimated.

6.1.1.3 Installation. Installation costs include all costs involved with deploying a leakage detection system within the tank farm. Deployment activities may include any of the following: mobilization, borehole or CPT well installation, equipment purchase or lease, materials and supplies, and labor.

6.1.1.4 Operation. Operation costs include the costs of operating and maintaining leakage detection equipment during retrieval actions. Operation costs may be expressed as a single value on a per-tank basis, on a per-time basis, or as a combination of the two. The per-time basis better reflects the increased total costs associated with leakage detection on a tank that requires a lengthy retrieval period.

6.1.1.5 Decommissioning. Decommissioning costs include the costs of removing and disposing of all associated equipment, materials and supplies, and waste related to the deployed technology following completion of retrieval activities.

6.1.2 Schedule Risk Methodology

The schedule risk methodology includes evaluation of a technology's ability to provide leakage detection data in a time frame that allows timely decisionmaking for how best to mitigate leakage. There is always a point in time during retrieval after which discovery of a leak cannot be acted upon to reduce or stop the leakage. This point is defined by one of two factors:

- Leakage detection data are not useful if they become available after retrieval activities have been completed. This may occur if a technology requires a lengthy data acquisition and processing time prior to determination that a tank is leaking.

- Leakage detection is not useful if leakage becomes unacceptably large before an operational response can be made to mitigate it. This may occur if the data acquisition and processing time is excessive, or if the minimum detectable leakage volume associated with a technology is too large.

It is recognized that an acceptable time frame for leakage detection is dependant on the physical characteristics of the tank and site, the waste it contains and its associated risks, and the leakage detection technology.

6.1.3 Operability and Effectiveness Methodology

The operability and effectiveness methodology included evaluation of the technologies were evaluated according to several criteria. The primary criterion for effectiveness of a technology for detecting leakage is ability to detect leakage volume. Other criteria of interest are ability to estimate the actual leakage amount and rate of leakage. Each of these criteria are discussed in the following sections.

6.1.3.1 Detected Leakage Volume. A critical parameter for evaluating leakage detection technologies is the volume of liquid waste that must exit a tank before a given leakage detection technology will respond to it. This parameter is termed the detected leakage volume. The minimum detected leakage volume is the volume of leaked waste that must occur before detection is possible. This volume corresponds to a best-case scenario, with all variable factors set to values that are most favorable to detection. The maximum detected leakage volume is the largest volume of leaked waste that can exist at detection. This volume corresponds to a worst-case scenario, with all variable factors set to values that are most unfavorable to detection.

The detected leakage volume is a function of several constant and variable factors. There are three variable factors included in the detected leakage volume calculations.

- The soil porosity, S_P, was assumed to be 32%. This value is based on sample data for selected wells in the T Tank Farm that provided a porosity range from 22 to 38% with an average of 32% (Routson et al. 1979). For this trade study, it was assumed that these data are typical of the 200 Areas.

- The natural soil moisture, q_n, was given a value of 6%, which is also based the data provided in Routson et al. (1979). This value indicates that the soils have a natural moisture content equal to 6% of the total volume of the soil.

- The soil void space available to leakage is the difference between the two factors, or 26%. Thus, each cubic foot of a leakage plume contains 0.26 ft^3 of leakage volume under saturated soil conditions.

There are three variable factors included in the detected leakage volume calculations:

- Shape of the soil plume saturated by leakage
- Type of leak source assumed
- Location of the leak source.

The shapes of actual leakage plumes in the soils at the 200 Areas are complex and depend on soil parameters such as geologic layering, porosity, vertical and horizontal hydraulic conductivities, as well as characteristics of the leakage liquids. It was assumed that the shape of a saturated soil plume can be approximated by either a sphere or an oblate ellipsoid with a major axis twice as long as the minor axis.

A hypothetical leakage from a tank was assumed to have one of two source types. The first is a point source, where all leakage enters the soil from a single discrete point. The second is a distributed source, in which leakage is assumed to enter the soil equally along an arc equal to one-eighth the circumference of the tank. While other source types are possible, this study selected the two described as a representation of source variation.

For this study the most likely leak scenario is considered to involve the following assumptions.

- Leakage would occur through stress corrosion cracks or other flaws in the tank liner, pool between the tank liner and the concrete containment wall and base, then seep out through the construction joint between the containment wall and base (Lowe et al. 1993).
- The point source was therefore assumed to be located somewhere along the perimeter of the tank base, while the distributed source would occupy a 45° arc of the perimeter of the tank base.
- The actual location may be anywhere along the perimeter of the tank base.
- For the minimum detected leakage volume calculations, the source location was assumed to be at a point nearest to detection instrument.
- For the maximum detected leakage volume calculations, the source location was assumed to be the greatest possible distance from any detection instrument.
- Other leak source locations are possible, such as a leak that develops at the center of the base of the tank. These were considered to be less likely and were not included in the evaluation.

Each technology evaluated has up to eight possible detected leakage volumes, as diagrammed in Figure 6-1. These are the result of different values given to the variable factors. Not all technologies will have eight distinct detected leakage volumes associated with them. Where two or more of the leak scenarios are equivalent, a single detected leakage volume was calculated. Mass balance, which is an internal tank leak detection technology, is independent of external factors and has only two detected leakage volumes, a minimum and a maximum. Discussion is presented with the results in Section 6.2.3.

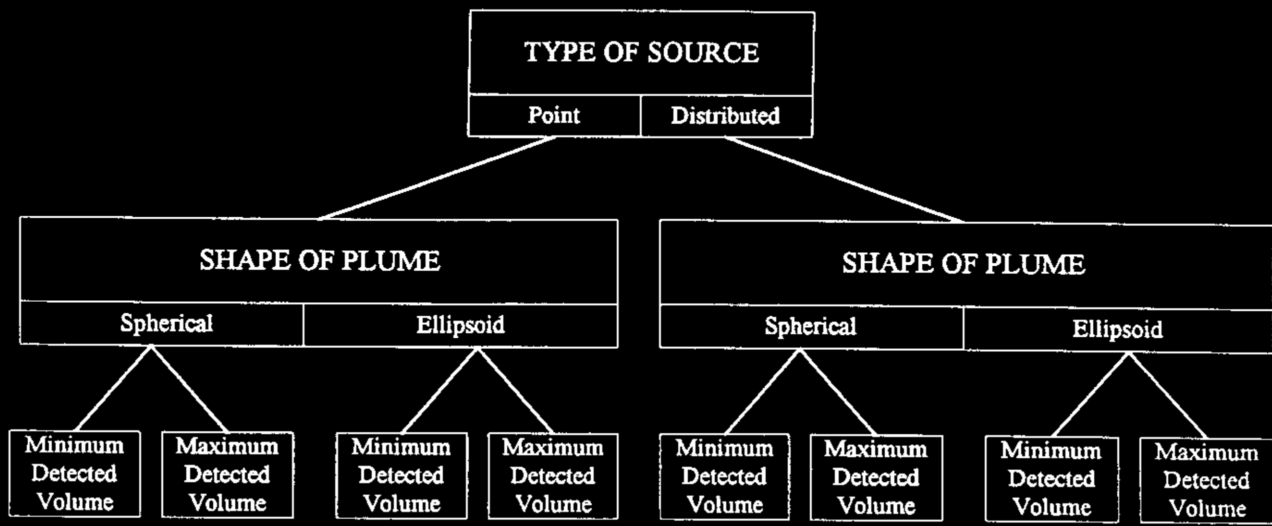

Figure 6-1. Possible Detected Leakage Volumes.

The calculations used to determine the detected leakage volumes for each technology are as follows:

Detected Leakage Volume of a Point Source:

$$V_L = (7.49\ gal/ft^3) * (S_p - q_n) * (4/3\ \pi\ r_a\ r_b^2)$$

Detected Leakage Volume of a Distributed Source:

$$V_L = (7.49\ gal/ft^3) * (S_p - q_n) * (1/8\ (2\ \pi^2\ r_a\ r_b\ R) + 4/3\ \pi\ r_a\ r_b^2)$$

Where:

S_p = Soil porosity (0.32)
q_n = Natural moisture content of soil (0.06)
r_a = Vertical radius of leakage plume
r_b = Horizontal radius of leakage plume
R = Radius of SST (37.5 ft)

The variable factor of the leakage source type (point or distributed) is accounted for by the choice of equation used in the calculation. The variable factors of the shape of the plume, the location of the leak, and whether a minimum or a maximum detected leakage volume is selected for evaluation are all accounted for in the choice of values for the vertical radius of the leakage plume, r_a, and the horizontal radius of the leakage plume, r_b. For a sphere-shaped plume, the radii were selected to be equal to each other, and for an ellipsoid, the horizontal radius was selected to have a value of twice that of the vertical radius, or $r_b = 2r_a$. The location of the leak and the minimum or maximum result desired determine the geometry of the scenario, and thus determine the numerical values of the vertical and horizontal radii. These calculations are provided in Appendix B and a complete discussion of this determination with figures is provided in Section 6.2.3.

6.1.3.2 Quantitative Analysis. Each technology was evaluated for its ability to provide a direct or inferred quantitative analysis of the true leakage volume and the leakage rate. The true leakage volume reflects the quantity of waste leaked, while the detected leakage volumes describe a range that bounds the leakage quantity. The difference between detected leakage volume and true leakage volume varies between technologies, and may be sensitive to the volume leaked.

Closely related to determination of leakage volume is determination of leakage rate. The leakage rate is the rate at which waste exits the containment shell and enters the soil, typically expressed in gallons per minute. Each technology was evaluated on its ability to directly or indirectly quantify the rate of leakage.

If the technology is able to support a determination of either the leakage volume or the leakage rate, the other can be estimated. Leakage volume is the product of the leakage rate (determined by the technology) and the duration of the leak (determined by the technology or estimated). The leakage rate can be estimated by making two determinations of the leakage volume separated by a known time period, and performing a simple calculation.

6.1.4 Health and Safety Risk Methodology

A formal definition of health and safety risk for leak detection technologies is the impact(s) of leak detection activities on the health and safety of workers and the public multiplied by the probability that the impact(s) will occur. Worker exposure and other elements of worker safety were assumed to be similar because all of the technologies would be operated remotely except borehole logging, which has a past history of negligible worker exposure. Deployment safety risks were assumed to be similar for all technologies after considering equipment installation steps and typical tank conditions. Conditions in and around individual tanks vary significantly, however. Large differences in worker risk may be projected on an individual tank basis.

Public health risk is predominantly a function of the quantity of waste leaked into the soil surrounding the tanks. A leakage detection technology that can detect leakage early and instigate an action that limits the leakage quantity will limit public health risk. A leakage detection technology that detects the same leak after more time has passed will not be as effective.

The public health risk was related to the quantity of leaked waste by determining the average exposure impact per gallon of tank waste, as defined in Treat et al. (1995). Treat et al. (1995) contains first approximations of carcinogenic risk and noncarcinogenic hazards to the maximally exposed individual for 30,000 years. The risks were based on the maximally exposed individual who uses well water obtained immediately downgradient of the closed tank farm. The well is used to provide drinking water and irrigation of a five-acre farm. Risk includes exposure through consumption of foodstuffs raised on the farm. The tank farm was assumed to have a surface barrier which limited recharge to 0.05 cm/yr. The Multimedia Environmental Pollutant Assessment System (MEPAS) code was used to consistently evaluate the relative magnitude of human health impacts from radiological (cancer impact) and chemical (toxicity impact) contaminants released to the environment during retrieval. This code includes a one-dimensional model capable of projecting radiological and chemical risks and hazards through the groundwater and other pathways. Only the pathways associated with the groundwater were analyzed.

An average risk per gallon of leaked waste was calculated for both carcinogenic risk and noncarcinogenic hazards. This calculation is shown in Appendix C. The volume of leakage which may result during use of the detection technology is multiplied by this risk per gal value. Determination of the volume of leakage associated with each of the detection technologies was based on the following assumptions:

- Application of the selected LDMM system results in lower volumes of leakage to the environment.
- The leakage is limited to the volume first detected (detection limit)
- There is no additional leakage associated with the mitigation process.
- Two of the tanks, per tank farm, retrieved with past-practice sluicing, will develop leaks. The leaks, if left unmitigated, would reach a maximum volume of 40,000 gal.

Based on review of historical tank integrity data, Treat et al. (1995) estimated that two previously "sound" tanks, per tank farm, would leak during past-practice sluicing. Thus, on a per tank farm basis, the volume assumed to leak to the environment is equal to 2 (tanks) times the technology's detection limit. The volumes leaked and resulting public risk are expressed on a per tank farm basis because of assumptions inherent in Treat et al. 1995. The primary assumption is that the MEI receives exposure from groundwater contaminants associated with a single tank farm.

6.1.5 Environmental Acceptability Methodology

The environmental acceptability methodology includes an assessment of the secondary impacts of a technology on the surrounding environment. Secondary impacts include processes or by-products that require further attention to be environmentally acceptable. Secondary waste generation and disposal, and effluent treatment and associated environmental releases are considered secondary impacts.

For each secondary environmental impact identified, the cost and feasibility of treating or eliminating the impact was determined, and the effectiveness of the treatment evaluated. It was assumed that an untreatable secondary environmental impact would add to overall environmental costs and risks; therefore, technologies that include such impacts should be screened from further consideration.

6.1.6 Technical Maturity Methodology

The technical maturity methodology includes a qualitative evaluation of the readiness of a technology for use. Each technology was evaluated with respect to three criteria: (1) available for use, (2) deployable around the Hanford Site SSTs, and (3) demonstrated at the Hanford Site. Certain technologies, such as borehole logging, have been used successfully at the Hanford Site for plume monitoring, but are essentially untested for leakage detection.

- **Available for use** means that the technology can be implemented immediately, assuming that the site is receptive and deployability is not an issue. This criterion implies that every component of the technology is fully developed, and can be procured and integrated into a complete technology system without further development. The evaluation of availability considered only the technology itself and not site-specific implementation issues. This criterion was evaluated as "Yes" or "Potentially" in this trade study. A "Yes" evaluation indicated that the technology is fully developed and commercially available without qualification. A "Potentially" evaluation implied that the technology is available, but may require modification for use. There were no negative results for this criterion because the screening process performed by Lewis et al. (1995) eliminated those technologies that were not available.

- **Deployable around the Hanford Site SSTs** considers site-specific implementation issues. The primary focuses of the deployability evaluation were the physical interfaces described in Section 6.1.7. This criterion was evaluated as "Yes" or "Potentially" in this trade study. A "Yes" evaluation indicated that the technology is deployable without qualification, i.e., the technology has been successfully implemented in the past. A "Potentially" evaluation implied that deployment of the technology has not been demonstrated, but appears technically feasible. There were no negative results for this criterion because the screening process performed by Lewis et al. (1995) eliminated those technologies that were not deployable.

- **Demonstrated at the Hanford Site** means the technology has been shown to function successfully in a pilot-scale test or in full-scale operation at the Hanford Site. This criterion was not restricted to a demonstration using the SSTs, and thus "demonstrated" does not necessarily imply deployability. This criterion was evaluated as either "Yes" or "No."

6.1.7 Complexities of Interfaces Methodology

This methodology addresses interfacing equipment and services required to install and operate the technology. The interfaces and their associated complexities provide a basis for estimating the difficulty of preparing the technology for installation and operation.

The necessary interfaces are listed in Section 6.2.7 for each technology and any special requirements are identified. A given leakage detection technology may include any combination of the following interfaces:

- Inputs (utilities such as electrical, gas, steam, water)
- Outputs (waste treatment and disposal)
- Physical (borehole location and depth)
- Support (crafts, procurement, vendors).

6.2 LEAKAGE DETECTION COST/RISK EVALUATION RESULTS

This section presents the results of evaluating each of the leakage detection technologies against the seven performance measures described in Section 6.1.

6.2.1 Cost Results

The life-cycle cost of each technology was estimated as the sum of five category costs: development, preparation, installation, operation, and decommissioning. Estimated costs are order-of-magnitude due to the high uncertainty of deployment configurations that will satisfy all functions and requirements. The following assumptions were used in developing these cost estimates (costs current as of March 1996):

- Eighty-two tanks would be retrieved. This is the number of assumed "sound" or non-leaking tanks. Of the 149 tanks, 67 were assumed to be leaking.

