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RPP-10901, Rev. 0

August 7, 2002

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HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER MILESTONE M-45-05-T16: S-102 INITIAL WASTE RETRIEVAL FUNCTIONS AND REQUIREMENTS

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EXECUTIVE SUMMARY

This document is an agreement primary document defined by Section 9.1 of the Hanford Federal Facility Agreement and Consent Order (HFFACO) and establishes the functions and requirements to retrieve waste stored in Single Shell Tank (SST) 241-S-102. These functions and requirements establish the retrieval system specifications, including Leak Detection Monitoring and Mitigation (LDMM), for the 241-S-102 Waste Retrieval System (WRS). In addition, this document includes a scoping level Retrieval Performance Evaluation (RPE) that provides environmental and human health risk associated with estimated waste volumes to be retrieved, the maximum volume which could leak during retrieval, and risk from residual waste following retrieval. Approval of this document by the U.S. Department of Energy (DOE) Office of River Protection (ORP) and Washington State Department of Ecology (WDOE) allows final design of the retrieval system to commence and subsequent retrieval actions to be completed. This document is patterned after similar functions and requirements documents involving the retrieval of waste from tanks S-112 and C-104 and incorporates, to the extent practicable, WDOE comments and lessons learned from those documents.

Classified as a non-leaking combined salt-cake/sludge tank, 241-S-102 is located in the 200 West Area of the Hanford Site. Retrieval of 241-S-102 uses fluidic technology that integrates LDMM with low water volume retrieval to improve upon past-practice sluicing by improving retrieval efficiency, and minimizing leak loss potential during retrieval.

The goals of the 241-S-102 initial waste retrieval, as defined by HFFCO milestone M-45-05A, are to retrieve approximately 490 curies of mobile, long-lived radioisotopes and 99 percent of tank contents by volume per U.S. Department Of Energy Best Basis Inventory (BBI) data, 8/01/2000. Retrieval of 241-S-102 will utilize a waste retrieval system capable of mixing the waste and pumping it to a Double Shell Tank (DST) SY-102.

This document includes a scoping-level RPE (Appendix B). The scoping-level RPE (Appendix B) includes a human health and environmental risk assessment that establishes the risks from waste remaining in the tank after retrieval and risks posed by potential leakage during retrieval. The RPE includes known and estimated radionuclide contamination and

contaminate migration within the vadose zone as a basis for calculation. The results of the scoping level RPE are integrated into this Functions and Requirements document to establish performance requirements and criteria applicable to the design of an integrated retrieval and LDMM system.

The scoping level RPE indicates that mixed waste remaining in the tank will exceed Class C limits as established by 10 CFR 61.55 even when the 99 percent HFFCO retrieval goal is achieved. An evaluation is included in the RPE to determine the minimum depth of grout required to reduce radiological constituent concentrations to levels that would not exceed Class C limits. The Class C limits could be met for the 99 percent retrieval goal by grouting residual waste to a depth of approximately eleven inches. However, post-retrieval residual waste grouting is not within the scope of this retrieval project.

This Functions and Requirements document details known and estimated radionuclide contamination and containment migration within the vadose zone as a bases of calculation. This document incorporates lessons learned, including LDMM, retrieval, instrumentation, and operational experience from previous DOE and industry related retrieval projects and establishes a retrieval strategy consistent with the Functions and Requirements in Section 4.0 of this document.

To mitigate potential impacts to human health and the environment the 241-S-102 retrieval system relies on a low water volume retrieval method to reduce potential leak volumes during retrieval. LDMM technologies deployed for 241-S-102 will rely on the Best Available Technology Economically Achievable (BATEA). Alternate LDMM technologies, if economically available and/or developed to a level suitable for tank farm deployment, will be evaluated for incorporation into the 241-S-102 retrieval system design.

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ABBREVIATION AND ACRONYM LIST

BATEA	best available technology that is economically achievable
BBI	Best Basis Inventory
CFR	Code of Federal Regulations
COC	contaminants of concern
DOE	U.S. Department of Energy
DST	double-shell tank
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
F&R	functions and requirements
ILCR	Incremental Lifetime Cancer Risk
ILL	interstitial liquid level
LDMM	leak detection, monitoring, and mitigation
MOU	Memorandum of Understanding
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
ORP	Office of River Protection
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction-Oxidation
RPE	Retrieval Performance Evaluation
RPP	River Protection Project
SST	single-shell tank
WAC	Washington Administrative Code
WDOE	Washington State Department of Ecology

1.0 INTRODUCTION

The River Protection Project (RPP) mission includes storage, retrieval, immobilization, and disposal of high-level radioactive waste presently stored in 177 underground tanks located in the 200 East and 200 West Areas of the U.S. Department of Energy (DOE) Hanford Site. These tanks consist of 149 single-shell tanks (SSTs) constructed between 1943 and 1964 and 28 newer double-shell tanks (DSTs). The SSTs and DSTs contain a variety of solid and liquid wastes resulting from several decades of nuclear fuel reprocessing and radionuclide recovery processes conducted at the Hanford Site. Immobilization of the retrieved tank wastes for subsequent interim storage and eventual disposal will be performed at a waste treatment facility that is to be constructed at the Hanford Site.

Due to concerns related to the liquid containment integrity of the older SSTs, current plans call for retrieving the SST waste and staging it in more reliable DSTs to serve as feed material for the waste immobilization process. The 241-S-102 (Tank S-102) waste retrieval activities will be conducted, to the extent practical, to meet requirements that allow ultimate closure of the tank and the tank farm. Steps taken in retrieving waste from Tank S-102 will be conducted in such a way as to not preclude future tank closure.

DOE, the Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA) have adopted a risk-based approach to SST retrieval. This approach includes:

- Demonstrating alternate retrieval approaches and baseline planning; leak detection, monitoring, and mitigation (LDMM) technologies in tanks containing sludge, saltcake, and mixed saltcake and sludge; and using the results of these projects for future SST retrieval approaches.
- Retrieving tanks that pose higher long-term risk first to minimize the impact of potential releases to the environment.
- Using independently reviewed human health and environmental risk analysis tied to ongoing vadose zone characterization and contaminant transport estimates to establish LDMM and retrieval system performance requirements and operating strategies.

1.1 BACKGROUND

During the 1950s, 1960s, and 1970s, waste from SSTs was retrieved using past-practice sluicing. Past-practice sluicing used one or more high volume liquid jets to dislodge and mobilize the tank waste slurry. The slurry was then pumped from the tank. Most recently, waste from Tank C-106 was retrieved using past-practice sluicing to resolve a potential safety problem associated with high amounts of heat generated by the decay of radioactive isotopes in the waste. In this approach, the LDMM methods included a static liquid surface measurement along with ex-tank monthly drywell monitoring. The primary concern with continuing the use of past-practice sluicing is the potential to leak

large volumes of waste during retrieval, as the sluicing systems introduce large volumes of liquid into the tank during retrieval operations.

Viable waste retrieval technologies that have been identified to date are liquid based and rely on the use of water or supernatant to mobilize and transfer the waste. Inherent in the use of liquid based retrieval technologies is the potential for waste to leak to the soil during the retrieval action. Although zero leakage from tank systems is a desired outcome of waste retrieval, the Hanford Federal Facility Agreement and Consent Order signatories have recognized the difficulty with performing waste retrieval from aging SSTs where zero leakage cannot realistically be guaranteed during retrieval. Leak detection, monitoring, and mitigation are capabilities and actions that have been legally agreed to by DOE, Ecology, and EPA in the Hanford Federal Facility Agreement and Consent Order (DOE et al. 1989).

A risk based retrieval strategy, the retrieval performance evaluation process, lessons learned, and an evaluation of best available retrieval technologies have provided the basis for establishing HFFCO functions and requirements for Tank S-102. The Retrieval Performance Evaluation (RPE) process is an outgrowth of procedures negotiated in 1994 to evaluate the 99 percent retrieval goal, including the determination of alternative retrieval goals, as appropriate, if the interim 99 percent retrieval goal could not be met on a tank-by-tank basis. The RPE methodology was developed in response to a 1996 memorandum of understanding (MOU) between Ecology and DOE that acknowledged the uncertainty to attain the 99 percent interim retrieval goal and associated LDMM requirements (Memorandum of Understanding, "Required Percent of Waste Retrieval" [Ecology 1996]). Under the MOU, DOE was tasked to assess retrieval performance criteria for the AX Tank Farm as a means of improving the agency's understanding of the applicability of various performance requirements (e.g., the Hanford Federal Facility Agreement and Consent Order, State Dangerous Waste Regulations, and DOE Orders). A scoping-level RPE is identified in Milestone M-45-05-T16 as a requirement for this function and requirements document. The design, development, screening, and assessment of alternative technologies according to these functions and requirements will result in an integrated LDMM and retrieval system design that is protective to human health and the environment.

The SST Retrieval Program has established a technically defensible program plan that results in deployment of retrieval and LDMM technologies capable of retrieving waste from SSTs that contain varied waste forms and pose tank-specific physical constraints. The Tank S-102 Retrieval Project has the following goals (Milestone M-45-05A):

- Retrieval to safe storage of approximately 490 curies of mobile long-lived radioisotopes and,
- Retrieval to safe storage of 99% of tank contents by volume (per DOE Best Basis Inventory (BBI) Data, 8/01/2000.

The Tank S-102 retrieval goals established in the above TPA Milestone (M-45-05A) are a subset of M-45-00 that establishes the residual waste goal. The specific language from the M-45-00 TPA Milestone states:

> *"Closure will follow retrieval of as much tank waste as technically possible, with tank waste residues not to exceed 360 cubic feet (cu. ft.) in each of the 100 Series tanks, 30 cu. ft. in each of the 200 Series tanks, or the limit of waste retrieval technology capability."*

DOE, Ecology, and EPA have not established closure requirements for SSTs. The DOE's current planning baseline is to landfill-close the SST farms (DOE 2001). In absence of these requirements, however, the results of the RPE are used to determine the risk posed by residual waste (i.e., past leaks, and residual tank waste) in the S-Farm to establish performance requirements that are protective of human health and the environment. The RPE process and development of risk-based and technically feasible LDMM and retrieval requirements are discussed in Section 3.0.

In addition to the risk-based requirements established by the RPE, nuclear safety requirements, environmental permits, and existing SST and DST system operational limits imposed on the waste retrieval system design are presented in this F&R (see Section 4.0).

Additions of liquids for retrieval purposes and actions are discussed in the current Resource Conservation and Recovery Act of 1976 (RCRA) Part A, Form 3, "Interim Status Permit Application." The permit application addresses treatment in the single shell tank farms, which is defined as including but not limited to, mechanical retrieval, sluicing and pumping of waste, and addition of cooling liquids.

1.2 PURPOSE

The purpose of this document is to establish the (1) functions and requirements, (2) LDMM strategy, and (3) retrieval strategy for the Tank S-102 retrieval specified in the Hanford Federal Facility Agreement and Consent Order Milestone M-45-05-T16. Approval of this document allows start of design. Definition of design start, for purposes of the Hanford Federal Facility Agreement and Consent Order milestone (DOE et al., 1989) is the initiation of final design (DOE Order 413.3, *Program and Project Management for the acquisition of Capital Assets* [DOE Order G430.1-3]), i.e., beginning of activities to produce the products, engineering design drawings, and written specifications that will be used for procurement and construction.

1.3 SCOPE

This document provides the functions and requirements necessary to support the design of the waste retrieval system for Tank S-102. This document also provides a preliminary strategy commensurate with the functions and requirements for retrieval and leak detection based on the RPE (Appendix B) and satisfies the requirements established in Hanford Federal Facility Agreement and Consent Order Milestone M-45-05-T16 by:

- Establishing the system requirements including the LDMM requirements (Section 4.0).
- Including a scoping-level RPE (Appendix B) to provide environmental and human health risk evaluation data/information associated with estimated waste volumes to be retrieved, the maximum volume that could be leaked during retrieval, and risk from residual waste based on known and estimated radionuclide contamination and contaminant migration within the vadose zone as the basis of calculation.
- Including a design and operating approach that takes into consideration a range of leak and residual waste volumes (Appendix B).
- Including lessons learned from previous DOE and industry retrieval projects (Appendix A).
- Including the LDMM and retrieval strategy for the Tank S-102 retrieval program (Section 5.0).
- Addressing mitigation strategies and decision thresholds for potential leaks during retrieval (Section 3.0).

The functions and requirements identified in this document provide the basis for the design criteria and design requirements documented in Project Level 2 specifications. Level 2 specifications are used to develop the project engineering concepts, scope, and boundaries. The content of the specifications will include detailed requirements such as operating pressures, temperatures, materials of construction and control system requirements, confinement boundaries and controls, interface requirements, and similar detailed application requirements. The specifications for the Tank S-102 retrieval system are currently in development and will be revised during preliminary and final design activities consistent with this approved functions and requirements document.

1.4 TANK S-102 CONDITIONS

Tank S-102 was constructed between 1950 and 1951. It is second in a cascade series of three tanks beginning with Tank S-101 and ending with Tank S-103. The tank is constructed with a painted grout layer, an asphalt (waterproof) membrane, and an outer reinforced concrete shell to maintain the structural integrity of the steel liner by protecting it from soil loads. The reinforced concrete shell is cylindrical with a domed roof. The interior of the tank contains a steel liner constructed of mild steel. The steel liner extends up the tank wall to a height of 7.6m (25 feet). It was constructed to support an operating volume of 750,000 gallons.

The tank currently contains approximately 447,000 gallons of saltcake and sludge waste, and is categorized as a Flammable Gas Facility Group 2 tank for hydrogen/flammable gas. The tank received waste from Reduction-Oxidation (REDOX) between 1953 and 1979. The tank received its waste from Tank S-101 via cascade operation. The REDOX waste was generated between 1952 and 1957. The tank received evaporator bottoms and recycled waste from the 242-S Evaporator from 1973 to 1976. The tank had a final transfer from it in 1992, after being labeled inactive in 1980. A large surface spill

occurred in 1973 that contaminated the soil around Tanks S-102, and S-103. The gamma-ray-emitting radionuclides cobalt-60 (60Co) and cesium-137 (137Cs) were detected in the resulting plume. The surface spill appears to have migrated through the backfill material, cascaded along the tank domes, and collected at the base of the tank farm excavation. However, a small portion of the contamination extends below the base of the tanks and into the Hanford formation sediments to a depth of at least 73 feet. The majority of the contaminated soil at grade was remediated and covered with an indeterminate depth of clean soil overburden (ARH-2935, *Report on Investigation of the S-Farm Contamination Incident* [ARH 1973]). Tank S-102 is currently in the process of being interim stabilized. Specific volumes and constituents, including contaminants of concern (COC), are listed in Table 1-1.

Table 1-1: Tank S-102 Selected Inventory

Tank S-102 Constituent	Inventory
Salt Cake [a]	314,000 gallons
Sludge [a]	16,000 gallons
Retained Gas [a]	117,000 gallons
Total Waste [a]	447,000 gallons
Drainable Interstitial Liquid [a]	81,000 gallons
Sodium [b]	364,000 kg
^{14}C [b]	47.8 Ci
^{79}Se [b]	0.39 Ci
^{90}Sr [b]	92,900 Ci
^{99}Tc [b]	217 Ci
^{129}I [b]	0.68 Ci
^{137}Cs [b]	255,000 Ci
^{241}Am [b]	122 Ci
Uranium (total) [b]	9.4 Ci
Plutonium (total) [b]	287 Ci
Mobile, Long-Lived Isotopes (defined as ^{79}Se, ^{99}Tc, ^{14}C, ^{129}I, Uranium Isotopes per Appendix B, Section 5.1.5.5) [b]	275 Ci
Others not listed above [b]	515,929 Ci
Total Isotopes [b]	1,030,000 Ci

a) Volume data is from the Tank Interpretive Report dated February 5, 2002.
b) Total isotope and sodium data obtained from the BBI in June 2001 and used in the RPE (Appendix B).

The above data are taken from the BBI, which has been developed for all Hanford underground tank waste. The BBI estimated inventory is based on sample data, calculations, and estimates based on process modeling and flow sheets (Tank Waste Information Network System [TWINS] 2001). The RPE provides additional information on tank waste constituents. Though the tank contents are likely to change through interim stabilization and other events preceding the retrieval of Tank S-102, the inventory used in the RPE is based on a snapshot of the BBI from June 2001.

Figure 1-1 provides a plan view of the S-Farm and nearby existing RCRA groundwater monitoring wells. Groundwater monitoring activities are outside of the S-102 WRS project scope. However, it is anticipated that groundwater monitoring activities will

continue consistent with the current RCRA groundwater monitoring plans (PNNL 2001), and coordinated with other environmental monitoring as appropriate.

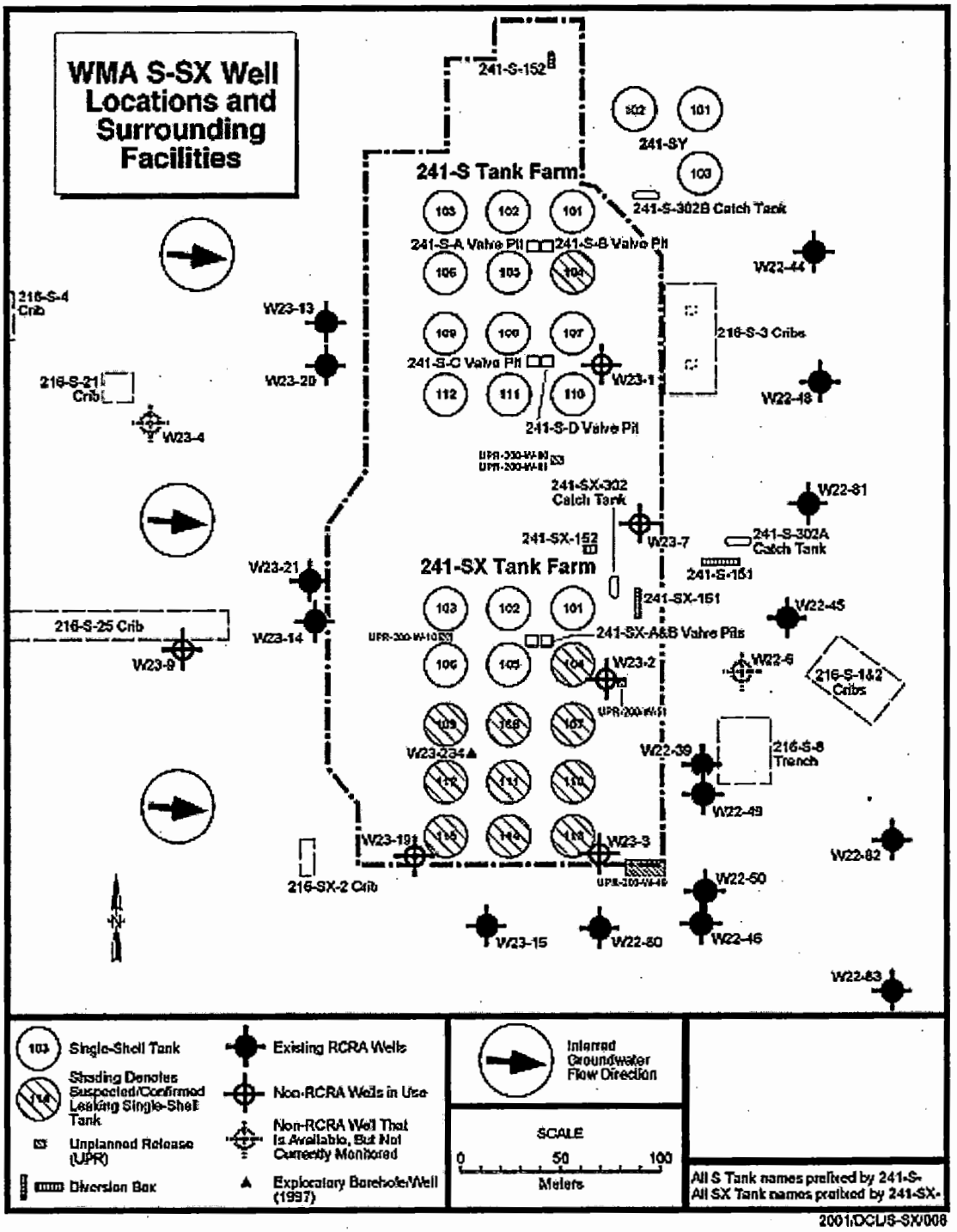

Figure 1-1: S- and SX-Farms Plan View of RCRA Monitoring Wells as of 2001

Figure 1-2 below shows a plan view of the S-Farm with borehole (drywell) locations shown inside the tank farm (*Hanford Tank Farms Vadose Zone S Tank Farm Report*, [MACTEC 1998]). Eight drywells (also called vadose zone monitoring boreholes) were installed around Tank S-102 to provide a means of detecting tank leaks. The casings are 6-inches in diameter. The wells end above the water table and vary in depth. Six wells are approximately 100-feet deep. One is 130-feet deep, and one is 150-feet deep [Vadose 2001]. Leak detection is accomplished through periodic geophysical logging of the drywells (e.g., to detect radiation and moisture increases). The drywells around Tank S-102 will be used in addition to other methods (see Section 5.0) for leak detection and monitoring of possible leaks. Drywell monitoring will occur prior to, during, and following the Tank S-102 retrieval. Specific monitoring plans will be developed and documented in a Process Control Plan during retrieval system design.