- The total time to retrieve 82 tanks would be 13 years. This is based on the schedule developed in *Cost-Benefit and Risk Assessment of Alternate High-Level Waste Treatment Strategies* (Foster Wheeler 1995). It was assumed that the first 82 SSTs on the schedule are the "sound" tanks and are retrieved in 13 years.

- The total time period for the leakage detection and monitoring program would be the same as the retrieval program, or 13 years. It was assumed that leakage plume detection and monitoring supports the retrieval program only. Longer-term costs associated with continued monitoring in support of closure were not considered.

- The average time to retrieve a SST would be 3 months (12 weeks) (Boomer et al. 1993).

- The average number of existing boreholes per tank is five (Hanlon 1995).

- Hanford Site oversight effort is expressed as the number of full-time equivalents (FTEs) required to support a field activity. This includes project management, health and safety monitoring, procurement, and craft support. A value of four oversight FTEs per field activity was used. Therefore, installing a well in eight hours would consume 32 hours of Hanford Site oversight support.

- Grout for in-situ closure of wells would cost $71.25 per cubic yard delivered (Riggsbee 1996).

- No new boreholes would be drilled. Technologies such as borehole logging and TDR would use only existing boreholes.
- CPT wells can be installed in the tank farms. It was assumed that three attempts are required to successfully push a CPT well to the desired depth. The two unsuccessful attempts were assumed to reach 50 ft in depth.
- The cost of pushing a CPT well was assumed to be $360 per foot.
- The average cost of labor at the Hanford Site would be $50 per hour.
- Permitting a soil vapor extraction (SVE) system for tracer gas would require four weeks of labor.
- Each vertical caisson would be capable of being used as a platform for installation of lateral wells under an average of three tanks.

Detailed cost estimates are included in Appendix A. A summary of the results of the cost estimates is provided in Table 6-1.

Table 6-1. Summary of Estimated Leakage Detection Program Costs (1996 dollars).
(Results shown are in $1,000)

Cost Category	No Action	Mass Balance	Tracer Gas	4,1 ERT	8,3 ERT	Borehole Logging	TDR
Development	$0	$0	$2,000	$2,000	$2,000	$0	$500
Preparation	0	8	41	8	8	8	8
Installation	0	5,100	17,000	21,000	44,000	0	46,000
Operation	0	1,000	1,400	490	490	89,000	490
Decommissioning	0	0	1,000	920	1,800	1,000	990
TNPW	0	5,600	20,000	23,000	47,000	49,000	47,000
TNPW per Tank Farm	0	470	1,700	1,900	3,900	4,100	3,900

6.2.2 Schedule Risk Results

Schedule risk can be defined as the schedule impact of implementing a leak detection or monitoring technology, multiplied by the probability of that impact occurring. There are essentially three ways in which a leakage detection technology may affect the retrieval schedule: (1) through installation delays, (2) through leakage detection and monitoring system failure, and (3) by retrieval cessation due to leakage detection. A qualitative review of the three possible impacts and their probability of occurrence is provided in this section.

Installation delays may result in postponement of waste retrieval activities. Delays are most likely to occur for tracer gas, 4,1 and 8,3 ERT, and TDR technologies, all of which include borehole or CPT installation.

Failure of the leakage detection system will force shutdown of retrieval operations until operation of the system is restored. Mechanical systems, or systems with mechanical components, are considered to have a greater probability of failure than purely electrical systems. Thus, tracer gas and, to a lesser extent, mass balance and borehole logging technologies were assumed to be more likely to fail than ERT or TDR. However, the consequence of a mechanical failure may be much lower than that of an electrical failure since the mechanical components are aboveground and easily accessible, whereas an electrical failure may indicate that a subsurface instrument or probe needs to be repaired or replaced, resulting in a longer down time.

If reliance on leakage detection data is deemed essential during sluicing (which is not the current plan), then cessation of retrieval activities may be required for technologies that operate within the tanks or require attended operation within the tank farm. In either case, retrieval activities may have to be temporarily suspended to make a leakage detection determination. Of the technologies evaluated, only mass balance and borehole logging may require suspension of retrieval. Mass balance technology employs equipment inside the tank, and borehole logging requires personnel within the tank farm. It was assumed that retrieval operations could not proceed while personnel other than essential operators and monitoring personnel were near the tank.

A quantitative analysis of schedule risk was not attempted because there are too many unknown factors. However, using the available information and best engineering judgement, the following conclusions were drawn.

- Installation delays can be avoided with careful planning. Installing leak detection systems well in advance of scheduled retrieval activities would mitigate many problems, and problems that occur in initial installations should be alleviated in subsequent installations. For these reasons, schedule risk due to installation delay was considered minor.

- The probability of a failure of a leakage detection system is difficult to measure, particularly on experimental or underdeveloped systems. It has been noted that mechanical systems may have a greater probability of failure but a lower consequence than electrical systems. If the general complexity of the leakage detection system may be assumed to be proportional to the schedule risk due to system failure, then engineering judgement suggests that the no action alternative offers the least schedule risk, followed by mass balance, ERT and TDR (approximately equivalent), borehole logging, and finally tracer gas technology.

- Periodic cessation of waste retrieval activities may be instigated by mass balance and borehole logging data. Although the current plan is to use the "natural/planned" retrieval breaks for obtaining leakage detection data, it cannot be determined if such cessations will be required until a desired operations schedule is proposed. If such a schedule includes periodic halts in retrieval activities for other reasons, then these technologies may take advantage of the breaks and have no schedule risk due to this factor. If periodic halts are not part of the desired retrieval schedule, then some of the technologies would require them, and the schedule would thus impacted.

6.2.3 Operability and Effectiveness Methodology Results

This section summarizes results of the evaluations of detected leakage volumes and ability to quantify leakage and leakage rates.

6.2.3.1 Detected Leakage Volume Results. Detected leakage volume calculations were performed for each of the technologies under consideration. The methodology and equations used in the calculations are presented in Section 6.1.3.

The no action alternative was based on the assumption that there would be no leakage detection system in place and the retrieval process, once begun, would continue to completion. If a leak occurs during retrieval, it was assumed that the leak would also continue to the completion of retrieval activities. At that time the leak would cease because all drainable fluid would have been retrieved. Lowe et al. (1993) evaluated the potential size of an undetected and unmitigated leak as approximately 40,000 gal (Table 6-2). This value represented a leakage rate of 1.3 gal/min and a leakage duration of 500 hours. The leakage volume result for the no action alternative is independent of the plume shape, leak source type (point or distributed), and the leak source location. Because of this, only one leakage volume is provided in Table 6-2.

Table 6-2. Assumed Leakage Volume for No Action Alternative.

Description	Volume (gal)
Leakage Volume	40,000

The detected leakage volume when mass balance technology is used would be independent of the variable factors of the plume shape, the leak source type (point or distributed), and the leak source location because the detection system operates inside the tank. There are no variations in the equations, and therefore only a minimum detected leakage volume and a maximum detected leakage volume are reported. The minimum detected leakage volume was taken directly from Stuart et al. (1996). Stuart et al. (1996) assumed that the visual estimate of solids can be accomplished with an overall accuracy of

+/-1 in. and that the liquid level measurement, liquid density, and temperature instruments operate continuously at the manufactures' rated accuracy and precision.

The maximum detected leakage volume for mass balance technology is based on estimates of additional error contributors such as inaccuracy of tank characterization data, heterogeneity of tank waste, evaporative losses, and calibration drift. Additionally, a lower overall accuracy of +/- 6 in. was assumed for the visual estimate of solids, resulting in a maximum detected leakage volume of 20,000 gal. The results are summarized in Table 6-3.

Table 6-3. Detected Leakage Volumes for Mass Balance Technology.

Description	Volume (gal)
Minimum Detected Leakage Volume	5,570
Maximum Detected Leakage Volume	20,000

Tracer gas technology is unique in that it is independent of all of the variable factors introduced in Section 6.1.3. In an effective tracer gas detection system, the tracer would be available for detection by the system soon after exiting the tank. An ideal system could theoretically provide extremely low detected leakage volumes. However, effectiveness of the tracer gas system would depend on many factors that have not yet been studied including: behavior of the tracer in heterogeneous Hanford Site soils, effectiveness of the SVE system in inducing a subsurface vacuum and extracting soil gas, and possible escape of tracer gas through holes in the tank above the waste level, thereby falsely signalling a leak. Therefore, the detected leakage volumes were not determined (Table 6-4).

Table 6-4. Detected Leakage Volumes for Tracer Gas Technology.

Description	Volume (gal)
All Detected Leakage Volumes	Undetermined

The 4,1 configuration of ERT provides a plane of interrogation located a minimum of 15 ft below the base of the tank. As leakage occurs, the resulting plume would expand until the lowest point of the plume reached the plane of interrogation and was detected. The plane of interrogation was assumed to be at a constant depth of 15 ft below all possible leak locations, so the vertical radius of the leakage plume, r_a, was assigned a value of 7.5 ft. The horizontal radius of the leakage plume, r_b, is arbitrary because the interrogation zone is a horizontal plane rather than a set of discrete points. For the first case, the shape of the plume was assumed to be spherical; thus, r_b is equal to r_a, or 7.5 ft. For the second case, the shape of the plume was assumed to be an oblate ellipsoid; thus, r_b equals two times r_a, or 15 ft. These geometries are shown in Figure 6-2.

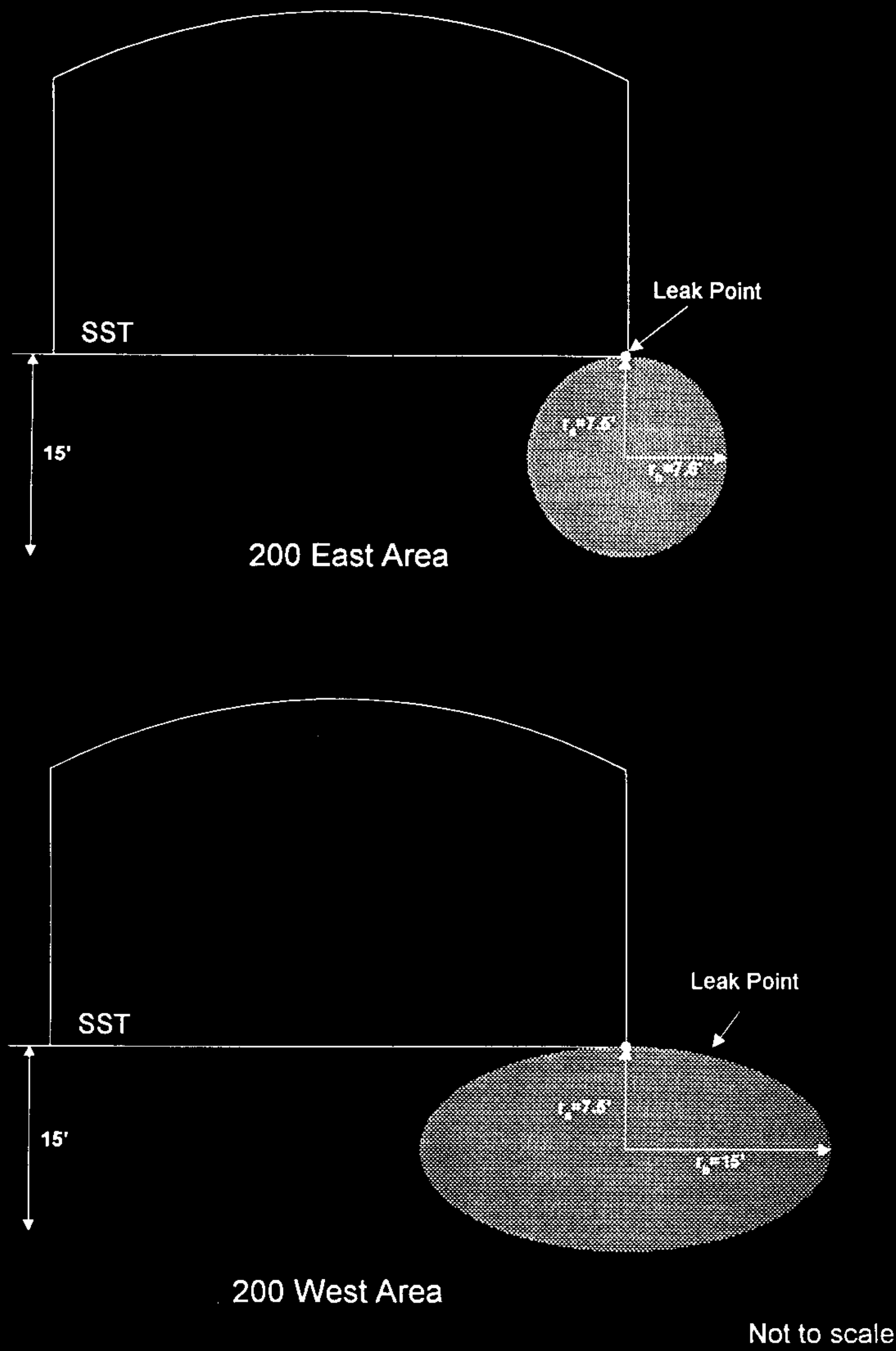

Figure 6-2. 4,1 ERT Configuration - Geometry for Calculating Detected Leakage Volume.

Based on the geometries described, four detected leakage volumes for 4,1 ERT were estimated as shown in Table 6-5.

Table 6-5. Detected Leakage Volumes for 4,1 ERT Technology.

Description	Volume (gal)
Oblate Ellipsoid, Point Source	13,800
Oblate Ellipsoid, Distributed Source	34,000
Sphere, Point Source	3,400
Sphere, Distributed Source	13,600

The 8,3 ERT configuration provides a plane of interrogation located 10 ft below the base of the tank. Using the same logic described for 4,1 ERT, the vertical radius of the leakage plume, r_a, was assigned a value of 5 ft and the horizontal radius of the leakage plume, r_b, was assigned a value of 5 ft for a spherical geometry and a value of 10 ft for an oblate ellipsoid geometry. The geometries are shown in Figure 6-3.

Based on the geometries described, four detected leakage volumes for 8,3 ERT were estimated as shown in Table 6-6.

Table 6-6. Detected Leakage Volumes for 8,3 ERT Technology.