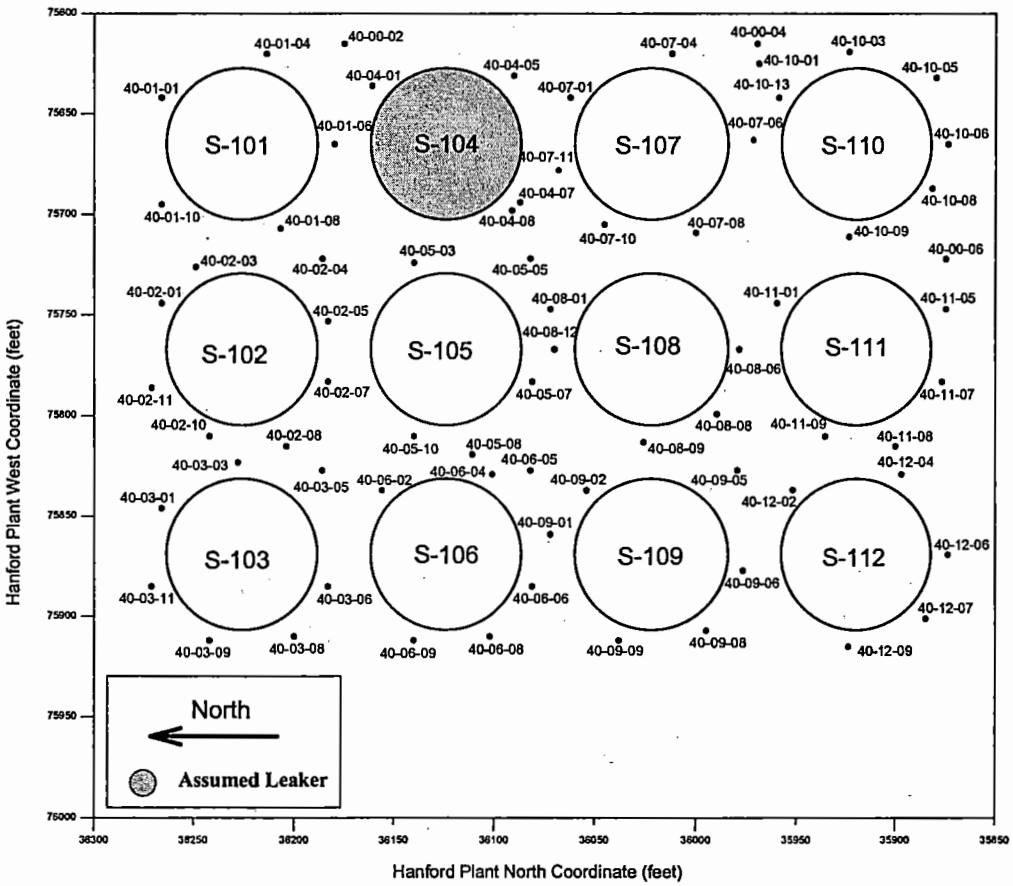

Figure 1-2: S-Farm Plan View of Borehole (Drywell) Location

1.5 DOCUMENT ORGANIZATION

This document is organized as follows:

- Section 1.0 provides an introduction, background, purpose, and scope to the document, in addition to a summary of current data for Tank S-102 conditions.
- Section 2.0 identifies the regulatory framework and governing requirements documents under which the retrieval of Tank S-102 will be conducted.
- Section 3.0 presents a description of the technical approach that leads to the development of the risk-based requirements, including the LDMM requirements. The technical approach includes the use of experience from other similar retrieval projects that are captured as lessons learned.
- Section 4.0 lists the functions and requirements that govern the design of the Tank S-102 retrieval.
- Section 5.0 defines a retrieval and LDMM strategy, including a description of the retrieval system and LDMM system features that will guide the design of the retrieval system for Tank S-102.
- Section 6.0 includes a discussion of the change control procedures that will govern changes to this document.
- Section 7.0 lists the references cited throughout this document.
- Appendix A is a summary of lessons learned and a bibliography of documented DOE and industry retrieval experience considered in developing the technical approach and F&Rs for retrieving Tank S-102.
- Appendix B is the draft scoping-level RPE for S-Farm, which supports the technical approach to the development of the retrieval and LDMM strategy for Tank S-102. The RPE includes known and estimated radionuclide contamination and contaminant migration within the vadose zone as bases for the risk calculations.

2.0 REQUIREMENTS FRAMEWORK

This section defines the requirement framework under which Tank S-102 retrieval system will be designed and operated. Sources of requirements include the Hanford Federal Facility Agreement and Consent Order, Code of Federal Regulations (CFR), and applicable Washington Administrative Codes (WAC) governing DOE activities. This functions and requirements document establishes the upper-level functions and corresponding requirements to which the retrieval system must be designed and operated. Requirements specific to this level of functional decomposition are summarized in Section 2.0 and related to specific functions in Section 4.0. Other requirements not directly applicable at this level of functional decomposition are promulgated to CHG via the DOE-CHG Contract (ORP 2001). Retrieval and LDMM technologies will be designed and operated in accordance with state and federal requirements as specified in the Hanford Federal Facility Agreement and Consent Order and DOE contracts.

The SST system was designed and built before existing standards were promulgated for radiological, environmental, and worker safety. The age and condition of the SSTs limit the extent of the upgrades and corrections that are physically possible. DOE, Ecology, and EPA have approved Hanford Federal Facility Agreement and Consent Order Milestone M-45-00. This milestone and the draft change proposed for it in August 30, 2000, both state the following:

> *"All parties recognize that the reclassification of previously identified RCRA past practice units to ancillary equipment associated with the Treatment, Storage, and Disposal unit is strictly for application of a consistent closure approach. Upgrades to previously classified RCRA past practice units to achieve compliance with RCRA or dangerous waste interim status technical standards for tank systems (i.e., secondary containment, integrity assessments, etc.) will not be mandated as a result of this action. However, any equipment modified or replaced will meet interim status standards. In evaluating closure options for single shell tanks, contaminated soil, and ancillary equipment, Ecology and EPA will consider cost, technical practicability, and potential exposure to radiation. Closure of all units within the boundary of a given tank farm will be addressed in a closure plan for the Single Shell Tanks." (DRAFT Hanford Federal Facility Agreement and Consent Order Change, M-45-00-01A, August 30, 2000 [DOE/Ecology 2000]).*

This agreement allows the project to apply appropriate design and construction standards that are relevant to the retrieval and LDMM of Tank S-102 and that emphasize protection of human health and the environment.

2.1 HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER REQUIREMENTS

Table 2-1 lists the milestones for the Tank S-102 waste retrieval system. This document meets the submittal requirements identified by Milestone M-45-05-T16 of the Hanford Federal Facility Agreement and Consent Order (DOE/Ecology 2000).

Table 2-1: Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank S-102 (Approved 2001)

Milestone	Description	Required Completion
M-45-00 LEAD AGENCY: ECOLOGY	COMPLETE CLOSURE OF ALL SINGLE SHELL TANK FARMS. CLOSURE WILL FOLLOW RETRIEVAL OF AS MUCH TANK WASTE AS TECHNICALLY POSSIBLE, WITH TANK WASTE RESIDUES NOT TO EXCEED 360 CUBIC FEET (CU. FT.) IN EACH OF THE 100 SERIES TANKS, 30 CU. FT. IN EACH OF THE 200 SERIES TANKS, OR THE LIMIT OF WASTE RETRIEVAL TECHNOLOGY CAPABILITY, WHICHEVER IS LESS. IF THE DOE BELIEVES THAT WASTE RETRIEVAL TO THESE LEVELS IS NOT POSSIBLE FOR A TANK, THEN DOE WILL SUBMIT A DETAILED EXPLANATION TO EPA AND ECOLOGY EXPLAINING WHY THESE LEVELS CANNOT BE ACHIEVED, AND SPECIFYING THE QUANTITIES OF WASTE THAT THE DOE PROPOSES TO LEAVE IN THE TANK. THE REQUEST WILL BE APPROVED OR DISAPPROVED BY EPA AND ECOLOGY ON A TANK-BY-TANK BASIS. PROCEDURES FOR MODIFYING THE RETRIEVAL CRITERIA LISTED ABOVE, AND FOR PROCESSING WAIVER REQUESTS ARE OUTLINED IN THE APPENDIX TO THIS CHANGE REQUEST. FOLLOWING COMPLETION OF RETRIEVAL, SIX OPERABLE UNITS (TANK FARMS), AS DESCRIBED IN APPENDIX C (200-BP-7, 200-PO-3, 200-RO-4, 200-TP-5, 200-TP-6, 200-UP-3), WILL BE REMEDIATED IN ACCORDANCE WITH THE APPROVED CLOSURE PLANS. FINAL CLOSURE OF THE OPERABLE UNITS (TANK FARMS) SHALL BE DEFINED AS REGULATORY APPROVAL OF COMPLETION OF CLOSURE ACTIONS AND COMMENCEMENT OF POST-CLOSURE ACTIONS. FOR THE PURPOSES OF THIS AGREEMENT ALL UNITS LOCATED WITHIN THE BOUNDARY OF EACH TANK FARM WILL BE CLOSED IN ACCORDANCE WITH WAC 173-303-610. THIS INCLUDES CONTAMINATED SOIL AND ANCILLARY EQUIPMENT THAT WERE PREVIOUSLY DESIGNATED AS RCRA PAST PRACTICE UNITS. ADOPTING THIS APPROACH WILL ENSURE EFFICIENT USE OF FUNDING AND WILLREDUCE POTENTIAL DUPLICATION OF EFFORT VIA APPLICATION OF DIFFERENT REGULATORY REQUIREMENTS: WAC 173-303-610 FOR CLOSURE OF THE TSD UNITS AND RCRA SECTION 3004(U) FOR REMEDIATION OF RCRA PAST PRACTICE UNITS.	9/30/2024

Table 2-1 (cont'd): Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank S-102 (Approved 2001)

Milestone	Description	Required Completion
M-45-00 LEAD AGENCY: ECOLOGY	ALL PARTIES RECOGNIZE THAT THE RECLASSIFICATION OF PREVIOUSLY IDENTIFIED RCRA PAST PRACTICE UNITS TO ANCILLARY EQUIPMENT ASSOCIATED WITH THE TSD UNIT IS STRICTLY FOR APPLICATION OF A CONSISTENT CLOSURE APPROACH. UPGRADES TO PREVIOUSLY CLASSIFIED RCRA PAST PRACTICE UNITS TO ACHIEVE COMPLIANCE WITH RCRA OR DANGEROUS WASTE INTERIM STATUS TECHNICAL STANDARDS FOR TANK SYSTEMS (I.E., SECONDARY CONTAINMENT, INTEGRITY ASSESSMENTS, ETC.) WILL NOT BE MANDATED AS A RESULT OF THIS ACTION. HOWEVER, ANY EQUIPMENT MODIFIED OR REPLACED WILL MEET INTERIM STATUS STANDARDS. IN EVALUATING CLOSURE OPTIONS FOR SINGLE-SHELL TANKS, CONTAMINATED SOIL, AND ANCILLARY EQUIPMENT, ECOLOGY AND EPA WILL CONSIDER COST, TECHNICAL PRACTICABILITY, AND POTENTIAL EXPOSURE TO RADIATION. CLOSURE OF ALL UNITS WITHIN THE BOUNDARY OF A GIVEN TANK FARM WILL BE ADDRESSED IN A CLOSURE PLAN FOR THE SINGLE-SHELL TANKS. COMPLIANCE WITH THE WORK SCHEDULES SET FORTH IN THIS M-45 SERIES IS DEFINED AS THE PERFORMANCE OF SUFFICIENT WORK TO ASSURE WITH REASONABLE CERTAINTY THAT DOE WILL ACCOMPLISH SERIES M-45 MAJOR AND INTERIM MILESTONE REQUIREMENTS. NOTE: DOE HAS APPEALED THE ISSUE NOTED WITHIN THE PROCEEDING SENTENCE TO THE WASHINGTON POLLUTION CONTROL HEARINGS BOARD. THE OUTCOME OF THIS APPEAL MAY AFFECT THIS M-45-00 LANGUAGE. DOE INTERNAL WORK SCHEDULES (E.G., DOE APPROVED SCHEDULE BASELINES) AND ASSOCIATED WORK DIRECTIVES AND AUTHORIZATIONS SHALL BE CONSISTENT WITH THE REQUIREMENTS OF THIS AGREEMENT. MODIFICATION OF DOE CONTRACTOR BASELINE(S) AND ISSUANCE OF ASSOCIATED DOE WORK DIRECTIVES AND/OR AUTHORIZATIONS THAT ARE NOT CONSISTENT WITH AGREEMENT REQUIREMENTS SHALL NOT BE FINALIZED PRIOR TO APPROVAL OF AN AGREEMENT CHANGE REQUEST SUBMITTED PURSUANT TO AGREEMENT ACTION PLAN SECTION 12.0.	9/30/2024

Table 2-1 (cont'd): Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank S-102 (Approved 2001)

Milestone	Description	Required Completion
M-45-05-T16	SUBMIT S-102 INITIAL WASTE RETRIEVAL FUNCTIONS AND REQUIREMENTS DOCUMENT. THIS DOCUMENT WILL ESTABLISH DEMONSTRATION SYSTEM SPECIFICATIONS (INCLUDING LDMM SYSTEM SPECIFICATIONS) AND WILL ALSO INCLUDE A SCOPING LEVEL RETRIEVAL PERFORMANCE EVALUATION (RPE). THE FUNCTIONS AND REQUIREMENTS DOCUMENT AND ITS ASSOCIATED RPE SHALL PROVIDE ENVIRONMENTAL AND HUMAN HEALTH RISK EVALUATION DATA/INFORMATION ASSOCIATED WITH ESTIMATED WASTE VOLUMES TO BE RETRIEVED, THE MAXIMUM VOLUME WHICH COULD LEAK DURING RETRIEVAL, AND RISK FROM RESIDUAL WASTE. THIS DOCUMENT WILL DETAIL KNOWN AND ESTIMATED RADIONUCLIDE CONTAMINATION AND CONTAMINANT MIGRATION WITHIN THE VADOSE ZONE AS BASES OF CALCULATION. LDMM AND RPE DOCUMENTATION PROVIDED WILL BE ADEQUATE TO ALLOW ECOLOGY TO ASSESS THE ADEQUACY OF THE DEMONSTRATION SYSTEMS. THIS DOCUMENT WILL INCORPORATE LESSONS LEARNED, INCLUDING LDMM, RETRIEVAL, INSTRUMENTATION, AND OPERATIONAL EXPERIENCE FROM PREVIOUS DOE AND INDUSTRY RELATED RETRIEVAL PROJECTS. DOE WILL SUBMIT ITS S-102 LDMM STRATEGY AS PART OF THE FUNCTIONS AND REQUIREMENTS DOCUMENT, PRIOR TO INITIATION OF DESIGN. THIS DOCUMENT WILL BE SUBMITTED FOR ECOLOGY APPROVAL AS AN AGREEMENT PRIMARY DOCUMENT. THIS FUNCTIONS AND REQUIREMENTS DOCUMENT WILL BE TIMELY SUBMITTED SO THAT PROJECT CRITICAL PATH IS NOT AFFECTED, AND SO AS TO ALLOW ADEQUATE TIME FOR DOE AND ECOLOGY REVIEW, REVISION AND APPROVAL.	10/30/2002
M-45-05B	COMPLETE S-102 INITIAL RETRIEVAL PROJECT DESIGN (TO INCLUDE ALL PHYSICAL SYSTEMS INCLUDING DESIGN AND OPERATING STRATEGIES NECESSARY FOR LEAK DETECTION, MONITORING AND MITIGATION (LDMM). THE DESIGN WILL BE CONSIDERED COMPLETE WHEN 90% OF THE DESIGN HAS BEEN APPROVED FOR FABRICATION AND/OR CONSTRUCTION.	3/31/2004

Table 2-1 (cont'd): Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank S-102 (Approved 2001)

Milestone	Description	Required Completion
M-45-05C	COMPLETE S-102 INITIAL WASTE RETRIEVAL PROJECT CONSTRUCTION (TO INCLUDE ALL PHYSICAL SYSTEMS INCLUDING THOSE NECESSARY FOR LEAK DETECTECTION MONITORING AND MITIGATION). CONSTRUCTION WILL BE CONSIDERED COMPLETE WHEN ALL PROCESS EQUIPMENT IS INSTALLED AND ACCEPTANCE TESTS ARE COMPLETED.	11/30/2005
M-45-05A	COMPLETE INITIAL WASTE RETRIEVAL FROM 241-S-102 THE S-102 INITIAL WASTE RETRIEVAL TECHNOLOGY (OR TECHNOLOGIES) WILL BE SELECTED BASED ON THE PRINCIPLE CRITERIA OF MAXIMIZING THE RETRIEVAL OF MOBILE, LONG-LIVED RADIOISOTOPES AND NON-RADIOLOGICAL HAZARDOUS CONSTITUENTS. THE PARTIES RECOGNIZE AND AGREEE THAT THIS ACTION IS FOR INITIAL WASTE RETRIEVAL PURPOSES. COMPLETION OF THIS INITIAL RETRIEVAL SHALL BE BY APPROVAL OF DOE AND ECOLOGY. GOALS OF THIS INITIAL WASTE RETRIEVAL PROJECT SHALL INCLUDE THE RETRIEVAL TO SAFE STORAGE OF APPROXIMATELY 490 CURIES OF MOBILE, LONG-LIVED RADIOISOTOPES AND 99% OF TANK CONTENTS BY VOLUME (PER DOE BEST-BASIS INVENTORY DATA, 8/01/2000). COMPLETION OF S-102 INITIAL WASTE RETRIEVAL IS SUBJECT TO SAFE STORAGE SPACE AVAILABILITY CONSISTENT WITH M-45-00B.	9/30/2006

2.2 REGULATORY REQUIREMENTS

Table 2-2 identifies the state and federal regulations that apply to the retrieval of Tank S-102. These regulatory requirements are imposed on the design of the Tank S-102 waste retrieval system via the requirement statements in Section 4.0 of this document.

Table 2-2: State and Federal Regulations/DOE Requirements

Document Number	Title
10 CFR 830	"Nuclear Safety," *Code of Federal Regulations*
10 CFR 835	"Occupational Radiation Protection," *Code of Federal Regulations*
29 CFR 1910	"Occupational Safety and Health Standards," *Code of Federal Regulations*, as amended
40 CFR 265	"Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," *Code of Federal Regulations*, as amended
40 CFR Subchapter R	"Toxic Substances Control Act," *Code of Federal Regulations*
DOE 2001a	*Hanford Site Title Air Operating Permit, 00-05-006*, June 2001, U.S. Department of Energy, Richland, Washington
DOE/Ecology 2000 (Milestone M-45-05A)	"DRAFT Hanford Federal Facility Agreement and Consent Order Change", U.S. Department of Energy and Washington Department of Ecology Negotiation Team
DOE Order 430.1A (DOE Order 430.1A)	"Life Cycle Asset Management", DOE Order 430.1A, October 14, 1998, U.S. Department of Energy, Washington, D.C.
WAC 173-303-640	"Dangerous Waste Regulations - Tank Systems," *Washington Administrative Code*, as amended "Hanford Facility RCRA Permit," WA7890008967, Rev. 6, December 2000. (Rev. 7 is under appeal)
DOE Order 413.3	"Program and Project Management for the acquisition of Capital Assets", 2000, U.S. Department of Energy, Washington, D.C.

3.0 TECHNICAL APPROACH TO DEVELOPING RISK-BASED RETRIEVAL REQUIREMENTS

This section summarizes the current integrated SST waste retrieval and LDMM risk-based requirements development strategy embodied in the Hanford Federal Facility Agreement and Consent Order M-45 milestones. This strategy originates with risk-based analysis regarding existing contamination and potential future leakage and then promulgates requirements that are judged to be technically feasible. This section discusses how the current strategy evolved from the strategy embodied in the 1994 Hanford Federal Facility Agreement and Consent Order M-45 milestones. In addition, this section describes the approach that DOE-Office of River Protection (ORP) and Ecology have agreed to use to support interim retrieval decisions. The interim retrieval decisions are needed to demonstrate waste retrieval and LDMM technologies for waste retrieval from the 149 SSTs at the Hanford Site.

3.1 INTEGRATED SINGLE-SHELL TANK WASTE RETRIEVAL AND LEAK DETECTION MITIGATION AND MONITORING RISK-BASED STRATEGY

The Hanford Federal Facility Agreement and Consent Order recognizes that waste retrieval from aging SSTs poses technical challenges, including the potential for release of waste to the environment. These challenges require DOE to demonstrate alternative retrieval technologies that seek to improve upon the past-practice sluicing baseline in the areas of expected retrieval efficiency, leak potential, and suitability for use in potentially leaking tanks. The retrieval effort is also required to be integrated with LDMM technologies. The near-term M-45 series of milestones through 2006 were established to provide a framework for implementation of near-term waste retrieval in an environmentally sound manner within the context of:

- A schedule for retrieval driven by the availability of space in DSTs to support interim storage of SST waste;
- Utilizing available space in DSTs as waste from DSTs is transferred to waste treatment facilities; and
- A phased approach to capture lessons learned for the vadose zone, retrieval performance, and establishing new milestones.

DOE and Ecology recognized that SST waste retrieval poses risks associated with retrieving waste from aging tanks. There are limited proven retrieval technologies, limited LDMM technologies, and constraints imposed by radiological, chemical, physical, and environmental conditions. To address these uncertainties the Hanford Federal Facility Agreement and Consent Order included milestones associated with development and demonstration of retrieval and LDMM technologies. Since 1994, DOE in partnership with Ecology has:

- Reviewed and assessed lessons learned from retrieval and LDMM technologies deployed at other DOE sites (e.g., Oak Ridge and Savannah River sites, see (Appendix A);

- Assessed emerging waste retrieval and LDMM technologies (*Annual Progress Report on the Development of Waste Tank Leak Monitoring/Detection And Mitigation Activities in Support of M-45-08* (TPA Milestone M-45-09E Fiscal Year 2000 Progress Report [CHG 2000]);
- Retrieved waste from Tank C-106 to resolve safety issues;
- Modified the Hanford Federal Facility Agreement and Consent Order to initiate Corrective Actions for eight of the twelve SST Farms to improve understanding of the nature and extent of soil and groundwater contamination resulting from past tank leaks and spills and to identify, if appropriate, interim actions to mitigate threats to human health and the environment posed by past tank leaks (Hanford Federal Facility Agreement and Consent Order Change Control Number M-45-98-03, [Ecology 1999]);
- Refined the strategy for the implementation of LDMM to ensure the integration of LDMM with the retrieval systems and to establish LDMM requirements based on protection of human health and the environment (CHG 2000); and
- Developed a methodology for evaluating retrieval options on a tank-specific basis that will support interim decisions on the extent of waste retrieval and retrieval leak volume. The methods/decisions should not restrict final decisions associated with tank farm closure and/or corrective action under WAC 173-303 or DOE Order 435.1 (See Section 3.2).