Description	Volume (gal)
Oblate Ellipsoid, Point Source	4,100
Oblate Ellipsoid, Distributed Source	13,100
Sphere, Point Source	1,000
Sphere, Distributed Source	5,500

Borehole logging provides a vertical column of interrogation at each borehole being logged. The leakage plume from a hypothetical leak would expand outward and downward from the leak source until the outer edge of the plume comes into range with one of the boreholes and is subsequently detected. It was assumed that the depths of the boreholes and therefore the depths of the column of interrogation are sufficient to reach any leakage plume. From this, it is apparent that the vertical radius of the leakage plume, r_a, is arbitrary. The horizontal radius of the leakage plume, r_b, is equal to the horizontal distance from the source of the leak to the nearest borehole. In a best-case scenario, the leak source is located on the tank perimeter at a point closest to a borehole. Boreholes were assumed to be located 10 ft from the perimeter of the tank, so for the best-case scenario, r_b equals 10 ft. This result applies for either a point source or a distributed source. In a worst-case scenario, the leak source is located at a maximum distance from any borehole. Thus, the worst-case leak is

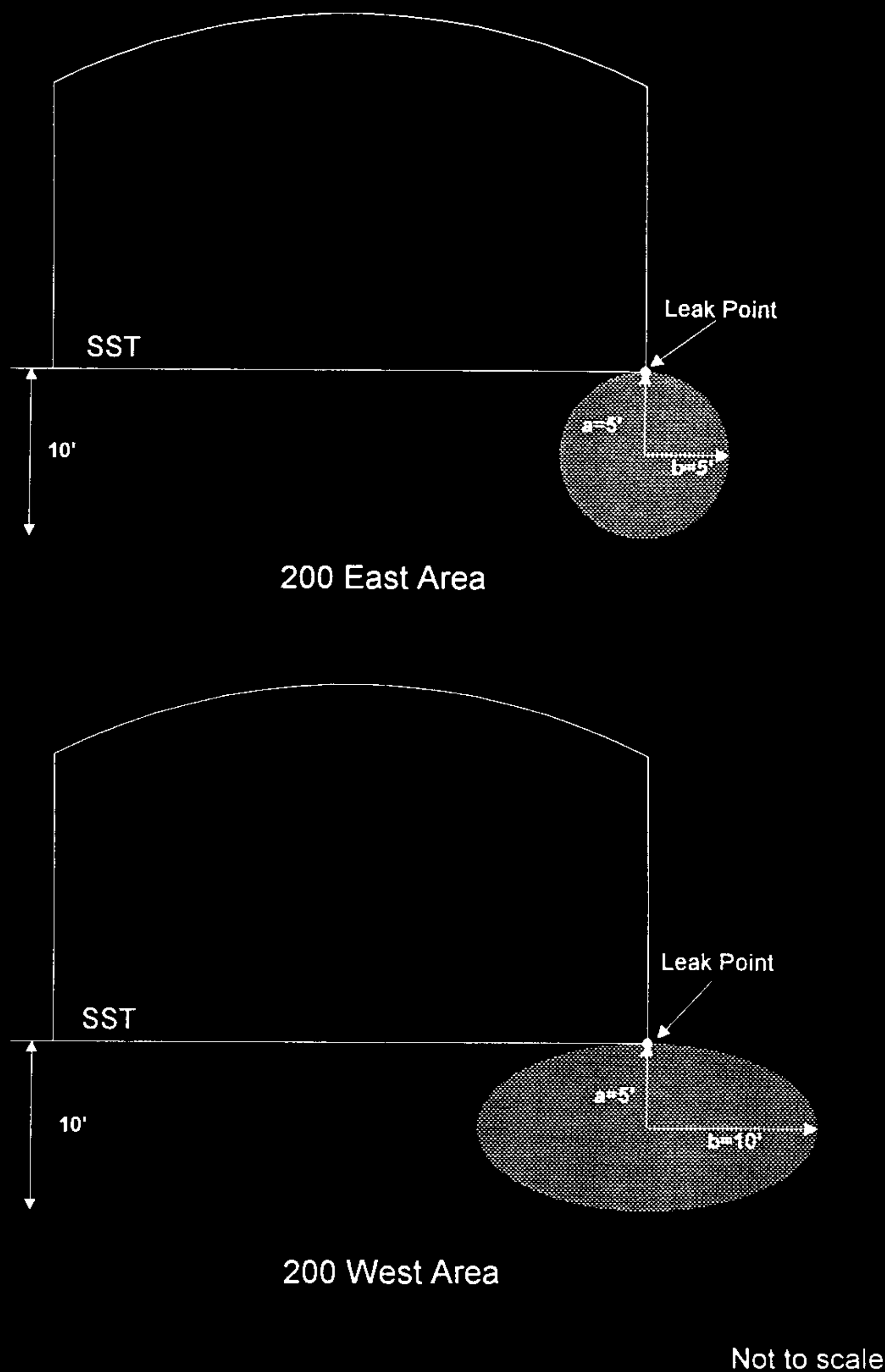

Figure 6-3. 8,3 ERT Configuration - Geometry for Calculating Detected Leakage Volume.

equidistant from its nearest two boreholes. For the purposes of this evaluation, it was assumed that there are five boreholes equally spaced around the tank and located 10 ft from the perimeter of the tank. From the geometry as described, a point source results in r_b equaling 28 ft. For a distributed source, r_b equals 14 ft. The geometries are shown in Figures 6-4 and 6-5.

Based on the geometries described, eight detected leakage volumes were estimated for borehole logging as shown in Table 6-7.

TDR provides a somewhat more complex volume of interrogation. Each TDR probe is 6 ft long and was assumed to be placed in the soil 10 ft from the perimeter of the tank. As with borehole logging, it was assumed that each tank has five TDR probes spaced equally around the tank. This results in five discrete column sections of interrogation that are 6 ft high. It was assumed that each probe is located at the optimum depth for detection in all cases. Thus, the TDR geometries are the same as those derived for borehole logging, as shown previously in Figure 6-4, and the detected leakage volumes would be the same as shown in Table 6-7.

Table 6-7. Detected Leakage Volumes for Borehole Logging or TDR Technology.

Description	Volume (gal)
Oblate Ellipsoid, Point Source, Minimum	4,100
Oblate Ellipsoid, Point Source, Maximum	89,500
Oblate Ellipsoid, Distributed Source, Minimum	13,100
Oblate Ellipsoid, Distributed Source, Maximum	28,800
Sphere, Point Source, Minimum	8,200
Sphere, Point Source, Maximum	179,100
Sphere, Distributed Source, Minimum	26,200
Sphere, Distributed Source, Maximum	57,700

6.2.3.2 Quantitative Analysis Results. Quantitative analysis reflects the ability of each technology to determine true leakage volumes and rates, either by direct calculation or by inference from collected data. Only two technologies, mass balance and 8,3 ERT, can provide quantitative analysis.

The 4,1 ERT technology, borehole logging, and TDR.can provide qualitative information that is similar to or less sensitive than data that can be provided by mass balance technology. These data are considered qualitative because they do not improve upon data that can be generated using the baseline mass balance technology.

Mass balance technology provides leakage data that can be directly manipulated to calculate quantity of leaked waste, within the error limits of the technology. Measurements

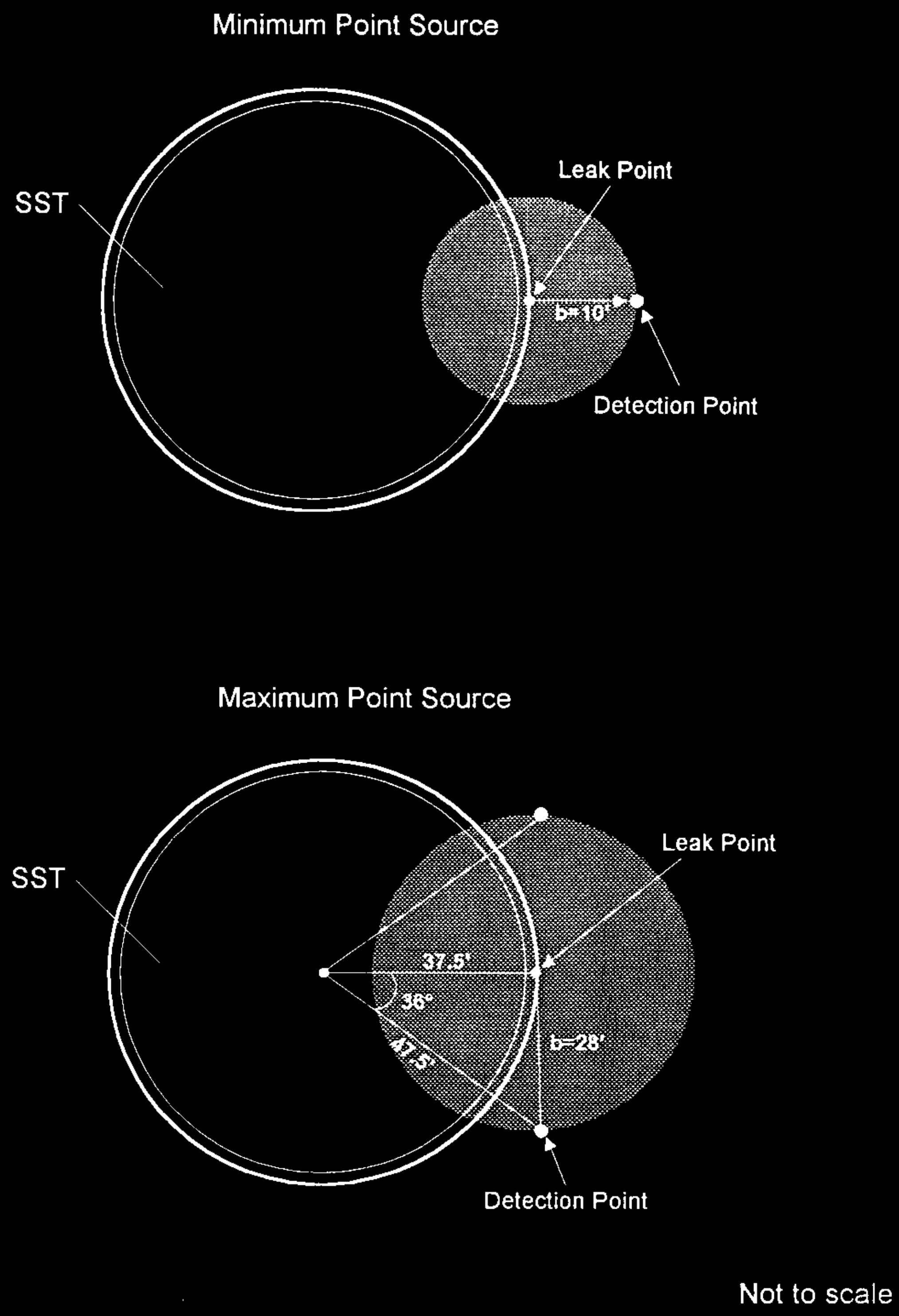

Figure 6-4. Borehole Logging and TDR - Point Source.

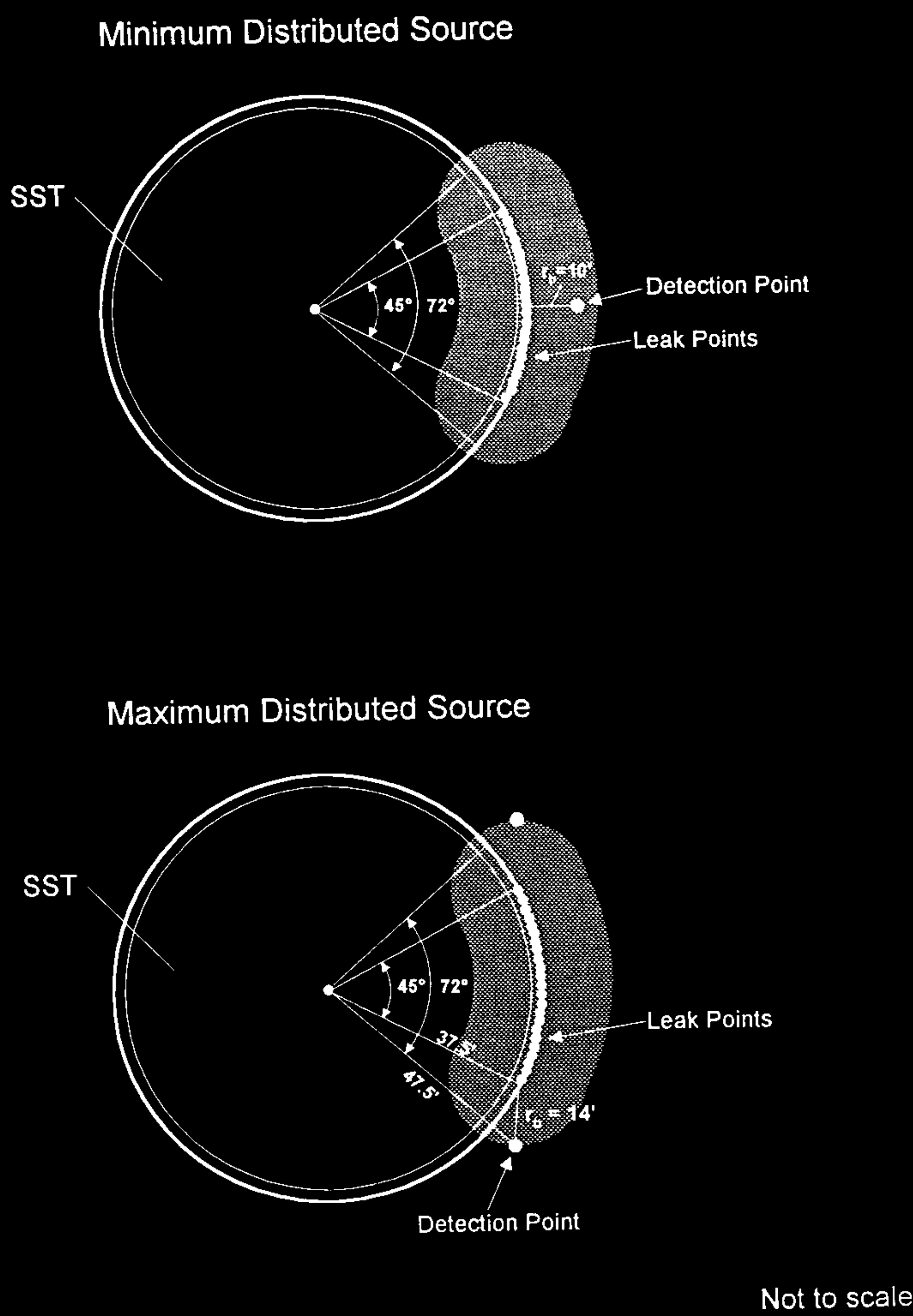

Figure 6-5. Borehole Logging and TDR - Distributed Source.

would be taken that allow calculation of the initial volume of waste in the retrieval tank, and the final volumes of waste in the retrieval and receiving tanks. The difference between the initial volume and the sum of the final volumes, if any, is the true quantity of waste leaked. Repeating the measurements a known time from the previous measurements allows the leakage rate to be calculated.

The 8,3 ERT technology would use multiple data points and sophisticated software algorithms to form a three-dimensional tomograph of the subsurface leakage plume. The actual volume of leakage can be calculated from the inferred volume of the plume. The results of the pilot tests reported in Ramirez et al. (1995), provide excellent determination of plume volume. However, the ERT system used in the three-dimensional tomograph modeling by Ramirez et al. (1995) was an 16,8 configuration, and the proposed 8,3 configuration is not expected to provide equivalent results. Nevertheless, 8,3 ERT technology may provide the best quantitative results of the technologies evaluated. The results of the quantitative analysis evaluation are summarized in Table 6-8.

Table 6-8. Technology Operability and Effectiveness - Quantitative Analysis.

Technology	Quantitative Analysis
Mass Balance	Volume - Yes, Calculated Rate - Yes, Calculated
Tracer Gas	Volume - None Rate - None
4,1 ERT	Volume - Qualitative Only Rate - Qualitative Only
8,3 ERT	Volume - Yes, Inferred Rate - Yes, Inferred and Calculated
Borehole Logging	Volume - Qualitative Only Rate - Qualitative Only
TDR	Volume - Qualitative Only Rate - Qualitative Only

6.2.4 Health and Safety Risk Evaluation Results

As described in Section 6.1.4, the evaluation of health and safety risk was reduced to determining the public cancer and toxicity impacts associated with leakage from an average tank farm.

The cancer and toxicity impacts were determined using the results in Treat et al. (1995). The average cancer impact was calculated to be 2.4×10^{-11} per gallon of waste and the average toxicity impact was calculated to be 5.8×10^{-7} per gallon of waste. The detailed results of this analysis are provided in Appendix C.

As reported in Sections 6.1.3 and 6.2.3, several detected leakage volumes are associated with each technology. For the health and safety risk evaluation, a single minimum and a single maximum detected leakage volume were chosen for each technology as representative of the technology's health and safety performance. The end result of the evaluation is a comparative risk value useful for ranking the technologies. Table 6-9 summarizes the results of the safety risk analysis. Detected leakage volumes were not determined for tracer gas technology, so safety risk values for the tracer gas technology are likewise undetermined.

Table 6-9. Summary of Leakage Technology Public Health Risk.

Technology	Cancer Risk		Hazard Index	
	Minimum	Maximum	Minimum	Maximum
No Action	1.9E-6	1.9E-6	4.6E-2	4.6E-2
Mass Balance	2.7E-7	9.6E-7	6.4E-3	2.3E-2
Tracer Gas	Undetermined	Undetermined	Undetermined	Undetermined
4,1 ERT	1.6E-7	1.6E-6	3.9E-3	3.9E-2
8,3 ERT	4.8E-8	6.2E-7	1.2E-3	1.5E-2
Borehole Logging	2.0E-7	8.6E-6	4.7E-3	2.1E-1
TDR	2.0E-7	8.6E-6	4.7E-3	2.1E-1

6.2.5 Environmental Acceptability Results

Each technology was evaluated for environmental acceptability with respect to effluent treatment and secondary waste generation. Tracer gas technology was the only technology identified that involved secondary environmental impacts. The remaining technologies are not considered further in this section.