In 1998, the DOE initiated a re-baselining of the SST retrieval project. The basis for the re-baselining and the strategy adopted to implement the SST retrieval project, were documented in the *SST Retrieval Program Mission Analysis Report HNF-2944* (LMHC 1998). The focus of the re-baselining was to:

- Provide a technically defensible program plan that will result in deployment of retrieval and LDMM technologies capable of retrieving waste from SSTs containing varied waste forms and posing tank-specific physical constraints;
- Comply with applicable regulatory requirements (e.g., Hanford Federal Facility Agreement and Consent Order interim waste retrieval and LDMM requirements, RCRA Permit, Air Operating Permit);
- Accelerate reduction of potential risks to human health and the environment; and
- Enhance integration with the planning and scheduling for waste processing that will free DST space to support SST waste transfers to DSTs.

In 1999 and 2000, following completion of the SST Mission Analysis Report, DOE initiated revision of its SST LDMM and retrieval strategy. The outcome of this effort is documented in the *Single Shell Tank Retrieval Sequence: Fiscal Year (FY) 2000 Update* RPP-7087 (CHG 2000a), the FY 2000 Annual Progress Report on the Development of Waste Tank Leak Monitoring /Detection and Mitigation Activities in Support of M-45-08 (CHG 2000), and the change package for the M-45 series milestones (DOE/Ecology 2000). Key features of the revised strategy include:

- Integration of LDMM with retrieval technology and requirements on a tank specific basis;
- Development of risk-based and technically feasible requirements for extent of waste retrieval (i.e., volume of residual waste) and potential retrieval leak volume, based on a screening level assessment of threats to human health, that serve as risk based and technically feasible performance requirements for design and operation of retrieval and LDMM systems;
- Technology deployments early in the SST retrieval program to provide a basis for selecting cost-effective, tank-specific retrieval and LDMM technologies; and
- Integration of retrieval activities with tank farm corrective action and closure to mitigate potential risks to human health and the environment (see Figure 3-1).

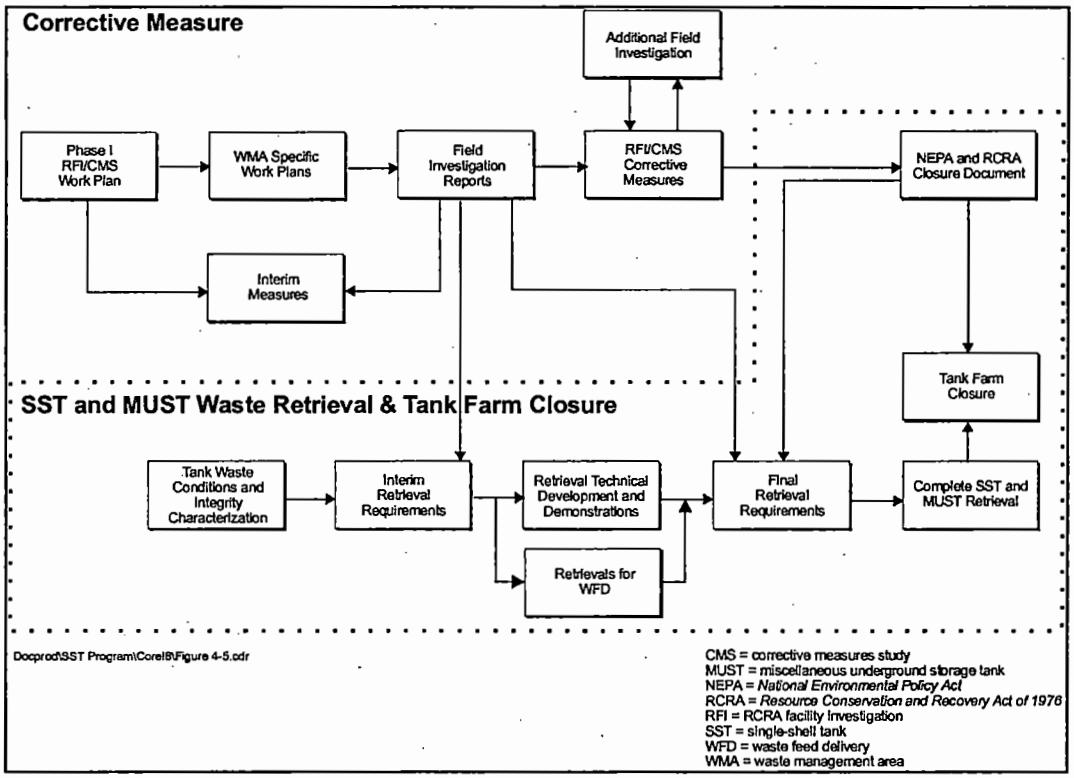

Figure 3-1: Corrective Actions for Tank Farm Closure

In 2000, the Hanford Federal Facility Agreement and Consent Order was modified to reflect the revised strategy. The modifications reflect an agreement among the agencies to retrieve waste from fewer SSTs that contain more hazardous long-lived radioactive waste, instead of retrieving waste from ten relatively empty SSTs, and to establish a risk-based and technically feasible strategy and actions necessary for DOE to demonstrate alternative SST waste retrieval technologies. The technologies are targeted to be suitable to use in suspect, leaking, and deteriorating aging SSTs to minimize the potential for leaks that can impact the environment, and to develop performance and cost data necessary for application to future

retrieval actions. These retrievals also include development and demonstration of LDMM methods. In addition to demonstrating waste retrieval technologies, the actions will focus on SSTs that pose the greater risks (i.e., COC) to the environment and on using available DST space.

The retrieval strategy is founded on methods for evaluating retrieval performance that were developed in response to a MOU (Ecology 1996) between DOE and Ecology. The agencies concurred that DOE should demonstrate the analysis necessary to make decisions on a tank-by-tank basis regarding the interim retrieval goal of at least 99 percent of the waste volume from SSTs and to establish tank-by-tank retrieval leakage loss limits (Ecology 1996). The RPE of one tank farm (241-AX) was used to demonstrate a methodology for establishing tank-by-tank retrieval performance requirements by evaluating a range of screening level performance measures that included short- and long-term human health impacts, closure requirements, technology limitations, stakeholder values, and cost (*Retrieval Performance Evaluation Methodology for the AX Tank Farm* [DOE 1999]).

The S-Farm RPE establishes three screening-level performance measures that are drivers for decisions on leak volume limits and residual waste volume. These measures are used in the absence of final closure requirements for the single-shell tank farms.

- **Long-Term Risk (Residential Farmer and Industrial Worker) Scenario.** The long-term risk scenario estimates long-term health risks to a human receptor located outside of the tank farm following closure of the tank farms (per Hanford Federal Facility Agreement and Consent Order and State Dangerous Waste Regulations). The risks arise from mixed waste (hazardous and radioactive) resulting from past tank leaks, retrieval losses, and residual waste (i.e., waste left in the tank following retrieval migrating through the soil to groundwater). Under this scenario, the receptor uses groundwater for domestic purposes and other uses, depending on the specific exposure scenario. This performance measure is sensitive to change in the total waste inventory (i.e., past leaks, retrieval losses, and residual waste) and thus drives limits on leak volumes and residual waste. Leak losses and residual waste are dependent variables (i.e., as one increases the other must decrease to stay within a total inventory limit). Leak waste is not contained, whereas the residual waste remains in the tank for 500 years (its release is due to tank deterioration). The contaminants that most influence this performance measure tend to be highly mobile in the environment (e.g., nitrates, technetium-99, see Appendix B, Section 3.6.1). The S-Farm RPE uses the Residual Farmer and Industrial Worker lifestyle scenarios to evaluate the long-term risk. The risks, which change with time, are estimated as the sum of the contributors from the individual source terms past leaks, retrieval losses, and residual waste.

- **Intruder Risk Scenario**. Human health risks posed by intrusion into the waste site 100 years after closure. Two aspects of intruder risk are evaluated in the S-Farm RPE: (1) compliance with DOE intruder protection dose limits (DOE O 435.1) using driller and post-drilling resident exposure scenarios, and (2) compliance with Nuclear Regulation Commission (NRC 2002) waste classification criteria using comparisons against radionuclide upper concentration limits (10 CFR 61). This performance measure is sensitive to changes in the residual waste inventory. The contaminants

that most influence this performance measure tend to be less mobile in the environment (e.g., cesium, strontium, plutonium) (Appendix B, Section B.3.7). This is because the intruder comes into direct contact with contaminants that are exhumed by well drilling. Evaluation of groundwater exposure pathways, as is done for the long-term human health risk scenarios, is not included in the intruder scenarios. Intruder risk conclusions are given in Section B.6.2.4 of Appendix B.

- **Remediation Worker Risk Scenario.** Human health risks to involved workers, noninvolved workers, and the general public from chemical and radiological exposures that are expected to occur during routine remedial actions (e.g., waste retrieval) or that could result from postulated accidents, and injuries and fatalities resulting from industrial type accidents. Worker risk is estimated as the human health risk posed by past tank leaks, retrieval losses, and residual waste to remediation workers who are assumed to implement various retrieval and closure strategies. This performance measure is sensitive to waste inventory and duration of retrieval activities and tends to be most influenced by contaminants that are less mobile in the environment (e.g., cesium, strontium, plutonium) (Appendix B, Section B.3.4). This is because the exposure pathway to workers is primarily through the air and not through the groundwater.

The performance requirements for waste retrieval leak volume and residual waste are intended to limit the Incremental Lifetime Cancer Risk (ILCR) to a level below 10^{-5}. The RPE in Appendix B, Section 5.1.5.3 states "for carcinogenic risk, the level of protection provided under the regulations range from 1 in 10,000 (1×10^{-4}) to 1 in 1,000,000 (1×10^{-6}). For hazardous chemicals under the residual farmer or industrial worker scenarios, Washington State requires the ILCR to be no higher than 1×10^{-6} for individual contaminants and 1×10^{-5}) for cumulative contaminants." This is the case with Tank S-102 (WAC-173-340-640). Because the risk levels at the tank farm fence line are high (exceeding 1×10^{-4}) relative to an ILCR of 10^{-5}, the RPE evaluates retrieval leakage volumes using alternate risk scenarios to provide information on the performance of different leak volumes against alternate limits.

3.2 DEVELOPMENT AND USE OF PERFORMANCE REQUIREMENTS THROUGH THE RPE PROCESS

Risk based goals for SST waste retrieval have been incorporated into the Hanford Federal Facility Agreement and Consent Order through the recent change package for the M-45 series milestones (DOE/Ecology 2000). Milestone M-45-05-T16 for Tank S-102 (Table 2-1) requires a scoping level RPE as part of this F&R document. Scoping level RPE is interpreted to be the same as a screening level risk assessment that uses currently available data and information. The RPE is located in Appendix B.

The RPE process was developed to support waste retrieval and closure decisions using a systems approach that considers contributions from multiple sources (i.e., past leaks, potential retrieval leakage, and residual waste) across a number of performance measures. The RPE methodology is an iterative process that will be applied before waste retrieval to help develop criteria for the extent of retrieval leak volumes and residual waste and then after retrieval to evaluate performance measures using actual retrieval leak volume and residual

waste data. This iterative process allows for inclusion of additional information and rigor into the assessment as the tank and tank farm move toward final closure decisions. The RPE process for the 241-S SST Tank Farm follows these steps:

1. The scoping level RPE focuses on Tank S-102 and evaluates the risks associated with varying assumptions for leak volume and residual waste both in Tank S-102 and the other S-Farm tanks. The tank-specific performance requirements are given in terms of the maximum leak volume during retrieval and maximum residual waste after retrieval that would individually, or in combination, allow Tank S-102 to maintain compliance with risk-based and technically feasible regulatory action thresholds.
2. After the Tank S-102 waste retrieval effort is complete, the tank farm RPE will be updated to reflect the actual residual waste volume and estimated retrieval leak volume, if any. The risk associated with the remainder of the farm tanks will be recalculated.
3. Steps one and two are repeated for each tank to be retrieved in the tank farm with the final RPE amended to include tank farm specific performance data as well as information regarding the cumulative impacts of the post-closure tank farm with other 200 Area waste sites as the tank farm closure RPE.

The current RPE is used to develop retrieval leak volume and residual waste criteria for Tank S-102. The impact analysis is conducted for a range of waste retrieval cases and includes assessment of the three key screening-level performance measures from Section 3.1 as well as additional performance measures, as listed below.

- **Short-Term Human Health Risks**—Human health risks to involved workers, noninvolved workers, and the general public from chemical and radiological exposures that are expected to occur during routine remedial actions (e.g., waste retrieval) or that could result from postulated accidents, and injuries and fatalities resulting from industrial type accidents. Worker risk is estimated as the human health risk posed by past tank leaks, retrieval losses, and residual waste to remediation workers who are assumed to implement various retrieval and closure strategies. This performance measure is sensitive to waste inventory and duration of retrieval activities and tends to be most influenced by contaminants that are less mobile in the environment (e.g., cesium, strontium, plutonium) (Appendix B, Section B.3.4). This is because the exposure pathway to workers is primarily through the air and not through the groundwater. Short-term human health risk conclusions are given in Section B.6.2.1 of Appendix B.
- **Long-Term Human Health Risks**—Human health risks to hypothetical future site users (assumed to be at the current tank farm boundary and at potential compliance points beyond the tank farm boundary) that would occur after completing waste retrieval and implementing closure (post remediation). Long-term human health risk analysis involves evaluating health risks resulting from exposure to tank waste released to the subsurface soils from past leaks, retrieval losses, and residual waste. The released waste migrates over time into the groundwater in response to infiltration and percolation of precipitation through the soil column. Human receptors are assumed to receive exposure to the waste through the use of groundwater for domestic and other uses, depending on the specific exposure scenario. This

performance measure is sensitive to changes in the total source term inventory (i.e., past leaks, retrieval losses, and residual waste) and thus has the potential to drive limits on leak volumes and residual waste. Retrieval leak volumes and residual waste are dependent variables (i.e., as one increases the other must decrease to stay within a total risk-based regulatory action limit). Contaminants of concern to long-term human health risks are those that are persistent and mobile in the environment (e.g., technetium-99, nitrate) (Appendix B, Section 3.6.1). Long-term human health risks are evaluated over a 10,000-year period of interest. (DOE performance assessments require use of a 1,000 year time period; however, the RPE uses 10,000 years based on NRC and National Environmental Policy Act of 1969 [NEPA] practices and because maximum impacts from residual waste in the tank are not expected to be seen at receptor locations until after 1,000 years [Appendix B, Section 3.1]). The RPE establishes limits on Tank S-102 leak volume and residual waste volume by developing risk-to-volume relationships and comparing peak risks against risk-based regulatory standards (e.g., the 1 x 10-4 federal [55 FR 8666] and 1 x 10-5 state [WAC 173-340-640] standards for ILCR). Risks are evaluated for two exposure scenarios, a residential farmer and an industrial worker. The residential farmer scenario assumes greater use of and contact with groundwater than the industrial worker scenario and therefore results in higher risks and more restrictive limits on retrieval performance for a given combination of retrieval loss and residual waste volume. Under both exposure scenarios, risks change with time as contaminants are dispersed and decayed during transport in the vadose zone and groundwater. Risks, at any given point in time, are estimated as the sum of the contributions from the past leaks, retrieval losses, and residual waste source terms. Peak risks are estimated as the highest risk values projected to occur over the 10,000-year assessment period. Since this analysis is being conducted to support interim tank farm decisions on the waste retrieval from one tank and not final tank farm closure decisions, the risk assessment is limited to evaluating the incremental risks from S-Farm only. The risk assessment does not address risks to down-river future populations or the cumulative risks from other SSTs and waste sites outside the tank farm. Conclusions from the long-term human health risk evaluation are summarized in Section 3.2.2 and given in detail in Section B.6.2.3 of Appendix B.

- **Groundwater Quality**—Impacts on groundwater quality resulting from contaminant release and migration to the groundwater from past leaks, retrieval losses, and residual waste are assessed and compared to regulatory standards. Groundwater quality impacts are evaluated at the tank farm boundary and at potential compliance points beyond the tank farm boundary (Appendix B, Section B.3.5). The projected peak groundwater contaminant concentrations are used in the RPE as the basis for the peak long-term human health risk calculations. Groundwater quality conclusions are given in Section B.6.2.2 of Appendix B.

- **Compliance Assessment**—The applicable and appropriate regulatory requirements are identified including areas where open issues and specific quantitative performance measures exist. Regulatory compliance conclusions for Tank S-102 are located in Section 6.2.5 of Appendix B.

Risk assessments require a number of modeling assumptions to be made and parameter values selected in order to calculate the potential risks to future site users. There is uncertainty associated with these assumptions and in selecting parameter values for use in calculating risks. Uncertainty analysis can be used to support risk-based decision-making because it incorporates system and parameter uncertainties in calculating impacts to human health and the environment. By capturing uncertainties a degree of confidence can be assigned to the estimated risk levels. Additionally, sensitivity analysis of the results can be used to identify the risk drivers. Uncertainties associated with the S-Farm RPE methodology are further discussed in Section 6.4 of Appendix B.

The AX-Tank Farm (DOE 1999) included an uncertainty and sensitivity analysis to investigate how variability and uncertainty in model input parameters propagating through the system model translates into uncertainty in long-term human health risk projections. The results of 241-AX-Tank Farm RPE uncertainty analysis indicated that when the exposure parameters were held constant, the uncertainty in source term parameters (i.e., inventory and release model) had the greatest influence on the long-term human health risk. Contaminant distribution coefficients and infiltration rates were also influential in contributing to risk. Uncertainties in other model inputs, such as vadose zone hydraulic parameters, accounted for little of the uncertainty in risk. These results would be expected to hold at the S-Farm for Tank S-102 since the COC and exposure pathways for contaminant release and transport is similar for both farms. Therefore, uncertainty analysis will not be performed for S-102. The results of the Tank S-102 RPE indicate that technetium-99 is the principal contributor to long-term risk and the risks are sensitive to the solubility and inventory of technetium-99 in the retrieval leakage and residual waste source terms. The solubility of technetium-99 and other key COC will be investigated during the Tank S-102 retrieval activity, as well as during the planned retrieval, to improve the basis for estimating residual inventories and the concentration of COC in potential retrieval leaks. This investigation will involve the collection of waste from specific (i.e., saltcake and sludge) concentrations and release rates. This data will serve to improve risk analyses conducted in support of future retrievals.

The best available data for each component of the tank farm system and the tanks of interest are used to provide a deterministic calculation for each performance measure. Where data were unavailable or highly uncertain, reasonably conservative assumptions were developed to complete the analysis. These assumptions were based on a review of available data or information from other Hanford Site, DOE complex, or non-DOE remediation programs. These assumptions were validated by an independent peer review.

Application of the RPE methodology to the evaluation of Tank S-102, and the S-Farm included the following:

- Developing a conceptual model of the tank and tank farm system (e.g., the components of the tank farm, sources of contamination, engineered systems, and the natural environment) to analyze the potential implication of SST waste retrieval. Contaminant releases were modeled using a two-dimensional cross-sectional model of the vadose zone and a portion of the underlying aquifer consistent with the modeling approach used for the WMA S-SX Field Investigation Report (RPP-7884).

- Identifying retrieval cases that span a reasonable range of residual waste volume and retrieval leakage volumes that will be used to develop risk versus volume relationships for both residual waste and retrieval leakage.
- Performing a risk assessment to assess short-and long-term human health risks to human receptors. Tank-specific impacts are evaluated at the tank farm fence line. Impacts are also evaluated on a tank farm basis at the 200 West Area fence line and at the 200 Area exclusion boundaries. Impacts from the entire tank farm are not evaluated at the tank farm boundary because the contaminant releases were modeled using two-dimensional cross-sectional (west-east) models through each of the four three-tank rows, consistent with the modeling approach used for the WMA S-SX Field Investigation Report (RPP-7884). Using this modeling approach, the impacts from individual tanks and cross-sections are evaluated at the tank farm fence line but the impacts from all tanks and cross-sections in combintion are evaluated only at locations downgradient from the tank farm fence line..
- Comparing performance of the total system to requirements established by federal and state regulations, and the Hanford Federal Facility Agreement and Consent Order.
- Evaluating the ability of static (measurements while pumping is shut down) and dynamic (measurements during pumping) in-tank leak detection methods to compare with risk-based limits.

The RPE for the S-Farm is provided as Appendix B to this report. The Tank S-102 RPE models ten cases, varying the amounts of leakage and residual waste assumed in Tank S-102 and the other tanks in S-Farm. Results of the RPE show that the bounding scenario for risk is the long-term human health risk via the residual farmer scenario.

Results of the short-term human health risk analysis indicate that short-term risks fall within criteria limits for radiological and chemical exposure and are not a driver for establishing retrieval performance limits. By extrapolating the data from the case results, the RPE indicates that the long-term human health risks from Tank S-102 retrieval leakage, when considered by them, exceed ILCR of 10^{-5} for the industrial worker scenario at the tank farm fence line at volumes as low as 3,600 gallons.

The long-term human health risks from Tank S-102 residual waste, when considered by them, are below an ILCR of 10^{-5} for the industrial worker at the tank farm fence line for residual volumes below approximately 6,800 gallons. When the residential farmer scenario is considered, the long-term human health risks from a residual volume equal to the Hanford Federal Facility Agreement and Consent Order Milestone M-45-00 retrieval goal of 360 cubic feet (2,700 gallons) in Tank S-102 are above an ILCR of 10^{-5}, which means that under this scenario there would be no retrieval leakage allowance (Appendix B).

Not retrieving the waste from Tank S-102 will result in its eventual and certain release, when the tank ultimately fails. The RPE process has determined that the risk from not retrieving the waste in Tank S-102 would result in an estimated ILCR of 8.8×10^{-2} to the residential farmer at the tank farm fence line (8,800 times the regulatory threshold of 1×10^{-5}). Any

inventory reduction from Tank S-102 by retrieval will reduce the unacceptable long-term risk.

Waste retrieval will use techniques that manage the amount of waste that could leak. If there is leakage from the tank, remediation of the soil is not precluded. Since the soils around the tank farms are already contaminated, the area around Tank S-102 will be addressed as part of the tank farm closure. The RPE risk estimate does not address the short- or long-term impacts associated with the soil remediation.