Tracer gas technology requires an SVE system to withdraw soil vapor from the subsurface for analysis. A SVE system may include both treatment for collected soil moisture and generation of secondary wastes, e.g., spent filters and granular activated carbon (GAC). While different SVE configurations are possible, the most common system configuration includes treatment of the effluent soil vapor stream by directing it through GAC, where volatile organic contaminants adsorb onto the GAC and are thus removed from the effluent air stream. Use of GAC results in spent GAC that must be regenerated, usually by a vendor for a fee. The presence of radionuclides in soil around SSTs may complicate the regeneration process. Tank waste characterization data must be evaluated to determine if GAC is necessary for treatment of the effluent soil vapor following a leak. Other potential volatile organic treatment strategies are thermal and/or catalytic oxidation, in which the contaminants are heated to sufficiently high temperatures to cause their destruction. Tritium and other radioactive materials may be captured in condensate and collected by the SVE system. This effluent may require treatment or transfer to a DST.

6.2.6 Technical Maturity Results

The results of the technical maturity evaluation are summarized in Table 6-10.

Table 6-10. Technical Maturity of Leakage Detection Technologies.

Technology	Available	Deployable Around SSTs	Demonstrated at Hanford
Mass Balance	Yes	Yes	No
Tracer Gas	Yes	Potentially	No
4,1 and 8,3 ERT	Potentially	Potentially	Yes
Borehole Logging	Yes	Yes	No
TDR	Potentially	Potentially	No

The results of "Potentially" under the available criterion in Table 6-10 indicate that the technology is available, but not through commercial vendors. In these cases, the technology is considered to be experimental for the application of leakage detection and is available only from the developing laboratory. ERT is being developed by the Lawrence Livermore National Laboratory and is currently only available from Lawrence Livermore. TDR is commercially available in other configurations, but as proposed and described in this study, is only available from Pacific Northwest National Laboratories.

The results of "Potentially" under the deployable criterion in Table 6-10 indicate that the technology is fully deployable in principle, but has never been deployed around the Hanford Site SSTs. Site-specific issues of implementation are unresolved at this point. These issues primarily involve the physical interfaces identified in Section 6.1.7. Tracer gas technology would require installation of an extraction well beneath the center of each tank. ERT and TDR technologies both would require installation of numerous CPT wells in close proximity to the tanks. There are potential worker safety, cost, and tank structural impacts associated with these requirements.

The only technology that has been tested for tank leakage detection at the Hanford Site is ERT. Pilot tests using a 50-ft diameter tank and liquids designed to simulate actual tank waste were performed in 1994 and 1995. These tests are reported in Ramirez et al. (1995). Mass balance technology is scheduled to be used during the retrieval of Tank 241-C-106, and should be reevaluated as additional data are obtained.

6.2.7 Complexity of Interfaces Results

The complexity of interfaces for each technology was evaluated for four sets of interfaces: inputs, outputs, physical, and support. These interfaces are described below.

- The input interfaces are those resources that must be supplied to the technology to install and operate it. These include utilities, such as electrical, gas, steam, or water, and consumable materials and supplies.

- The output interfaces are output streams that result from installation or operation of the technology and that require attention. All technologies include a data output stream for processing and all produce used equipment streams requiring disposal.

- The physical interfaces are the prerequisite demands of the technology for space and location on the installation site.

- The support interfaces include coordination between different departments or groups necessary to complete installation and maintenance, such as crafts, procurement, and third-party vendors.

Each set of interfaces was evaluated using available information and best engineering judgement; a complexity index range of 0 to 5 was used. A complexity index of 0 indicates that the interface does not apply or there is no impact. A complexity index of 2 designates a moderate complexity, and an index of 5 designates a significant or difficult complexity. The complexity indexes were then multiplied by a weighting factor assigned to each interface type to represent the relative importance of each interface. The physical interfaces were weighted highest due to the high difficulty of emplacing and operating equipment in tank farms, especially during active operations. The support interfaces were weighted next highest due to expected high coordination difficulties with other tank farm operations. The input and output interfaces were weighted equally low because they pose readily solvable problems. The results of the evaluation are summarized in Table 6-11, and described below.

Table 6-11. Summary Leakage Detection Technology Evaluation of Complexity of Interfaces.
(W.F. = weighting factor)

Technology	Inputs (W.F.=1)		Outputs (W.F.=1)		Physical (W.F.=3)		Support (W.F.=2)		Interface Index
No Action	0	0	0	0	0	0	0	0	0
Mass Balance	1	1	0	0	1	3	1	2	6
Tracer Gas	2	2	2	2	5	15	2	4	23
4,1 ERT	1	1	0	0	3	9	1	2	12
8,3 ERT	1	1	0	0	5	15	1	2	18
Borehole Logging	1	1	0	0	0	0	3	6	7
TDR	1	1	0	0	3	9	1	2	12

Mass balance technology has relatively few input requirements. Remote video cameras installed within the tanks for waste estimation will require power to operate. Pumping a tank of drainable liquids prior to waste estimation requires the use of the existing retrieval equipment. The only output of mass balance technology is the data stream that will require processing to determine if a leak has occurred. This output is essentially constant across all technologies and is sufficiently minor that it is not reflected in Table 6-11. The physical interfaces of mass balance are the necessity of a video camera and ENRAF or equivalent measurement instrument in each tank to be retrieved, and the equipment to drain the tank of fluids. The latter is satisfied by retrieval operations and is not considered further. The former is judged to have relatively minor interface complexity. The support interfaces are primarily labor and considered to have minor complexity. The interface index for mass balance is 6.

Tracer gas technology inputs include utilities to operate the SVE system and GAC, if required, for treatment of the effluent soil vapor stream. The GAC would be purchased from a third-party vendor. The output interfaces for tracer gas testing include the data stream and secondary waste streams. As the only technology with a secondary waste stream other than failed and discarded equipment, tracer gas technology is considered to have greater complexity of output interfaces than the other technologies. The physical interfaces include the requirements of installing CPT wells in the tank farms. Location of a CPT well is subject to the presence of aboveground and belowground piping, the minimum proximity to a tank, and other factors. This makes optimum well placement difficult at best. The physical interface complexity is therefore judged to be relatively high. The support interface includes labor, crafts, procurement, and vendors, but the necessary tasks are routine and should pose no unusual problems. The support interface complexity is considered minor. The interface index for tracer gas technology is 23.

The 4,1 ERT and 8,3 ERT are two configurations of the same technology and have the same interfaces. Input interfaces include utilities, primarily electrical, and are considered minor. Output interfaces are limited to the data stream and are not considered further. The physical interfaces for the ERT configurations include CPT well placement and pose the same problems as described above for tracer gas testing. However, the larger added number of CPT wells in the 8,3 ERT configuration increases the probability of physical interferences. The support interface for both ERT configurations includes craft labor and procurement prior to and during installation, but is essentially automated and free of support requirements during operation, save for processing the data stream. The support interface complexity is considered minor. The interface indexes for the ERT configurations are 12 for 4,1 ERT and 18 for 8,3 ERT.

Borehole logging input interfaces are limited to utilities as required by the logging vendor and are of minor complexity. It is assumed that the vendor is responsible for any output interfaces other than the data stream, and therefore there are no interfaces shown. This evaluation assumes that borehole logging will occur only in existing tank farm boreholes, thus no additional physical interfaces are required. Support interfaces include the vendor to perform the logging and associated procurement. Support interfaces are considered minor. The interface index for borehole logging is 7.

The TDR interfaces parallel those of the 4,1 ERT configurations. The application of the technology is the same, involving the placement of subsurface probes in CPT wells, and differing only in the types of measurements taken and an additional CPT well for TDR. For this reason, the interfaces and the associated complexities are similar. The interface index for TDR is 12.

6.3 LEAKAGE DETECTION COST-BENEFIT ANALYSIS

The cost-benefit for leakage detection technologies was estimated using the carcinogenic risk and hazard index (HI) measures presented in Section 6.2.4 and the TNPW cost measures presented in Section 6.2.1. The benefit is expressed as **the risk that is avoided** if leakage is limited to the volume first detected. This also assumes that no additional leakage is associated with the mitigation process and does not account for the additional costs associated with leakage mitigation (which may be large).

This benefit is calculated by the risk-difference method and is expressed as a percentage. This method is defined as 100% times 1 minus the ratio of the relative risk ($Risk_n$ or HI_n) associated with the leakage detection technology to the relative risk ($Risk_i$ or HI_i) of the no action alternative.

$$Benefit_{HI} = \% \ Risk\ Avoided = (1 - [HI_n/HI_i])100\%$$

$$Benefit_{risk} = \% \ Risk\ Avoided = (1 - [Risk_n/Risk_i])100\%$$

Cost is defined as the TNPW of the leakage detection technology.

$$Cost = TNPW$$

Hence, benefit by this method reflects the percentage increase or decrease in risk and cost is the increase or decrease in TNPW cost. Cost-benefit in this analysis is defined as the ratio of the risk-difference benefit (the "bang") to the cost (the "buck"). Thus a higher cost-benefit is desirable as it results from either increasing the risk avoided and/or lowering the cost.

As can be seen in Table 6-13, the cost-benefit for borehole logging and TDR systems is zero. The upper detection limit for these technologies is greater than the total leakage estimated to occur under a no action scenario. In those situations, the assumed maximum no action leakage (40,000 gal) could occur with no detection by borehole logging or TDR, thus no benefit would be obtained. For this reason, neither of these technologies are considered feasible for the *leakage detection* function.

As seen in Tables 6-12 and 6-13, *mass balance* has a significantly better cost-benefit than any of the other technologies. This is a result of detection limits relatively equivalent to other technologies at a significantly lower cost.

Table 6-12. Cost-Benefit of Leakage Detection Technologies Relative to No Action (Lower Range Detection Limit).

Technology	% Public Risk Avoided (Benefit)[a]		Cost	Cost-Benefit	
	Cancer Risk	HI	TNPW ($M per Tank Farm)	Cancer Risk	HI
No Action	0	0	0	0	0
Mass Balance	86	86	0.47	184	184
Tracer Gas	Undetermined	Undetermined	1.7	Undetermined	Undetermined
4,1 ERT	92	92	1.9	48	48
8,3 ERT	98	98	3.9	25	25
Borehole Logging	90	90	4.1	22	22
TDR	90	90	3.9	23	23

[a] The % public risk avoided assumes that the leakage is limited to the volume first detected (detection limit).

Table 6-13. Cost-Benefit of Leakage Detection Technologies Relative to No Action (Upper Range Detection Limit)

Technology	% Public Risk Avoided (Benefit)[a]		Cost	Cost-Benefit	
	Cancer Risk	HI	TNPW ($M per Tank Farm)	Cancer Risk	HI
No Action	0	0	0	0	0
Mass Balance	50	50	0.47	107	107
Tracer Gas	Undetermined	Undetermined	1.7	Undetermined	Undetermined
4,1 ERT	15	15	1.9	8	8
8,3 ERT	68	68	3.9	17	17
Borehole Logging	-350	-350	4.1	0	0
TDR	-350	-350	3.9	0	0

[a] The % public risk avoided assumes that the leakage is limited to the volume first detected (detection limit).

7.0 ANALYSIS OF ALTERNATIVES FOR LEAKAGE MONITORING

The leakage detection and monitoring systems described in Section 4.1 were evaluated based on the leakage monitoring performance measures described in Section 5.2. The evaluation approach, the results of the analysis, and the cost-benefit of each technology are provided in Sections 7.1, 7.2, and 7.3, respectively.

7.1 LEAKAGE MONITORING COST/RISK EVALUATION APPROACH

The approach taken to assess the leakage monitoring technologies against the three performance measures, (i.e., cost, operability, and technical maturity) are described in the following sections. No additional evaluation was necessary for the schedule, safety, environmental acceptability, and complexity of interface performance measures because the analysis presented in Section 6 for leakage detection also applies to leakage monitoring.

Two of the technologies under consideration, mass balance and tracer gas, are not applicable as monitoring technologies. Mass balance technology considers only factors within the tank, making it unsuitable for monitoring a leakage plume exterior to the tank. Tracer gas technology depends on the presence of a tracer in the waste leakage. Unless the tracer content of the leakage plume is continuously recharged through additional leakage, the ability of the technology to monitor the leakage plume will decrease. The tracer content of the leakage plume will be recharged while there exists an active leak, but following completion of retrieval activities on a tank, no further leakage will occur. Therefore, tracer gas technology is not suitable for monitoring leakage plumes.

7.1.1 Costing Methodology

The costing methodology used for evaluating the leakage monitoring costs is the same as that described in Section 6.1.1. The only difference is that the operating and maintenance (O&M) costs for borehole logging were based on quarterly logging of each borehole rather than daily logging, which is required to support leakage detection.

7.1.2 Operability/Maintainability/Effectiveness Methodology

A functional requirement specific to leakage monitoring is the ability to identify the location of the leakage plume and track its movement. This requirement can be satisfied if a technology can locate a point in a leakage plume, locate a transect of the leakage plume cross-section, and/or locate the volume of the leakage plume. The technologies were assessed for ability to meet these three progressively more challenging objectives. The ability to locate a point in a leakage plume, ability to locate a transect of a plume cross-section, and ability to locate the volume of a plume were each assigned a value of 1. Inability was assigned a value of zero. The values for each technology were then summed to provide a score for each. These scores were used as described in Section 7.3 to evaluate the cost-benefit of the technologies for leakage monitoring.

7.1.3 Technical Maturity Methodology

The methodology used for evaluating the technical maturity of leakage monitoring technologies is the same as that described in Section 6.1.6 for leakage detection.

7.2 LEAKAGE MONITORING COST/RISK EVALUATION RESULTS

This section contains a summary of results of the cost and system effectiveness evaluations.

7.2.1 Cost Results

The detailed costs estimates are included in Appendix A. A summary of the results of the cost estimates is provided in Table 7-1.

Table 7-1. Summary of Estimated Leakage Monitoring Program Costs (1996 dollars).
(Results shown are in $1,000)

Cost Category	No Action	Mass Balance[a]	Tracer Gas[a]	4,1 ERT	8,3 ERT	Borehole Logging	TDR
Development	$0	N/A	N/A	$2,000	$2,000	$0	$500
Preparation	0	N/A	N/A	8	8	8	8
Installation	0	N/A	N/A	21,000	44,000	0	46,000
Operation	0	N/A	N/A	230	230	42,000	230
Decommissioning	0	N/A	N/A	270	530	290	290
TNPW	0	N/A	N/A	23,000	46,000	42,000	47,000
TNPW per tank	0	N/A	N/A	280	570	520	580

[a] Mass balance and tracer gas technologies are not applicable for leakage plume monitoring, therefore monitoring costs were not evaluated.

7.2.2 Operability/Maintainability/Effectiveness Results

The results of the effectiveness evaluation based on the leakage plume location are shown in Table 7-2. Three technologies do not meet the functional requirements for effectiveness: mass balance, tracer gas, and 4,1 ERT. The TDR technology can provide a point in the vadose zone for each TDR probe, while borehole logging technology can provide a cross-section of the plume because logging generates data for the full depth of the borehole. ERT technology in the 8,3 configuration can provide volumetric data regarding the plume location and size.

Table 7-2. Summary of Leakage Plume Location Monitoring Capabilities.

Technology	Leakage Plume Location			Total Score
	Point Data	Cross-Section Data	Volume Data	
Mass Balance	N/A	N/A	N/A	N/A
Tracer Gas	N/A	N/A	N/A	N/A
4,1 ERT	0	0	0	0
8,3 ERT	1	1	1	3
Borehole Logging	1	1	0	2
TDR	1	0	0	1

7.2.3 Technical Maturity Results

The results of the technical maturity evaluation are shown in Table 7-3. The only change from the results shown in Section 6.2.6 for leakage detection technologies is because both borehole logging and TDR have been demonstrated at the Hanford Site for leakage plume monitoring.

Table 7-3. Technical Maturity of Leakage Monitoring Technologies.

Technology	Available	Deployable Around Hanford SSTs	Demonstrated at the Hanford Site
Mass Balance	N/A	N/A	N/A
Tracer Gas	N/A	N/A	N/A
4,1 and 8,3 ERT	Potentially	Potentially	Yes
Borehole Logging	Yes	Yes	Yes
TDR	Potentially	Potentially	Yes

7.3 LEAKAGE MONITORING TECHNOLOGY COST-BENEFIT ANALYSIS

The cost-benefit of leakage monitoring technologies is defined as the relative benefit divided by the cost (TNPW). Benefit is based on the effectiveness scores shown in Table 7-2. The cost-benefit results for leakage monitoring are shown in Table 7-4. The 8,3

ERT technology provides a higher cost-benefit than the baseline monitoring technology (borehole logging).