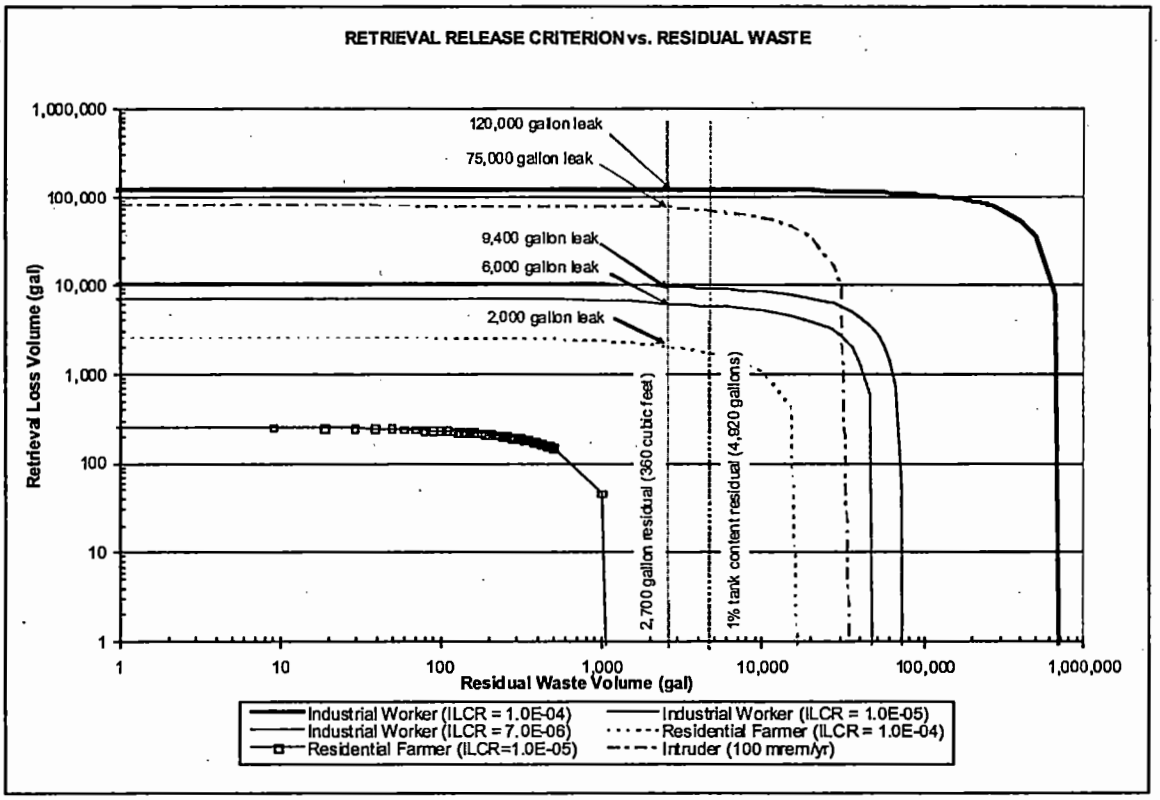

Figure 3-2: Tank S-102 Preliminary Retrieval Release Criterion vs. Residual Waste

Figure 3-2 depicts the relationship established in the RPE between Tank S-102 residual waste volume and retrieval leakage volume for the industrial worker and residential farmer scenarios, and the post-drilling resident inadvertent intruder scenario. The basis for the results presented in Figure 3-2 is provided in Appendix B, Section B.6.2.3. The basic procedure for generating the curves shown in Figure 3-2 starts by selecting a risk threshold of interest, such as 1×10^{-4} ILCR for the industrial worker at the tank farm boundary. Risk to the selected receptor from residual waste is then calculated for a wide range of residual waste volumes (e.g., from 4 L [1 gal] to 95,000 L [250,000 gal]) by extrapolating from the results of the residual waste analysis cases presented in Appendix B, Section B.5.1.3. At the high end of the residual waste volume range, the calculated residual waste risk generally exceeds the risk threshold, indicating that the threshold could not be achieved with the residual waste volumes even in the absence of a retrieval leak. Progressing lower in the residual waste volume range, a volume is eventually reached where the calculated residual waste risk falls below the risk threshold. For this and all lesser residual waste volumes, there is a difference

between the residual waste risk and the risk threshold, which is used as the risk available to allocate to a retrieval leak. The amount of risk available is calculated by subtracting the residual waste risk from the risk threshold value. Finally, retrieval leakage volumes corresponding to the available retrieval leakage risks are calculated, again by extrapolating (or interpolating) from the analysis results (this time from the retrieval leakages cases). This procedure generates a set of data points that each contains a residual waste volume and a corresponding retrieval leakage volume whose respective risks sum to give the risk threshold of interest. Results of the procedure are plotted on an X-Y plot using logarithmic scale as shown in Figure 3-2.

Retrieval leakage volume limits identified in the preceding paragraphs assume the specified risk threshold is apportioned entirely to Tank S-102. When the threshold is apportioned across all of the tanks in the S-Farm and the contribution from S-Farm past leaks is considered, the retrieval requirements on Tank S-102 are significantly more restrictive. For example, a tank farm risk threshold of 1.0×10^{-4} for the industrial worker scenario allocates to a Tank S-102 risk budget of 7.0×10^{-6}. Using this apportioned risk budget lowers the Tank S-102 retrieval leakage limit from 120,000 gallons to 6,000 gallons (Figure 3.2). Tank farm risk thresholds of 1.0×10^{-5} for the industrial worker scenario and 1.0×10^{-4} for the residential farmer scenario allocate to Tank S-102 risk budgets of 6.2×10^{-7} and 3.9×10^{-6}, respectively (Appendix B). The RPE analysis results indicate that avoiding exceeding both of these apportioned risk budgets would not be possible unless waste were retrieved to significantly lower residual waste levels than specified in the interim retrieval goal and no leakage occurred during retrieval. It is not possible to allocate a tank farm risk threshold of 1.0×10^{-5} for the residential farmer scenario because the risk to the residential farmer from the S-Tank Farm past leaks alone exceeds 1.0×10^{-5}, leaving no risk to allocate to the other tanks or source terms.

Anticipated impacts from past tank leaks and tank residuals complicate the development of risk-based retrieval leakage criteria for the S-Farm. Peak impacts at the tank farm boundary resulting from past leaks range from an ILCR of 1.4×10^{-3} for the Industrial Worker to 5.5×10^{-2} for the Residential Farmer. The risk from past leaks in the S-Farm present ILCR levels that are two to three orders of magnitude above the traditional 10^{-5} risk standards. Therefore, to derive performance criteria for retrieval leak volume thresholds and mitigation strategies at 10^{-5} ILCR is not justified given the existence of substantial past leakage in the S-Farm. The peak impacts at the tank farm boundary associated with tank residuals after retrieving 99 percent of the tank contents range from an ILCR of 1.7×10^{-5} for the Industrial Worker to 3.6×10^{-4} for the Residential Farmer. The peak impacts from the mobile contaminants associated with past leaks would occur during the time period when peak impacts from retrieval leakage would occur and these two source terms would be additive. The peak past leak impacts would not occur during the time period when peak residual waste impacts would occur and would not be additive.

Given the magnitude of the predictions for past leak impacts at the tank farm fence line, coupled with predictions of future composite impacts in the 200 West Area from Environmental Restoration waste sites and tank farms described in the Composite Analysis, the risk basis for developing leak volume criteria is developed based on limiting further impacts rather than meeting traditional risk standards (i.e., 10^{-5}). While the goal of the

retrieval is to retrieve the waste with no leakage from the tank, leakage threshold volumes need to be established to provide requirements for the design process. Establishing retrieval leakage threshold volumes is not intended to imply that this is an "acceptable" event but rather an indication of when substantive impacts from a leak would be anticipated and that corrective and mitigating actions would need to be considered. Establishing retrieval leakage threshold volumes at risk levels of 10^{-3} for the residential farmer and 10^{-4} for the industrial worker scenario translates into a leakage threshold volume of 8,000 to 25,000 gallons for the residential farmer and industrial worker scenario, respectively. Leakage above this range (8,000 to 25,000 gallons) would increase risks from past leaks currently posed to a Residential Farmer and Industrial Worker. Leakage below this range would not measurably affect the risk posed by residual waste under these scenarios. Comparatively, if 10 times drinking water standards were to be used as a performance measure, similar to the 200-UP-1 Interim Record of Decision, the corresponding Tank S-102 retrieval leakage volume would be 23,000 gallons with no additional loss allowed for other retrieval actions.

3.3 LESSONS LEARNED SUPPORTING SELECTION AND DEPLOYMENT OF RETRIEVAL & LDMM TECHNOLOGIES

DOE and good engineering practice establish that lessons learned from previous activities to be documented and used in the design considerations for similar activities. This applies to tank waste retrieval and LDMM. Lessons learned from other similar projects provide valuable experience that is referred to during design activities and operation of the retrieval and LDMM system. Lessons learned do not form the functions and requirements for the retrieval and LDMM system design and execution. However they do influence, based on past experience and application, how the functions and requirements are achieved. During the various project phases (i.e., initial engineering development, preliminary design, detailed design, construction, and operations), lessons learned shall be identified and evaluated for application relevant to the Tank S-102 retrieval effort. This experience will guide the design team in the selection of the best retrieval and LDMM technologies.

Appendix A contains a description of the process used to gather lessons learned, the relevant lessons learned that apply to this project, and the bibliography of sources used in gathering the lessons learned information. The lessons learned topics include LDMM, retrieval, instrumentation, and operational experience from previous DOE and industry-related retrieval projects, as required by Milestone M-45-05-T03. DOE will incorporate these lessons learned during the design and operation of the Tank S-102 waste retrieval system. The best available and deployable, tank farms, LDMM technology will be used for Tank S-102 retrieval.

Lessons learned have already provided some design and operational features that are being given consideration for implementation in the retrieval effort system for Tank S-102. These features are highlighted in Appendix A.

4.0 FUNCTIONS AND REQUIREMENTS

The functions and requirements established by this document are derived from the need to satisfy the Hanford Federal Facility Agreement and Consent Order Milestone. The goal is to retrieve to safe storage approximately 490 curies of mobile, long-lived radioisotopes and 99 percent of the Tank S-102 contents by volume (per the DOE BBI data of August 1, 2000) while maintaining a tank and waste retrieval system that safely isolates the waste from the workers, the environment, and the public. This functions and requirements document establishes the upper-level functions and corresponding requirements to which the retrieval system must be designed and operated. Requirements specific to this level of functional decomposition are related to specific functions in Section 4.0 and summarized in Section 2.0. Other requirements not directly applicable at this level of functional decomposition are promulgated to CHG via the DOE-CHG Contract (ORP 2001) .

4.1 CONTROL TANK S-102 STRUCTURE AND WASTE TEMPERATURE

The Tank S-102 waste retrieval system shall control the structure and waste temperature to prevent structural damage to the tank.

[Basis: OSD-T-151-00013, CHG 2000c]

4.2 CONTROL TANK S-102 WASTE LEVEL

The Tank S-102 waste retrieval system shall control the waste level to prevent waste overflow and limit the hydrostatic head-induced stresses in the tank. The Tank S-102 waste retrieval system shall prevent the waste level in Tank S-102 from exceeding 711 cm (275 in.). The Tank S-102 waste retrieval system shall limit the hydrostatic forces on Tank S-102 such that the hydrostatic forces do not exceed the force equivalent to 711 cm (275 in.) of waste at a specific gravity (SpG) of 2.0.