Table 7-4. Cost-Benefit of Leakage Monitoring Technologies.

Technology	TNPW ($million per Tank)	Relative Benefit	Cost-Benefit
No Action	0	0	0
Mass Balance	N/A	N/A	N/A
Tracer Gas	N/A	N/A	N/A
4,1 ERT	0.28	0	0
8,3 ERT	0.57	3	5.3
Borehole Logging	0.52	2	3.9
TDR	0.58	1	1.7

8.0 ANALYSIS OF ALTERNATIVES FOR LEAKAGE MITIGATION

The leakage mitigation technologies described in Section 4.2 were evaluated on the same basis as the leakage mitigation technologies developed and evaluated in Treat et al. (1995). The approach to evaluating the performance measures, the results of the analysis, and the cost-benefit are provided in Sections 8.1, 8.2, and 8.3, respectively.

8.1 LEAKAGE MITIGATION COST/RISK EVALUATION APPROACH

The primary performance measures that were used to compare leakage mitigation technologies in Treat et al. (1995) were cost and public health risk resulting from waste leakage. The costs and public health risks provided in Treat et al. (1995) for traditional (past-practice) sluicing were modified to account for additional costs and potential leakage mitigation provided by the limited sluicing technology described in Stuart et al. (1996).

Leakage mitigation technologies evaluated by Treat et al. (1995) included: three types of tank waste retrieval technologies (past-practice sluicing, mechanical retrieval, and robotic sluicing), six types of subsurface barriers (close-coupled chemical barrier, modified close-coupled barrier, box-shaped chemical barrier, V-shaped chemical barrier, V-shaped freeze wall barrier, and circulating air barrier), two types of soil flushing to recover leaked waste (gravity flushing and suction flushing), a single method of stabilizing cleaned tanks (grouting), and a single method of capping the stabilized tanks (the Hanford Protective Barrier).

Treat et al. (1995) showed that there are large differences in worker safety risks associated with these technologies. Worker safety risk was not evaluated here to maintain consistency with the previous evaluations of leakage detection and monitoring which addressed only public health risk.

8.1.1 Costing Methodology

The costs for past-practice sluicing were evaluated by Treat et al. (1995) for the following life-cycle cost categories: technology readiness, capital, O&M, waste disposal, and decontamination and decommissioning (D&D). These costs were combined to provide the TNPW cost.

It was assumed that there would be a doubling of technology readiness costs associated with limited sluicing over those for past-practice sluicing due to uncertainties regarding effectiveness of the technology. The capital costs were also increased over past-practice sluicing because more complex sluicing nozzles and telescoping pumps are required for limited sluicing. The engineering and special equipment capital costs were assumed to increase by 25%. The O&M and D&D costs were estimated as a percentage of the capital costs. The O&M costs were assumed to be 3.8% of the capital costs and the D&D costs were assumed to be 10% of the capital costs plus one year of personnel costs.

8.1.2 Health and Safety Risk Methodology

The public health risk associated with leakage mitigation was calculated by Treat et al. (1995) for carcinogenic and chemical hazards introduced to the public by exposure to contaminated groundwater. The following discussion of the methodology is taken from Treat et al. (1995).

A first approximation of relative human health risks from exposure to contaminated groundwater was performed in a two-step analysis. The first step was definition of potential residual sources of groundwater contamination following completion of tank waste retrieval operations. This included identifying residual contaminant sources and their potential inventories of contaminants, and estimating the rates and duration of contaminant releases from these sources into the vadose zone.

The second step in the assessment of the relative risks involved modeling the transport of contaminants through the vadose zone and aquifer, and estimating potential human exposure and health risk. This was accomplished using the MEPAS Version 3.0g computer code (Droppo et al. 1989). The MEPAS is designed to evaluate relative human health risk from radiological and chemical contaminants released into the environment.

The potential sources of groundwater contamination that were analyzed include the following:

- Residue in tank following waste retrieval
- Residue between tank steel and concrete foundation
- Residue within tank concrete
- Residue in soil due to old and new leakage
- Residue following soil flushing of old and new leakage
- Residue within close-coupled barrier
- Residue following use of standoff barrier.

It was assumed that limited sluicing would impact only the waste residue in the soil by reducing the amount of new leakage. Treat et al. (1995) assumed that past-practice sluicing resulted in 150,000 L (40,000 gal) of leakage from a tank with a hydraulic head averaging 4.6 m (15 ft), while robotic sluicing resulted in 15,000 L (4,000 gal) of leakage from a tank with a 460-mm (1.5-ft) hydraulic head. Limited sluicing would likely operate with a lower hydraulic head in the tank relative to past-practice sluicing, but a higher hydraulic head than robotic sluicing. It was assumed that the average hydraulic head associated with limited sluicing would be 1,500 mm (5 ft) with resulting 50,000 L

(13,000 gal) leakage. The public health risk values associated with leakage from Treat et al. (1995) were used to estimate the risks associated with 90,000 L (13,000 gal) of leakage.

8.2 LEAKAGE MITIGATION COST/RISK EVALUATION RESULTS

Results of the cost and health and safety risk evaluations are presented.

8.2.1 Cost Results

The results of the cost evaluation are shown in Table 8-1. Limited sluicing adds $8 million, or approximately 7%, to the cost of past-practice sluicing.

8.2.2 Health and Safety Risk Results

The results of the health and safety risk evaluation are shown in Table 8-2. Limited sluicing would reduce the public health risk from all residual tank waste sources by approximately 30% relative to past-practice sluicing. This is a direct result of the assumed reduction in volume of new leakage achievable by limited sluicing. It was assumed that limited sluicing was applied to all SSTs, not just the 82 nonleaking tanks, in order to enable comparison with the results of Treat et al. (1995).

8.3 LEAKAGE MITIGATION COST-BENEFIT ANALYSIS

This section contains a comparison of the relative cost-benefit of the limited sluicing technology versus cost-benefits developed in Treat et al. (1995) for 12 other leakage mitigation alternatives. The cost-benefit was estimated using the TNPW measures presented in Table 8-1 and peak relative cancer risk and HI measures presented in Table 8-2. The cost-benefit of limited sluicing and the leakage mitigation alternatives from Treat et al. (1995, page 8-2) relative to a no action alternative is shown in Table 8-3.

The cost-benefit of an alternative is defined as its relative reduction in public health risk divided by the TNPW, as shown below:

$$\text{Cost-Benefit}_{risk} = ((\text{Risk}_i/\text{Risk}_n) - 1)/\text{TNPW}$$

$$\text{Cost-Benefit}_{HI} = ((\text{HI}_i/\text{HI}_n) - 1)/\text{TNPW}$$

This approach for calculating cost-benefit maximizes the credit for reducing residual risks to the lowest possible level. The method for calculating cost-benefit used earlier in this document to assess leakage detection technologies employs a fractional risk reduction approach. That approach would result in cost-benefit values that are essentially proportional

Table 8-1. Estimated TNPW Costs of Risk Mitigation Alternatives (in millions of dollars). (Note: All data except those for Limited Sluicing in Line 4 are from Treat et al. 1995)

Alternative	Subsurface Barrier Option	Retrieval Option	Flushing	Flush Water Treatment	Tank Stabilized	Surface Barrier	Total Costs
1. No Action	none	none	none	none	no	none	0
2. Surface Barrier Only	none	none	none	none	no	yes 8	8
3. Past-Practice Sluicing	none	past pract. sluicing 97	none	none	yes 5	yes 8	110
4. Limited Sluicing	none	limited sluicing 105	none	none	yes 5	yes 8	118
5. Robotic Sluicing	none	robotic sluicing 410	none	none	yes 5	yes 8	423
6. Mechanical Retrieval	none	mech. retrieval 347	none	none	yes 5	yes 8	360
7. Close-Coupled Chemical Barrier with Flushing	close-coupled chemical 263	past pract. sluicing 97	flushing & vacuum 234	14 Mgal 22	yes 5	yes 8	629
8. Close-Coupled Chemical Barrier w/o Flushing	none & close-coupled chemical 192	past pract. sluicing 97	none	none	yes 5	yes 8	302
9. Modified Close-Coupled Chemical Barrier w/o Flushing	partial close-coupled chemical 149	past pract. sluicing 97	none	none	yes 5	yes 8	259
10. Box-Shaped Chemical Barrier	box-shaped chemical 272	past pract. sluicing 97	flushing & pumping 185	245 Mgal 114	yes 5	yes 8	681
11. V-Shaped Chemical Barrier	V-shaped chemical 375	past pract. sluicing 97	flushing & pumping 185	278 Mgal 122	yes 5	yes 8	792
12. V-Shaped Freeze Wall Barrier	V-shaped freeze wall 369	past pract. sluicing 97	flushing & pumping 185	278 Mgal 122	yes 5	yes 8	786
13. Circulating Air Barrier	circulating air 171	past pract. sluicing 97	flushing & vacuum 264	20 Mgal 41	yes 5	yes 8	586

Table 8-2. Estimated Public Health Risk of Risk Mitigation Alternatives.
(Note: All data except those for Limited Sluicing in Line 4 are from Treat et al. 1995)

Alternative	Relative Cancer Risk	Relative HI
1. No Action	1.5E-01	2.8E+03
2. Surface Barrier Only	3.7E-04	8.6E+00
3. Past Practice Sluicing	1.1E-05	2.4E-01
4. Limited Sluicing	7.7E-06	1.7E-01
5. Robotic Sluicing	2.5E-06	5.7E-02
6. Mechanical Retrieval	2.1E-05	4.9E-01
7. Close-Coupled Chemical Barrier with Flushing	5.2E-06	1.2E-01
8. Close-Coupled Chemical Barrier w/o Flushing	7.0E-06	1.6E-01
9. Modified Close-Coupled Chemical Barrier w/o Flushing	8.0E-06	1.8E-01
10. Box-Shaped Chemical Barrier	4.9E-06	1.1E-01
11. V-Shaped Chemical Barrier	4.9E-06	1.1E-01
12. V-Shaped Freeze Wall Barrier	4.8E-06	1.1E-01
13. Circulating Air Barrier	5.1E-06	1.2E-01

Table 8-3. Cost-Benefit of Risk Mitigation Alternatives Relative to the No-Action Alternative.
(Note: All date except those for Limited Sluicing in Line 4 are from Treat et al. 1995)

Alternative	Relative Cancer Risk	HI	TNPW	Risk Cost-Benefit	HI Cost-Benefit
1. No Action	1.5E-1	2.8E+3	0	N/A[a]	N/A[a]
2. Surface Barrier Only	3.7E-4	8.6	8	51	41
3. Past Practice Sluicing	1.1E-5	2.4E-1	110	124	106
4. Limited Sluicing	7.7E-6	1.7E-1	118	165	140
5. Robotic Sluicing	2.5E-6	5.7E-2	423	142	116
6. Mechanical Retrieval	2.1E-5	4.9E-1	360	29	16
7. Close-Coupled Chemical Barrier with Flushing	5.2E-6	1.2E-1	629	46	37
8. Close-Coupled Chemical Barrier w/o Flushing	7.0E-6	1.6E-1	302	71	58
9. Modified Close-Coupled Chemical Barrier w/o Flushing	8.0E-6	1.8E-1	259	72	60
10. Box-Shaped Chemical Barrier	4.9E-6	1.1E-1	681	45	38
11. V-Shaped Chemical Barrier	4.9E-6	1.1E-1	792	39	32
12. V-Shaped Freeze Wall Barrier	4.8E-6	1.1E-1	786	40	33
13. Circulating Air Barrier	5.1E-6	1.2E-1	586	50	40

to cost due to the similarly high risk reduction effectiveness of each leakage mitigation alternative. The selected method for calculating cost-benefit allows for differentiation of alternatives based on both risk reduction and cost.

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9.0 CONCLUSIONS

Comparisons of the leakage detection, monitoring, and mitigation technologies against the functional requirements and performance criteria are provided in Tables 9-1, 9-2, and 9-3, respectively. Three technologies (mass balance, leakage detection pit, and ERT) meet or potentially meet the requirements for leakage detection and three (ERT, borehole logging, and TDR) meet or potentially meet the requirement for leakage monitoring. All of the identified mitigation technologies potentially meet the leakage mitigation requirements.

Due to the limited set of currently available technologies, all of the technologies identified as available and deployable were assumed to be used in conjunction as the selected baseline LDMM system. The baseline leakage detection component consists of liquid/waste level measurement devices inside the tank (i.e. mass balance) and leakage detection pits (where available). The baseline leakage monitoring component consists of borehole logging. Operational, procedural, and administrative methods and improved equipment would be used to mitigate leakage during past-practice sluicing.

9.1 LEAKAGE DETECTION

Excluding leakage detection pits that are specific only to the AX Tank Farm, only mass balance and ERT leakage detection technologies are applicable or potentially applicable to support past-practice sluicing (Table 9-1). Of these, only mass balance can be considered as available and deployable. The cost, cost-benefit, and detection limits range for each of the leakage detection and monitoring technologies are summarized in Table 9-4. The costs for both ERT configurations are higher than for mass balance. However, the potential for lower detection limits using 8,3 ERT may be attractive when a premium is placed on minimizing high-risk waste leakage. Minimizing leakage in certain cases may avoid expensive tank farm closure requirements that may be imposed when a relatively small volume of high-risk leakage contributes to excessive public health risk.

Tracer gas testing is an established leakage detection technology in the petroleum industry where it is reported that detection sensitivities of 0.05 gal/hr are obtained. The application of this technology to Hanford Site SSTs has not been developed to a stage that allows any estimate of detection limit. However, the success of the technology in other industries indicates a potential for success in this application. The primary issues regarding the use of tracer gas leakage detection include (1) establishing a functional and deployable configuration of vapor extraction wells around and/or under SSTs, (2) selecting an appropriate tracer for high-salt radioactive aqueous waste, (3) determining whether offgas treatment is necessary and if secondary waste would be generated, (4) finding a means of mixing the tracer with the interstitial liquid in the tank which is likely to be the first material to leak from an SST, (5) avoiding false-positive indications of leakage due to escape of tracer gas through holes in the tank above the liquid level, and (6) quantifying the detection limit for the technology based on the previous issues. These large issue some doubt about the feasibility of tracer gas for SST leakage detection.

Table 9-1. Comparison of Leakage Detection Technologies Based on Functional Requirements and Performance Criteria.

DETECTION TECHNOLOGY	REQUIREMENTS									RANKING VARIABLE
	AVAILABLE	DEMONSTRATED DEPLOYABLE	DEMONSTRATED RELIABLE	DETECTION INDEPENDENT OF LEAKAGE LOCATION	TIMELY DETECTION	LEAKAGE VOLUME	LEAKAGE RATE	SECONDARY WASTE GENERATION	EFFLUENT TREATMENT	KNOWN DETECTION LIMIT
Mass Balance	●	●	◐	●	●	●	◐			◐
Tracer Gas	●	○	○	○	◐			●	●	○
Leak Detection Pit	●	◐	●	●	●	●	◐			●
ERT	◐	◐	○	○	◐	◐	◐			○
Borehole Logging	●	●	●							◐
TDR	◐	◐	○							○

● YES

◐ YES with Qualifications

○ POTENTIALLY but unproven for SST application

Table 9-2. Comparison of Leakage Monitoring Technologies Based on Functional Requirements and Performance Criteria.

MONITORING TECHNOLOGY	REQUIREMENTS				RANKING VARIABLE		
	AVAILABLE	DEMONSTRATED DEPLOYABLE	DEMONSTRATED RELIABLE	PLUME LOCATION/ DIRECTION	LEAKAGE CONSTITUENTS	SECONDARY WASTE GENERATION	EFFLUENT TREATMENT
Mass Balance	●	●	◐				
Tracer Gas	●	○	○			●	●
Leak Detection Pit	●	◐	●		●		
ERT	◐	◐	○	◐			
Borehole Logging	●	●	●	◐	◐		
TDR	◐	◐	○	◐			

● YES

◐ YES with Qualifications

○ POTENTIALLY but unproven for SST application

Table 9-3. Comparison of Leakage Mitigation Technologies Based on Functional Requirements and Performance Criteria.

MITIGATION TECHNOLOGY	REQUIREMENTS: AVAILABLE	REQUIREMENTS: DEMONSTRATED DEPLOYABLE	REQUIREMENTS: DEMONSTRATED RELIABLE	REQUIREMENTS: REDUCE/CONTAIN LEAKAGE RELATIVE TO BASELINE	RANKING VARIABLE: SECONDARY WASTE GENERATION	RANKING VARIABLE: EFFLUENT TREATMENT
Past-Practice Sluicing	YES	YES	YES	N/A		
Limited Sluicing	YES with Qualifications	YES with Qualifications	YES with Qualifications	YES with Qualifications		
Robotic Sluicing	POTENTIALLY	POTENTIALLY	POTENTIALLY	YES		
Mechanical Retrieval	POTENTIALLY	POTENTIALLY	POTENTIALLY	YES		
Chemical Subsurface Barriers	POTENTIALLY	POTENTIALLY	POTENTIALLY	POTENTIALLY		
Freeze Wall Subsurface Barrier	POTENTIALLY	POTENTIALLY	POTENTIALLY	POTENTIALLY		
Circulating Air Subsurface Barrier	POTENTIALLY	POTENTIALLY	POTENTIALLY	POTENTIALLY	YES	YES

● YES

◐ YES with Qualifications

○ POTENTIALLY but unproven for SST application

Table 9-4. Comparison of Leakage Detection Technologies.

Leakage Detection Technologies	TNPW Cost per Tank Farm ($million)	Cost-Benefit		Detection Limit Range (gal)
		Lower Range Limit	Upper Range Limit	
No Action	0	0	0	N/A
Mass Balance	0.47	184	107	5,570 - 20,000
Tracer Gas	1.7	Undetermined	Undetermined	Undetermined
4,1 ERT	1.9	48	8	3,400 - 34,000
8,3 ERT	3.9	25	17	1,000 - 13,000
Borehole Logging	4.1	22	0	4,100 - 180,000
TDR	3.9	23	0	4,100 - 180,000

The ERT technology is a leakage detection technology that is in the middle stage of development. It has the potential to achieve low detection limits and determine leakage volume. The primary issues regarding the feasibility of ERT are: (1) establishing the feasibility of using CPTs with auguring as a contingency for deploying ERT in an adequate configuration in each tank farm and (2) defining a realistic leakage location probability and volume basis and completing testing against the basis under suitable conditions to establish a statistically defensible leakage detection range for the technology.

Borehole logging and TDR technologies do not meet the functional requirements for leakage detection.

9.2 LEAKAGE MONITORING

As shown in Table 9-2, there are three technologies that meet or potentially meet the requirements for leakage monitoring (specifically the ability to identify the location and movement of a leakage plume). These are 8,3 ERT, borehole logging (neutron-neutron or gamma probe), and TDR technologies. Of these, only borehole logging is available and deployable at the Hanford Site.

8,3 ERT can potentially map and track the three-dimensional movement of a leakage plume over time. This information can be used to quantify the leakage plume. Borehole logging and TDR technologies can only identify and monitor a cross-section or single points within a leakage plume. The successful development and deployment of ERT as both a leakage detection and leakage monitoring tool would provide the additional benefit of addressing the two functions with a single system.

TDR is a commercially available technology; however, its application at the Hanford Site has not been demonstrated. The radius of interrogation is limited to approximately 300 mm (1 ft) from the TDR probe, which is similar to the limitation of borehole logging. The primary benefit derived from the use of TDR technology is the gathering of real-time continuous data using recorders placed outside the tank farms. Borehole logging technology requires personnel to lower gamma or neutron probes into the boreholes adjacent to the tanks. The full gamma or neutron scan of a single borehole can take three hours to complete. However, when borehole logging is used for leakage monitoring, data are likely to be required only on a monthly or quarterly basis rather than continuous. Borehole logging for leakage monitoring would not be impacted by or impact tank waste retrieval operations because those activities would be largely completed before long-term leakage monitoring is conducted.

9.3 LEAKAGE MITIGATION

As shown in Figure 9-3, only past-practice sluicing, the baseline retrieval technology for tanks that have not previously leaked, is available, deployable, and proven reliable. Planned equipment and procedural enhancements are expected to further improve waste retrieval rates using past-practice sluicing. This will reduce the sluicing time frame during which leakage can occur, thereby reducing overall leakage and public health risk. The limited sluicing alternative, which is based on fundamental mechanical principles but has not been demonstrated in an SST, may prove to be effective in mitigating leakage. A 30% reduction in total risk posed by the average tank farm following closure activities was estimated if limited sluicing is used to retrieve wastes from each tank. Robotic sluicing and mechanical retrieval may reduce leakage and associated risk by limiting the amount of drainable water in a tank. The technologies are not available and are unproven for applications similar to SST waste retrieval, however.

Three types of subsurface barriers beneath SSTs were considered: chemical, freeze-wall, and circulating air. None of these barriers is available and each poses significant deployment challenges. The barriers would not reduce leakage and long-term risk unless they were installed in a close-coupled configuration (sealed to the exterior of the tank). Only chemical barriers can be installed in this configuration. Candidate chemical barrier materials such as grout have a sufficiently high permeability that some level of leakage into the barrier would occur. Subsurface barriers are also relatively expensive. Their high cost and low effectiveness in reducing leakage results in relatively low cost-effectiveness.

9.4 ITEMS NEEDING FURTHER RESOLUTION

The cost, risk, and cost-benefit analyses presented in this document were based on assumptions made to deal with a number of identified issues. The issues, assumptions, and suggested analyses are described in this section.

9.4.1 Issue 1 - Variability in Risk Posed by Leakage from Different Tanks

The applicability of LDMM technology may be dependant, in part, upon the risks posed by leakage from individual tanks. Cruse et al. (1995) developed preliminary LTVs for individual SSTs based on estimated concentrations of risk-contributing chemicals and radionuclides in SST waste. The LTVs ranged from 10,000 to more than 380,000 L (2,700 to 100,000 gal) for the same unit of posed risk. Although many simplifying assumptions were used, LTVs in Cruse et al. (1995) suggest that sensitive leakage detection may be advisable in some tanks if risk posed by residual waste and leakage will impact tank farm closure requirements.

To simplify the analysis of public health risk in this trade study, it was assumed that leakage contained chemicals and radionuclides at concentrations equal to the concentrations expected in average SST waste. The potential risk impacts of leakage at the average waste composition were evaluated for different LDMM technologies. No attempt was made to define possible LDMM requirements and feasibility for higher risk leakage.

Suggested Analysis

The LTVs provided in Cruse et al. (1995) should be updated and refined to reflect possible risk impacts of adjacent waste sites and site-specific conditions. These impacts include the potential for overlapping plumes, which may result in lowering the LTV to safely accommodate the combined impacts to the groundwater. Other potential impacts include issues related to tank integrity and other physical conditions that may preclude sluicing and associated leakage or installation of LDMM equipment. The risk-based logic for planning what and when LDMM technology should be deployed for individual tanks should be established.

9.4.2 Issue 2 - Design-Basis Leakage Configuration

The applicability of LDMM technology depends on its sensitivity to detecting and measuring the volume of leakage. A previous analysis by Lowe et al. (1993) identified a most-likely leak location and quantity. Leakage into the soil may occur from any location on the tank surface below the liquid level, however, resulting in plumes of many possible shapes and sizes.

This trade study evaluated minimum and maximum leakage detection limits for sets of conditions most advantageous to detection and least advantageous to detection. Wide ranges of leak detection sensitivities were found for the LDMM technologies evaluated. Minimum leakage detection sensitivities appeared attractive in many cases but maximum leakage detection sensitivities were often unacceptably high. No attempt was made to evaluate the probabilities of various leakage locations, sizes, and probabilities to enable prediction of a most-likely leakage detection volume.

Suggested Analysis

Before further work is performed on leakage detection and monitoring technologies it is suggested that design-basis leakage conditions be established, including probabilities of occurrence. The probability-weighted effectiveness of the technologies should then be determined and compared to the effectiveness of the baseline LDMM system. This effort may also help to improve leakage detection and monitoring sensor configurations for subsequent testing.

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APPENDIX A

DETAILED COST ESTIMATION

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APPENDIX A
DETAILED COST ESTIMATION

A.1 INTRODUCTION

This appendix provides the detailed worksheets used in determining the costs of each of the leak detection, monitoring, and mitigation technologies specified in the body of the associated report. The cost of each technology was evaluated on the basis of overall program costs which were subsequently put on a total net present worth (TNPW) basis and distributed evenly among the tanks to yield a per tank cost in current dollars.

A.2 ASSUMPTIONS

The costs for each technology evaluated were determined from information provided by previous reports and personal communications with knowledgeable persons in the fields in question. However, not all of the required information is currently available and it is necessary to make assumptions concerning each technology. A list of the assumptions used to develop costs is provided below.

- There will be 82 tanks retrieved. This is the number of assumed "sound" or non-leaking tanks (149 tanks less 67 known leaking tanks).

- The total time to retrieve 82 tanks is 13 years. This is based on the schedule developed in "Cost Benefit and Risk Assessment of Alternate High-Level Waste Treatment Strategies" (Foster Wheeler 1995, P. 3-5), which shows the all the SSTs and DSTs. It is assumed that the first 82 SSTs on the schedule are the "sound" tanks and are retrieved in 13 years during a 14 year period. There is one year during which no SST retrieval activity occurs; this year is discarded.

- The total time for the leak monitoring program is the same as the retrieval program, or 13 years. This report assumes that leakage plume monitoring is in support of the retrieval program and does not consider longer-term costs associated with continued monitoring as support of closure.

- The average time to retrieve a SST is 3 months (12 weeks) (Boomer 1993).

- The average number of existing boreholes per tank is 5 (Hanlon 1996).

- Hanford oversight is expressed as the number of additional persons required to support a field activity. This includes project management, health and safety monitoring, procurement, and craft support. A value of four persons per field activity is used. Therefore, installing a well in eight hours also requires a total of 32 hours (eight hours x equivalent four persons) of Hanford oversight.

- Grout for in-situ closure of wells costs \$71.25 per cubic yard delivered (Riggsbee 1996).
- No new boreholes will be drilled. Technologies such as borehole logging and TDR will use only existing boreholes.
- CPT wells can be installed in the Tank Farms. It is assumed that it takes, on average, three attempts to successfully push a CPT well to the desired depth. The two unsuccessful attempts are assumed to reach 50 feet in depth.
- The cost of pushing a CPT well is \$360 per foot (Riggsbee 1996).
- The average cost of labor at the Hanford Site is \$50 per hour.
- Permitting a soil vapor extraction system for tracer gas requires 4 man-weeks of labor.
- Each vertical caisson is capable of being used as a platform for installation of lateral wells under an average of 3 tanks.

A.3 TNPW CALCULATIONS

The costs for the detection and monitoring programs are expressed as total net present worth dollars based on the value of the dollar at the start of the programs. The costs for Development, Preparatory, and Installation are considered lump sum costs expended at the start of the program, and need no adjustments.

The operation costs are assumed to be expended over the 13 year lifetime of the program. These costs are adjusted in the following manner. The total program operation costs are divided by 13 years to determine the annual operation costs, which is then multiplied by a P/A factor to determine the TNPW costs. The P/A factor is calculated as (Collier 1982):

$$P/A = \frac{(1+i)^n - 1}{i(1+i)^n} \qquad \text{where } i = \text{interest rate} = 0.1\ (10\%), \quad n = \text{number of periods} = 13\ \text{(years)}$$

$$= 7.1$$

The decommissioning costs are assumed to be expended as a lump sum at the end of the program lifetime. These costs are adjusted to a value based on dollars at the beginning of the program. The total decommissioning costs are multiplied by a P/F factor to determine the TNPW costs. The P/F factor is calculated as (Collier 1982):

$$P/F = \frac{1}{(1+i)^n}$$

where i = interest rate = 0.1 (10%)
n = number of periods = 13 (years)

$$= 0.29$$

A.4 REFERENCES

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LDM System Mass Balance

COSTS	$	Comments
Development	$0	
Material Balance	no	Existing technology
Preparatory	$8,000	
Work Plans	$8,000	
Permitting Costs	$0	No permit required
Installation	$5,078,000	
Equipment costs	$4,094,000	
SST Camera	$3,520,000	
Cost of one camera	$440,000	Cost of camera modified for in-tank work (Riggsbee
Number of cameras	8	Assumes 4 required and 4 spares/replacements
SST ENRAFT Gauge	$574,000	
Cost of one gauge	$7,000	Cost of gauge (Riggsbee 1996)
Number of gauges	82	Assumes 1 gauge per tank, not re-usable
Installation costs	$984,000	
Number of tanks	82	
Manhours per tank	240	Assumes 6 person crew for one week (Riggsbee
Cost per manhour	$50	
Program Detection Costs	$1,014,000	
Consumable Supplies	$0	
Labor	$1,014,000	
Manhours	20280	Assumes 3 people at 2 hours per day, 260 day/yr, 13
Cost per manhour	$50	
Program Monitoring Costs	$0	
NOT APPLICABLE	$0	
Decommissioning Costs	$0	
Equipment disposal	$0	Assume equipment disposed as part of Tank closure

TOTAL COSTS FOR DETECTION		PRESENT VALUE	
Development	$0	$0	
Preparatory	$8,000	$8,000	
Installation	$5,078,000	$5,078,000	
Operation	$1,014,000	$553,800	Divide total costs by 13 yrs operating life and multiply P/A factor = 7.1, assumes 10% discount rate, 1
Decommissioning	$0	$0	Multiply by P/F factor = .290, assumes 10% discount r and decommissioning occurs 13 years from pre
TNPW		$5,639,800	
Per Tank		$68,778	

TOTAL COSTS FOR MONITORING

Not Applicable Technology for Monitoring

LDM System Tracer Gas

COSTS		$	Comments
Development Costs		$2,000,000	
Tracer	yes	$2,000,000	Selection of tracer gas(es) and on-site field
Preparatory Costs		$41,333	
Work Plans		$8,000	All Tank Farm related work plans (i.e. rad worker,
Permitting		$33,333	Assumes 4 man-months at $100,000/yr
Installation Costs		$16,816,200	
SVE wellfield		$16,050,000	NOTE BELOW
Center caissons		$14,000,000	
Number of caissons		28	Assumes an average of 1 caisson per 3 tanks
Installation cost per caisson		$500,000	Assumes 100 ft deep at $5,000 per foot
Lateral wells		$2,050,000	
Number of lateral wells		82	On lateral per tank
Installation cost per lateral well		$25,000	Assumes 50 ft long at $500 per foot
Tracer and Innoculation		$746,200	
Number of tanks		82	
Mobilization		$3,000	(Lewis, 1995)
Tracer and innoculation		$6,100	(Lewis, 1995)
Vapor Extraction/Sampling Equipment		$20,000	
Number of extraction/sampling systems		2	Assumes no more than 2 caissions (6 tanks) being
Cost per system		$10,000	Assumed
Program Detection Costs		$1,449,000	
Consumable Supplies		$123,000	Assumes 200 lbs GAC per tank per month at $2.5/lb
Labor		$1,326,000	
Manhours		26520	
Number of systems		2	
FTE per system		0.5	Assumed
Total time of operation		13	Years
Cost per manhour		$50	
Program Monitoring Costs		$1,449,000	
Consumable Supplies		$123,000	assume 200 lbs GAC per tank per month at $2.5/lb
Labor		$1,326,000	
Manhours		26520	
Number of systems		2	operating at any point in time
FTE per system		0.5	Assumed
Total time of operation		13	Years
Cost per manhour		$50	
Decommissioning Costs		$1,013,000	
SVE wellfield closure			
Center caissons		$1,013,000	
Consumable Supplies		$5,000	Assumes cleanfill and cap caisson
Labor		$1,008,000	
No. of caissons		28	
Manhours		720	Assuming 6 person crew, 15 days each person
Cost per manhour		$50	
Lateral wells		$98,436	
Consumable Supplies		$36	Assumes .5 cu yd of grout per lateral
Labor		$98,400	
No. of lateral wells		82	
Manhours		24	Assuming 6 person crew, 0.5 days each person
Cost per manhour		$50	
Equipment disposal/scrap		$0	Assumes no salvage value/cost
Waste disposal		$0	No wastes requiring disposal

NOTE: Cost of SVE Well, assume one 100-ft deep caisson services three tanks, each horizontal well is 50-ft long, pipe drilling and jacking cost of $500/ft and caisson cost of $5,000/ft. (ref. Treat et al. 1994, page C-13)

TOTAL COSTS FOR DETECTION			PRESENT VALUE	
Development	$2,000,000		$2,000,000	
Preparatory	$41,333		$41,333	
Installation	$16,816,200		$16,816,200	
Operation	$1,449,000		$791,377	Divide total costs by 13 yrs operating life and multiply P/A factor = 7.1, assumes 10% discount rate, 1
Decommissioning	$1,013,000		$293,770	Multiply by P/F factor = .290, assumes 10% discount and decommissioning occurs 13 years from pr
		TNPW	$19,942,680	
		Per Tank	$243,203	

TOTAL COSTS FOR MONITORING			PRESENT VALUE	
Development	$2,000,000		$2,000,000	
Preparatory	$41,333		$41,333	
Installation	$16,816,200		$16,816,200	
Operation	$1,449,000		$791,377	Divide total costs by 13 yrs operating life and multiply P/A factor = 7.1, assumes 10% discount rate, 1
Decommissioning	$1,013,000		$293,770	Multiply by P/F factor = .290, assumes 10% discount and decommissioning occurs 13 years from pr
		TNPW	$19,942,680	
		Per Tank	$243,203	

LDM System 4,1 ERT

COSTS	$	Comments
Development	$2,000,000	
4,1 ERT	$2,000,000	Assumed
Preparatory	$8,000	
Work Plans	$8,000	
Permitting	$0	No permits required
Installation	$20,751,520	
CPT wells	$20,073,600	
Number of wells	328	Assumes 4 wells per tank
Avg. depth of wells	170	Assumes pushing two 50-ft wells before getting a
Cost per ft of depth	$360	(Riggsbee, 1996)
Labor	$524,800	
No. of wells	328	Assumes 4 wells per tank
Manhours per well	32	Hanford oversight, crafts, and Health and Safety
Cost per manhour	$50	
Probes and Casing Equipment	$13,120	
No. of probes	328	Assumes 4 wells per tank
Cost per probe	$40	(Lewis 1995)
Data Acq Computer/Software	$140,000	Assumes one system can support multiple retrieval
Data collection computer	$50,000	(Lewis, 1995)
Data processing workstation	$70,000	(Lewis, 1995)
Data processing software	$20,000	Assumed
Program Detection Costs	$492,000	
Consumable Supplies	$0	
Labor	$492,000	
Manhours	9840	Assumes 2 man-hours per day per tank, average tank
Cost per manhour	$50	
Program Monitoring Costs	$426,400	
Consumable Supplies	$0	
Labor	$426,400	
Manhours	8528	Assumes 2 man-hours quarterly per tank, average tank
Cost per manhour	$50	Costs per person for work outside a rad zone
Decommissioning Costs	$918,400	
CPT well closure	$918,400	
Equipment	$0	Assumes equipment is owned by Tank Farms
Consumable Supplies	$1,753	Assumes 0.1 cy of grout per well
Labor	$918,400	
Number of wells	328	Assumes 4 wells per tank
Manhours per well	56	Assumes 3 person crew, 8 hours, plus Hanford
Cost per manhour	$50	Costs per person per hour for work within a rad zone

TOTAL COSTS FOR DETECTION			PRESENT VALUE	
Development	$2,000,000		$2,000,000	
Preparatory	$8,000		$8,000	
Installation	$20,751,520		$20,751,520	
Operation	$492,000		$268,708	Divide total costs by 13 yrs operating life and multiply b P/A factor = 7.1, assumes 10% discount rate, 13
Decommissioning	$918,400		$266,336	Multiply by P/F factor = .290, assumes 10% discount ra and decommissioning occurs 13 years from pres
		TNPW	**$23,294,564**	
		Per Tank	**$284,080**	

TOTAL COSTS FOR MONITORING			PRESENT VALUE	
Development	$2,000,000		$2,000,000	
Preparatory	$8,000		$8,000	
Installation	$20,751,520		$20,751,520	
Operation	$426,400		$232,880	Divide total costs by 13 yrs operating life and multiply b P/A factor = 7.1, assumes 10% discount rate. 13
Decommissioning	$918,400		$266,336	Multiply by P/F factor = .290, assumes 10% discount ra and decommissioning occurs 13 years from pres
		TNPW	**$23,258,736**	
		Per Tank	**$283,643**	

LDM System 8,3 ERT

COSTS	$	Comments
Development	**$2,000,000**	
8,3 ERT	$2,000,000	Assumed
Preparatory	**$8,000**	
Work Plans	$8,000	
Permitting	$0	No permits required
Installation	**$43,724,640**	
CPT wells	$42,508,800	
Number of wells	656	Assumes 8 wells per tank
Avg. depth of wells	180	Assumes pushing two 50-ft wells before getting a
Cost per ft of depth	$360	(Riggsbee, 1996)
Labor	$1,049,600	
No. of wells	656	Assumes 8 wells per tank
Manhours per well	32	Hanford oversight, crafts, and Health and Safety
Cost per manhour	$50	
Probes and Casing Equipment	$26,240	
No. of probes	656	Assumes 8 wells per tank
Cost per probe	$40	(Lewis 1995)
Data Acq Computer/Software	$140,000	Assumes one system can support multiple retrieval
Data collection computer	$50,000	(Lewis, 1995)
Data processing workstation	$70,000	(Lewis, 1995)
Data processing software	$20,000	Assumed
Program Detection Costs	**$492,000**	
Consumable Supplies	$0	
Labor	$492,000	
Manhours	9840	Assumes 2 man-hours per day per tank, average tank
Cost per manhour	$50	Costs per person for work outside a rad zone
Program Monitoring Costs	**$426,400**	
Consumable Supplies	$0	
Labor	$426,400	
Manhours	8528	Assumes 2 man-hours quarterly per tank, average tank
Cost per manhour	$50	Costs per person for work outside a rad zone
Decommissioning Costs	**$1,836,800**	
CPT well closure	$1,836,800	
Equipment	$0	Assumes equipment is owned by Tank Farms
Consumable Supplies	$1,753	Assumes 0.1 cy of grout per well
Labor	$1,836,800	
Number of wells	656	Assumes 8 wells per tank
Manhours per well	56	Assumes 3 person crew, 8 hours, plus Hanford
Cost per manhour	$50	Costs per person per hour for work within a rad zone

TOTAL COSTS FOR DETECTION			PRESENT VALUE	
Development	$2,000,000		$2,000,000	
Preparatory	$8,000		$8,000	
Installation	$43,724,640		$43,724,640	
Operation	$492,000		$268,708	Divide total costs by 13 yrs operating life and multiply b P/A factor = 7.1, assumes 10% discount rate, 13
Decommissioning	$1,836,800		$532,672	Multiply by P/F factor = .290, assumes 10% discount ra and decommissioning occurs 13 years from pres
		TNPW	**$46,534,020**	
		Per Tank	**$567,488**	

TOTAL COSTS FOR MONITORING			PRESENT VALUE	
Development	$2,000,000		$2,000,000	
Preparatory	$8,000		$8,000	
Installation	$43,724,640		$43,724,640	
Operation	$426,400		$232,880	Divide total costs by 13 yrs operating life and multiply b P/A factor = 7.1, assumes 10% discount rate, 13
Decommissioning	$1,836,800		$532,672	Multiply by P/F factor = .290, assumes 10% discount ra and decommissioning occurs 13 years from pres
		TNPW	**$46,498,192**	
		Per Tank	**$567,051**	

LDM Technology Borehole Logging

COSTS	$	Comments
Development	$0	
Borehole Logging	no	
[illegible]	$8,000	
Work Plans	$8,000	All Tank Farm related work plans (i.e. rad worker,
Permitting Costs	$0	No Permiting Required
[illegible]	$0	
Borehole Installation	$0	
No. of boreholes	0	Assumes use of existing boreholes
Average depth of borehole (ft)	80	
Cost per foot	$1,258	Total cost, labor and H&S inclusive (Riggsbee, 1996)
Data Acq probes or equipment	$0	Assumes all equipment costs included in operational
Program Detection Costs	$89,156,000	
Mobilization	$76,000	Cost for logging trucks to drive to and from Hanford
Number of logging trucks	4	Mobilization cost is $19,000 per truck (Lewis 1995)
Equipment	$520,000	
Mast Truck	$520,000	
Number of trucks	4	Assumes a truck can perform 3 loggings per day
Cost per day for mast truck	$500	(Lewis 1995)
Number of days work (total)	260	5 days per week, 52 weeks per year
Probes and Data Acquisition Equipment	$0	Vendor supplies equipment
Data Collection	$88,560,000	
Number of loggings	24600	
Number of wells	410	82 tanks x 5 boreholes per tank
Loggings per well	60	Assumes daily loggings, 5 days per week, average
Vendor costs per well logging	$3,000	Cost for logging a well is $3,000 (Lewis 1995)
Labor costs per well logging	$600	
Manhours	12	Includes Hanford management, oversight, and
Time per logging	3	
Cost per manhour	$50	Costs per person per hour (Riggsbee, 1996)
Program Monitoring Costs	$77,199,000	
Mobilization	$57,000	Cost for logging trucks to drive to and from Hanford
Number of logging trucks	3	Mobilization cost is $19,000 per truck (Lewis 1995)
Equipment	$390,000	
Mast Truck	$390,000	
Number of trucks	3	Assumes a truck can perform 3 loggings per day
Cost per day for mast truck	$500	(Lewis 1995)
Number of days work (total)	260	5 days per week, 52 weeks per year
Probes and Data Acquisition Equipment	$0	Vendor supplies equipment
Data Collection	$76,752,000	
Number of loggings	21320	
Number of wells	410	82 tanks x 5 boreholes per tank
Loggings per well	52	Assumes quarterly loggings for lifetime of monitoring
Vendor costs per well logging	$3,000	Cost for logging a well is $1,000 per hour for 3 hours
Labor costs per well logging	$600	
Manhours	12	Includes Hanford management, oversight, and
Time per logging	3	Hrs per borehole
Cost per manhour	$50	Costs per person per hour (Riggsbee, 1996)
Decommissioning Costs	$1,013,213	
Well Closure	$1,013,213	
Equipment	$0	Assumes equipment is owned by Tank Farms
Number of wells	410	
Comsumable Supplies, per well	$71	Assumes 1 cu yd of grout per 80 ft well
Labor	$2,400	
Manhours	48	Assumes 6 person crew, 8 hours each person
Cost per manhour	$50	Costs per person per hour for work within a rad zone
Equipment disposal	$0	Assumes continued use for all equipment
Waste disposal	$0	No wastes requiring disposal

TOTAL COSTS FOR DETECTION		PRESENT VALUE	
Development	$0	$0	
Preparatory	$8,000	$8,000	
Installation	$0	$0	
Operation	$89,156,000	$48,692,892	Divide total costs by 13 yrs operating life and multiply P/A factor = 7.1, assumes 10% discount rate, 1
Decommissioning	$1,013,213	$293,832	Multiply by P/F factor = .290, assumes 10% discount and decommissioning occurs 13 years from pre
	TNPW	**$48,994,724**	
	Per Tank	**$597,497**	

TOTAL COSTS FOR MONITORING		PRESENT VALUE	
Development	$0	$0	
Preparatory	$8,000	$8,000	
Installation	$0	$0	
Operation	$77,199,000	$42,162,531	Divide total costs by 13 yrs operating life and multiply P/A factor = 7.1, assumes 10% discount rate, 1
Decommissioning	$1,013,213	$293,832	Multiply by P/F factor = .290, assumes 10% discount and decommissioning occurs 13 years from pre
	TNPW	**$42,464,362**	
	Per Tank	**$517,858**	

Note: Above calculations assume an off-site vendor for borehole logging services.

LDM System TDR

COSTS	$	
Development	**$500,000**	
TDR	$500,000	Assumed
Preparatory	**$8,000**	
Permitting	$0	No permits required
Work Plans	$8,000	
Installation	**$46,248,000**	
Equipment Installation	$36,531,000	
No. of wells	410	Assumes 5 wells per tank
Drilling costs per well	$87,500	Assumes 70 ft per well at $1250 per ft
Labor per well	$1,600	
Manhours per well	32	4 person crew, four hours each, + Hanford oversight
Cost per manhour	$50	
Data Acq probes or equipment	$9,717,000	
No. of probes	410	Assumes 5 wells per tank
Cost to purchase probe	$3,700	(Lewis, 1995)
Cost to modify probe	$20,000	(Lewis, 1995)
Program Detection Costs	**$492,000**	
Consumable Supplies	$0	
Labor	$492,000	
Manhours	9840	Assumes 2 man-hours per day per tank, average tank
Cost per manhour	$50	
Program Monitoring Costs	**$426,400**	
Consumable Supplies	$0	
Labor	$426,400	
Manhours	8528	Assumes 2 man-hours quarterly per tank, average tank
Cost per manhour	$50	Costs per person for work outside a rad zone
Decommissioning Costs	**$986,921**	
Well closure	$986,921	
Equipment	$0	Assumes equipment is owned by Tank Farms
Consumable Supplies	$2,921	Assumes 0.1 cy of grout per well
Labor	$984,000	
No. of wells	410	Assumes 5 wells per tank
Manhours	48	Assumes 2 person crew, 8 hours, + Hanford oversight
Cost per manhour	$50	Costs per person per hour for work within a rad zone
Equipment disposal	$0	Assumes continued use for all equipment
Waste disposal	$0	Assumes in situ closure of CPT wells with neglible

TOTAL COSTS FOR DETECTION			PRESENT VALUE	
Development	$500,000		$500,000	
Preparatory	$8,000		$8,000	
Installation	$46,248,000		$46,248,000	
Operation	$492,000		$268,708	Divide total costs by 13 yrs operating life and multiply by P/A factor = 7.1, assumes 10% discount rate, 13 y
Decommissioning	$986,921		$286,207	Multiply by P/F factor = .290, assumes 10% discount rat and decommissioning occurs 13 years from prese
		TNPW	**$47,310,915**	
		Per Tank	**$576,962**	

TOTAL COSTS FOR MONITORING			PRESENT VALUE	
Development	$500,000		$500,000	
Preparatory	$8,000		$8,000	
Installation	$46,248,000		$46,248,000	
Operation	$426,400		$232,880	Divide total costs by 13 yrs operating life and multiply by P/A factor = 7.1, assumes 10% discount rate, 13 y
Decommissioning	$986,921		$286,207	Multiply by P/F factor = .290, assumes 10% discount rat and decommissioning occurs 13 years from prese
		TNPW	**$47,275,087**	
		Per Tank	**$576,525**	

Log Number

RECORD OF TELEPHONE CONVERSATION FORM

ENSERCH ENVIRONMENTAL

UNDERGROUND STORAGE TANK-INTEGRATED DEMONSTRATION (UST-ID) PROGRAM

CALL: ☑ TO ☐ FROM: Acme Materials & Construction Co. TASK: UST-ID #15

ORGANIZATION: Company Salesman DATE: 1/26/95 TIME: 1:30 pm

PHONE: 946-4131 PAGE 1 of 1

SUBJECT: Moisture Mitigation Technology Costs

Made contact with the company salesman for a cost of grout per cubic yard delivered to the 200 Area at Hanford - He indicated that it would be approximately $71.25 / cy and includes tax.

By: W. Riggsbee

Distribution: (A copy must be given to the Task Manager)

File: 1.10/3.6

Log Number______

RECORD OF TELEPHONE CONVERSATION FORM

ENSERCH ENVIRONMENTAL

UNDERGROUND STORAGE TANK-INTEGRATED DEMONSTRATION (UST-ID) PROGRAM

CALL: ☑ TO ☐ FROM: Dave Smet TASK: UST-ID #15

ORGANIZATION: Westinghouse Hanford Co. DATE: 1/26/96 TIME: 11:20

PHONE: # 373-4354 PAGE 1 of 1

SUBJECT: Monitoring Mitigation Technology Costs

I contacted Dave Smet, a WHC TWRS project engineer, in order to determine costs for an in-tank video system. He indicated that the cost of the video camera and arm is approximately $440,000. The system is considered semi-permanent and explosion proof.

By: W. Riggsbee

Distribution: (A copy must be given to the Task Manager)

File: 1.10/3.6

Log Number

RECORD OF TELEPHONE CONVERSATION FORM

ENSERCH ENVIRONMENTAL

UNDERGROUND STORAGE TANK-INTEGRATED DEMONSTRATION (UST-ID) PROGRAM

CALL: ☑ TO ☐ FROM: Jeff Barnes TASK: UST-# 15

ORGANIZATION: Westinghouse Hanford Co. DATE: 1/26/95 TIME: 10:20

PHONE: # ~~509~~ - 376-2241 PAGE 1 of 1

SUBJECT: Monitoring Mitigation Technology Costs

I contacted Jeff Barnes, a WHC TWRS project engineer, in order to determine the cost of an ENRAFT gauge. He indicated that they cost approximately $7,000 apiece.

By: W. Riggles

Distribution: (A copy must be given to the Task Manager)

File: 1.10/3.6

Log Number____________________

RECORD OF TELEPHONE CONVERSATION FORM

ENSERCH ENVIRONMENTAL

UNDERGROUND STORAGE TANK-INTEGRATED DEMONSTRATION (UST-ID) PROGRAM

CALL: ☑ TO ☐ FROM: John Parrier   TASK: UST-ID #15

ORGANIZATION: Bechtel Hanford Co.   DATE: 2/26/96 TIME: 2:30 PM

PHONE: ____________________   PAGE 1 of 1

SUBJECT: Mixture Mitigation Technology Costs

Contacted John Farrier and asked for unit cost for CPT drilling in a radiation zone - He indicated that cost was variable but $360.00/ft was on average for a recent demonstration by a sub at Hanford.

By: W. Riggsbee

Distribution: (A copy must be given to the Task Manager)

File: 1.10/3.6

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APPENDIX B

DETECTED LEAKAGE VOLUME CALCULATIONS

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APPENDIX B
DETECTED LEAKAGE VOLUME CALCULATIONS

B1. INTRODUCTION

This appendix provides the calculations performed to determine the detected leakage volumes for each of the technologies under consideration. There are eight possible detected leakage volumes associated with each technology, as described in Section 6.1.3 of the report. Each possible detected leakage volume is defined by the parameters of the leak and the capabilities of the technology. Because different detected leakage volumes may have the same key parameters, there may be repetition in the results, and therefore less than eight distinct values may be reported.

B2. CONSTANT AND VARIABLE DEFINITIONS

The calculations presented in this appendix use the following constants and variables. The variables are defined by the leak parameters and the particular detected leakage volume being determined.

R = radius of tank (ft)
a = vertical axis of spheroid (ft)
b = horizontal axis of spheroid (ft)
where b = a (spherical)
b = 2 a (oblate ellipsoid)

Q_s = volume of soil wetted by leak
S_v = soil void space
q_n = natural soil moisture content
q = soil moisture volume fraction (S_v - q_n)

For point source leak, $Q_s = {}^4/_3$ pi a b^2
For distributed leak, $Q_s = {}^1/_8 (2\ pi^2\ a\ b\ R) + {}^4/_3\ p\ a\ b^2$

B3. CALCULATIONS

The following tables contain the calculation data for the detected leakage volumes for 4,1 ERT, 8,3 ERT, borehole logging, and TDR. Mass balance is not included in this appendix because there is only a minimum and a maximum detected leakage volume, which were described in the text of the report.

Leakage Volume calculations for 4,1 ERT

Point Source

Leak is detected when leading edge of plume reaches 15 feet below tank bottom.

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	7.5	7.5
b (ft) =	15.0	7.5
Q_s (ft^3) =	7069	1767
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	14,000	3,000

Distributed Source

Leak is detected when leading edge of plume reaches 15 feet below tank bottom.

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	7.5	7.5
b (ft) =	15.0	7.5
Q_s (ft^3) =	17,478	6,972
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	34,000	13,600

Leakage Volume calculations for 8,3 ERT

Point Source

Leak is detected when leading edge of plume reaches 10 feet below tank bottom.

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	5.0	5.0
b (ft) =	10.0	5.0
Q_s (ft^3) =	2094	524
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	4,000	1,000

Distributed Source

Leak is detected when leading edge of plume reaches 10 feet below tank bottom.

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	5.0	5.0
b (ft) =	10.0	5.0
Q_s (ft^3) =	6721	2837
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	13,000	6,000

Leakage Volume calculations for Borehole Logging

Minimum Point Source

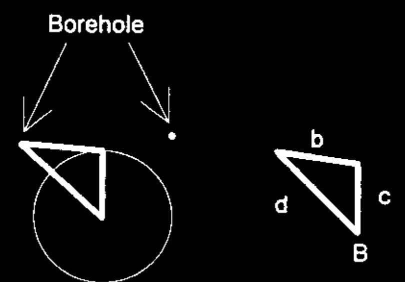
Leak is detected when leading edge of plume reaches 10 feet from edge of tank
Leak occurs from circumference of tank, closest to a borehole

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	5.0	10.0
b (ft) =	10.0	10.0
Q_s (ft^3) =	2094	4189
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	4,000	8,000

Maximum Point Source

Leak is detected when leading edge of plume reaches 10 feet from edge of tank
Leak occurs from circumference of tank, between two boreholes

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	14	28
b (ft) =	28	28
Q_s (ft^3) =	45485	90971
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	88,000	180,000



Law of Cosines:

$b^2 = d^2 + c^2 - 2\ d\ c\ \text{Cos}\ B$

B = 36 b = 28
c = 37.5
d = 47.5

Distributed Source

Leak is detected when leading edge of plume reaches 10 feet from edge of tank

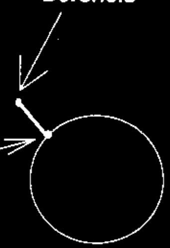
	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	7.0	14.0
b (ft) =	14.0	14.0
Q_s (ft^3) =	14,815	29,629
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	29,000	58,000

Leakage Volume calculations for TDR

Minimum Point Source

Leak is detected when leading edge of plume reaches 10 feet from edge of tank
Leak occurs from circumference of tank, closest to a borehole

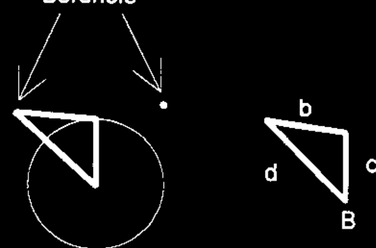
	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	5.0	10.0
b (ft) =	10.0	10.0
Q_s (ft^3) =	2094	4189
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	4,000	8,000



Maximum Point Source

Leak is detected when leading edge of plume reaches 10 feet from edge of tank
Leak occurs from circumference of tank, between two boreholes

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	14.0	27.9
b (ft) =	27.9	27.9
Q_s (ft^3) =	45658	91316
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	89,000	180,000



Law of Cosines:

$b^2 = d^2 + c^2 - 2\,d\,c\,\text{Cos}\,B$

B = 36   b = 27.9
c = 37.5
d = 47.5

Distributed Source

Leak is detected when leading edge of plume reaches 10 feet from edge of tank

	Ellipsoid	Sphere
R (ft) =	37.5	37.5
a (ft) =	7.0	14.0
b (ft) =	14.0	14.0
Q_s (ft^3) =	14,815	29,629
q =	0.26	0.26
S_v =	0.32	0.32
q_n =	0.06	0.06
s_{max} (gal/min)=	1.7	1.7
s_{ave} (gal/min)=	0.03	0.03
Q_t (gal)=	29,000	58,000

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APPENDIX C

RISK PER VOLUME CALCULATIONS

REFERENCE: WHC-SD-WM-ES-300, Rev. 1

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APPENDIX C
RISK PER VOLUME CALCULATIONS

C1. INTRODUCTION

This appendix summarizes the calculations performed to evaluate the risk per volume of waste, or specific risk, associated with an average tank.

C2. CALCULATIONS

The basis of the calculations are data presented by Treat et al. (1995). The key assumptions are that 5 of the 12 tanks in a representative tank farm leak 40,000 gal (no LDMM) during past-practice sluicing (Treat et al. 1995 p. 6-22, attached). The specific risk associated with this "new" leakage is not explicitly given by Treat et al. but it can be calculated simply. The Cancer Risk and Hazard Index values for old leaks and combined old and new leaks are provided by Treat et al (1995, p. 6-55, 6-57, attached). The total risk contribution from "new" leaks is determined by subtracting the two values. The specific risks are then determined by dividing by the total "new" leakage which gave rise to these risks (40,000 gal x 5 tanks).

$$Carcinogenic\,Risk = \frac{(5.9x10^{-6}) - (1.1x10^{-6})}{(40{,}000)(5)} = 2.4x10^{-11}\,per\,gal$$

$$Noncarcinogenic\,Hazard = \frac{(1.4x10^{-1}) - (2.5x10^{-2})}{(40{,}000)(5)} = 5.8x10^{-7}\,per\,gal$$

C3. REFERENCES

Treat, R.L, B.B. Peters, R.J. Cameron, W.D. McCormack, T. Trenkler, M.F. Walters, J.K. Rouse, T.J. McLaughlin, and J.M. Cruse, January 1995, *Feasibility Study of Tank Leakage Mitigation Using Subsurface Barriers*, WHC-SD-WM-ES-300, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

ref. WHC-SD-WM-ES-300
Revision 1

Feasibility Study of Tank Leakage Mitigation Using Subsurface Barriers

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Waste Management

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U.S. Department of Energy under Contract DE-AC06-87RL10930

Approved for Public Release

Lowe (1993) estimated that a leak of up to 150,000 L (40,000 gal) may occur during traditional sluicing of Tank 241-C-106 by the most likely leak mechanism. For this study it was assumed that five of the 12 tanks leak 150,000 L (40,000 gal) each during new sluicing operations at concentrations of half that of the interstitial liquid. It was also assumed that a total of 15,000 L (4,000 gal) leak from each of five of the 12 tanks in the case of robotic sluicing. This assumption was predicated on the lower head of liquid that will exist in tanks during robotic sluicing. This head was assumed to be 1/10 that required for traditional sluicing. The average head of liquid during traditional sluicing is expected to be about 4.6 m (15 ft) and the average head of liquid during robotic sluicing is expected to be about 0.5 m (1.5 ft). It is assumed that the lower head would be assured by pumping liquid as it slowly accumulates at existing and new salt wells in the tanks.

New leaks would likely occur in cracks or corroded areas of the tank wall where previous leaks occurred. Some locations of past leaks may have become sealed by particles or may exist at elevations above new sluicing liquid levels. New cracks may open during renewed sluicing operations. For ease of modeling, it was assumed that the five tanks that leak during renewed sluicing operations would discharge liquid waste through past leak locations.

Thus, alternatives without close-coupled barriers that involve traditional sluicing operations are modeled with five leaking tanks, each with assumed cumulative 193,000-L (51,000-gal) leaks. For comparison, the total nitrate discharged to the soil, per tank for assumed 42,000- and 193,000-L (11,000- and 51,000-gal) leaks, is 5,200 and 24,000 kg (11,000 and 53,000 lb), respectively. The total nitrate released from the five tanks was assumed to be 26,000 kg (57,000 lb) for old leaks and 120,000 kg (265,000 lb) for combined old and new leaks, respectively.

For robotic sluicing, the total old and new leakage per tank was assumed to be 57,000 L (15,000 gal), or 285,000 L (75,000 gal) for the five leaking tanks. This would be equivalent to 36,000 kg (80,000 lb) of nitrate released to the ground. For the Close-Coupled Chemical Barrier without Flushing Alternative and the Clean-Closure with Close-Coupled Chemical Barrier Alternative, a total of 293,000 L (77,000 gal) and 36,000 kg (79,000 lb) of nitrate would be released for each alternative. For the Modified Close-Coupled Chemical Barrier Without Flushing Alternative, a total of 26,000 kg (57,000 lb) of nitrate was assumed to have been released from old leaks. A total of 300,000 L (80,000 gal) would leak at the unprotected bases of two tanks during renewed sluicing operations. This would be equivalent to 39,000 kg (85,000 lb) of nitrate. Thus, the total nitrate that would leak to the soil in this alternative would be 63,000 kg (138,000 lb).

Boomer et al. (1993) reported data on the estimated depth of past SST leaks below the bottom of tanks, which are located 15 m (50 ft) beneath the surface. Data on the estimated depths of leaks reported by Boomer et al. (1993) are based on the assumptions that (1) plume dimensions are proportional to the well-characterized plume from Tank 241-C-106, and (2) plume volume is 57 times the leak volume. Local stratigraphy may greatly impact the size, shape, and depth of individual plumes. Using the data in Boomer et al. (1993), plume thicknesses of 8.5 and 15 m (28 and 49 ft) were estimated for leaks of 42,000 and 194,000 L

Table 6-11. Relative Source Contribution to Carcinogenic Risk. (sheet 1 of 2)

Alternative	Source	Cancer Risk Contribution at Peak	Relative Contribution (%)
1. No Action	Tank Residual Between Tank and Concrete In Concrete Old Leaks	1.5E-01 2.4E-05 1.6E-04 2.9E-05 1.5E-01	100 0 0 0 100%
2. Surface Barrier Only	Tank Residual Between Tank and Concrete In Concrete Old Leaks	3.7E-04 0.0E+00 4.8E-07 1.1E-06 3.7E-04	100 0 0 0 100%
3. Traditional Sluicing (Baseline)	Tank Residual Between Tank and Concrete In Concrete Old and New Leaks	3.9E-06 6.5E-09 7.0E-07 5.9E-06 1.1E-05	37 0 7 56 100%
4. Robotic Sluicing	Tank Residual Between Tank and Concrete In Concrete Old and New Leaks	2.6E-07 1.6E-08 5.0E-07 1.7E-06 2.5E-06	10 1 20 69 100%
5. Mechanical Retrieval	Tank Residual Between Tank and Concrete In Concrete Old Leaks	2.0E-05 8.8E-09 4.9E-07 1.3E-06 2.1E-05	92 0 2 6 100%
6. Close-Coupled Chemical Barrier with Flushing	Tank Residual Between Tank and Concrete In Concrete Flushed Old Leaks In Barrier	4.0E-06 7.5E-09 7.2E-07 2.5E-10 5.1E-07 5.2E-06	76 0 14 0 10 100%
7. Close-Coupled Chemical Barrier w/o Flushing	Tank Residual Between Tank and Concrete In Concrete Old and New Leaks In Barrier	4.0E-06 7.5E-09 7.2E-07 1.8E-06 5.1E-07 7.0E-06	57 0 10 26 7 100%

Table 6-12. Relative Source Contribution to Hazard Index Risk. (sheet 1 of 2)

Alternative	Source	HI Contribution at Peak	Relative Contribution (%)
1. No Action	Tank Residual	2.8E+03	100
	Between Tank and Concrete	4.0E-01	0
	In Concrete	3.0E+00	0
	Old Leaks	5.3E-01	0
		2.8E+03	100%
2. Surface Barrier Only	Tank Residual	8.6E+00	100
	Between Tank and Concrete	0.0E+00	0
	In Concrete	1.1E-02	0
	Old Leaks	2.5E-02	0
		8.6E+00	100%
3. Traditional Sluicing (Baseline)	Tank Residual	8.9E-02	37
	Between Tank and Concrete	2.3E-04	0
	In Concrete	1.6E-02	7
	Old and New Leaks	1.4E-01	56
		2.4E-01	100%
4. Robotic Sluicing	Tank Residual	6.0E-03	10
	Between Tank and Concrete	3.8E-04	1
	In Concrete	1.1E-02	20
	Old and New Leaks	3.9E-02	69
		5.7E-02	100%
5. Mechanical Retrieval	Tank Residual	4.5E-01	92
	Between Tank and Concrete	3.4E-04	0
	In Concrete	1.1E-02	2
	Old Leaks	2.9E-02	6
		4.9E-01	100%
6. Close-Coupled Chemical Barrier with Flushing	Tank Residual	9.0E-02	76
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	14
	Flushed Old Leaks	5.0E-09	0
	In Barrier	1.2E-02	10
		1.2E-01	100%
7. Close-Coupled Chemical Barrier w/o Flushing	Tank Residual	9.0E-02	57
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	10
	Old and New Leaks	4.0E-02	26
	In Barrier	1.2E-02	7
		1.6E-01	100%

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