[Basis: LMHC 1999]

4.3 CONTROL TANK S-102 VAPOR SPACE PRESSURE

The Tank S-102 waste retrieval system shall control the vapor space pressure in Tank S-102 to within the following specified design limits to prevent structural damage to the tank:

- If the waste level is ≥ 38.1 cm (15 in.),

Then -38.1 cm (-15 in.) w.g. ≤ vapor space pressure ≤ 1.5 m (60 in.) w.g.

- If the waste level is < 38.1 cm (15 in.),

Then (-waste level) ≤ vapor space pressure ≤ 1.5 m (60 in.) w.g.

[Basis: LMHC 1999]

4.4 CONTROL TANK S-102 GASEOUS DISCHARGES

The Tank S-102 WRS shall control the vapor space pressure in Tank S-102 and in the WRS and filter the air exhaust to restrict emissions to the environment as necessary to assure worker health and safety in accordance with WAC 173-400 and 173-460 (non-radioactive); and 40CFR61 and WAC 246 and 247 (radioactive).

[Basis: DOE 2001a]

4.5 REMOVE WASTE FROM TANK S-102

For the initial Tank S-102 waste retrieval, the Tank S-102 WRS shall be capable of removing as much of the Tank S-102 waste inventory as possible with a goal of leaving no more than 10.2 kL (360 cubic feet) within 69 days of operation over a 168-day duration [Basis: (Milestone M-45-05A and M-45-00) DOE/Ecology 2000] [RPP-7087 (CHG 2000a)].

4.6 CONTROL AND MONITOR THE TANK S-102 WASTE REMOVAL PROCESS

The Tank S-102 waste retrieval system shall monitor and control the process parameters for retrieving waste from Tank S-102.

[Basis: (Milestone M-45-05A) DOE/Ecology 2000]

4.6.1 Detect Leaks during Tank S-102 Waste Removal

The system shall be designed to detect a cumulative leak volume during the retrieval campaign of 8,000 gallons or the system shall be designed using the best available technology that is economically achievable (BATEA) to detect tank leaks during retrieval.

[Basis: Section 3.2]

4.6.2 Monitor Leaks from Tank S-102 During Waste Removal

The Tank S-102 waste retrieval system shall quantify liquid waste release volumes from Tank S-102 if a release is detected during waste retrieval operations. The data shall be collected, in the event of a leak, to support future RPEs, which will be used to address retrieval of the next S-Farm tank. Data collected will be used to estimate the volume and composition of leaked material.

[Basis: Section 3.2]

4.6.3 Control and Monitor Tank S-102 Waste Retrieval

Waste removal process parameters, environmental safety parameters, and equipment parameters shall be monitored and controlled for safe and effective operation of the Tank S-102 WRS.

[Basis: good engineering practice]

4.7 MEASURE AND ESTIMATE RESIDUAL WASTE IN TANK S-102

The Tank S-102 WRS shall estimate the residual waste in Tank S-102 to evaluate the Tank S-102 WRS effectiveness. Waste on the walls of the tank; on the stiffening rings attached to the walls of the tank; on the exterior surfaces of in-tank debris, hardware, and components; and on the bottom of the tank shall be estimated as necessary.

[Basis: (Milestone M-45-05A, DOE/Ecology 2000, and Appendix H, Attachment 1)]

4.8 MITIGATE LEAKS DURING TANK S-102 WASTE RETRIEVAL PROCESS

The Tank S-102 WRS shall mitigate leaks as the primary means of managing environmental impact caused by releases during retrieval of SST waste.

[Basis: CHG 1999]

4.9 SAFETY

The Tank S-102 waste retrieval system shall be designed to protect workers, the public, and the environment from exposure to tank radioactive waste during retrieval.

[Basis: 10 CFR 830 and 10 CFR 835]

4.10 DST DESIGN LIMITS

The Tank S-102 waste retrieval system shall not adversely affect the function of the DST System or exceed the DST Design and operational limits as specified in TSR-006, OSD-T-151-0007, and HNF-IP-1266.

4.10.1 Tank S-102 WRS Design

The Tank S-102 waste retrieval system new components shall be designed to ensure proper structural strength, compatibility with the waste and protection against corrosion in accordance with requirements of 40 CFR 265.192 and WAC 173-303-640.

4.11 OCCUPATIONAL SAFETY AND HEALTH

The Tank S-102 waste retrieval system shall incorporate design features that comply with the applicable requirements of 29 CFR 1910.

[Basis: 29 CFR 1910]

4.12 SST AND DST DOME LOADING

The Tank S-102 waste retrieval system shall not exceed the maximum dome loading on existing SSTs and DSTs specified in HNF-IP-1266, 5.16, Rev. 4.

[Basis: CHG 1997]

4.13 PROHIBITED MATERIALS

Materials regulated by 40 CFR Subchapter R shall not be used in the design of the 241-S-102 WRS.

[Basis: 40 CFR Subchapter R]

4.14 WASTE RETRIEVAL SYSTEM SECONDARY CONTAINMENT AND LEAK DETECTION

The Tank S-102 waste retrieval system shall incorporate in new components secondary containment and leak-detection design features in accordance with 40 CFR 265.193 and WAC 173-303-640.

[Basis: 40 CFR 265 and WAC 173-303-640]

4.15 WASTE RETRIEVAL SYSTEM DEACTIVATION AND DECONTAMINATION

The Tank S-102 waste retrieval system equipment deactivation shall be compatible with decontamination, reuse and/or disposal requirements, e.g., disposal as solid waste.

[Basis: DOE Order 413.3]

4.16 LDMM TANK HISTORY REVIEW

A pre-retrieval LDMM assessment will be undertaken for Tank S-102 prior to the start of retrieval operations. The pre-retrieval assessment will be consistent with the Hanford Federal Facility Agreement and Consent Order Appendix H – Single-Shell Tank Waste Retrieval Criteria Procedure.

5.0 LDMM AND RETRIEVAL STRATEGY

This section describes an LDMM and retrieval strategy for the Tank S-102 retrieval system consistent with the functions and requirements established by Section 4.0. Section 5.0 includes definitions for LDMM, uncertainties in detecting and monitoring leaks in waste tanks, LDMM and retrieval strategy, preliminary system descriptions, and alternative technologies being evaluated for ex-tank leak detection and monitoring. The functions and requirements established in Section 4.0 of this document govern the design and development of the integrated system.

5.1 LDMM DEFINITIONS

This section provides definitions for the LDMM terms used in Section 5.0. Sections 5.2 through 5.7 develop the detailed applications of LDMM for the Tank S-102 retrieval.

Leak detection, monitoring, and mitigation are defined in RPP-7012 (CHG 2000). These definitions have been accepted by ORP and Ecology and are presented here for reference.

- **Leak Detection:** technologies, methods, or systems used to detect a leak.
- **Leak Monitoring:** technologies, methods, or systems used to quantify liquid waste release volumes from a SST, if a release is detected during waste retrieval operations.
- **Leak Mitigation:** technologies, methods, or systems that can reduce a leak, or reduce the environmental impact of a leak.

5.1.1 Strategy

The integrated LDMM and retrieval strategy for the Tank S-102 waste retrieval system has been developed to meet the requirements specified in the M-45 series of milestones (DOE/Ecology 2000). The purpose of this strategy is to ensure that the waste retrieval system:

- Manages all waste releases to the environment;
- Is technically practicable and defensible;
- Complies with all applicable regulations and requirements;
- Meets the programmatic needs of the DOE Office of River Protection; and

Figure 5-1 illustrates the three elements necessary for a release of liquid waste from a tank to occur. If there are no leak paths in the tank (i.e., holes, pits or cracks), then by definition there is no possibility of a leak unless the tank is overfilled. If however, there are one or more leak paths in the tank, the volume of liquid released can be reduced by controlling the volume of free liquid or the hydraulic head of the liquid. If any of the legs of the triangle are severed, then no leak can occur. An additional factor in leak minimization is the amount of time available for liquid to leak. The less time that drainable liquid is present in the tank, the smaller the volume of liquid that could leak.

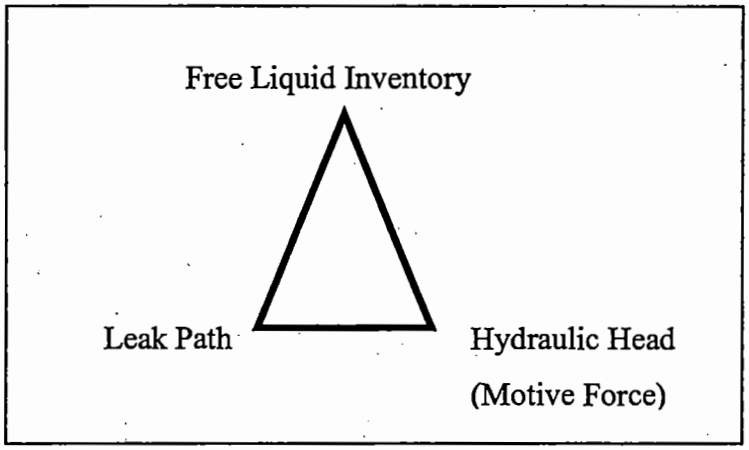

Figure 5-1: Leak Rate Minimization Triangle

5.1.2 Leak Detection

Detecting a leak from a waste tank requires application of suitable technologies, methods, or systems. Work documented over much of the past decade shows that there are many possible methods to detect leaks in underground storage tanks. However, there are a limited number of methods that can be readily implemented in the Single Shell Tank Farms. In 1998, a review of previous LDMM investigations and new information regarding technologies applicable to SST retrieval was published (LMHC 1999). This review recommended the use of in-tank volumetric methods similar to the EPA approved methods used on underground petroleum tanks, and external methods for leak detection. In 1999, an update of the SST retrieval LDMM strategy repeated these recommendations (LMHC 1999). These recommendations were based on tanks with a free liquid surface.

A review of recent waste retrieval projects indicates that internal monitoring of liquid inventories is the most commonly used technology applicable to retrieval from Tank S-102 (See Appendix A). The approved EPA methods for leak detection, where a free liquid surface exists, are "dynamic" and "static." Dynamic leak detection is monitoring of liquid and waste inventories while waste is actively being retrieved. Static leak detection is performed when operations are temporarily suspended. Each technique is defined further below.

5.1.2.1 Dynamic Leak Detection

Akin to a mass balance, the dynamic volumetric inventory balance method uses level instruments in the retrieval and receiver tanks along with flow meters to continuously balance the flow in and flow out of the retrieval tank. This method is similar to "Statistical Inventory Reconciliation" employed by the petroleum industry in distribution systems like gas stations. It is important to note that the complexities of waste solubility, retained gas, and evaporation combined with the scale difference between a local gas station tank and a 75-foot diameter SST are significant. The advantage of this technology is that it provides a continuous on-line measurement. The method does not, however, provide real-time leak detection capability, but can reconcile the pre-retrieval and post-

retrieval data to approximate any leaks that may occur. This technique is sensitive to a number of environmental and operational interferences, and requires compensation for those interferences to achieve acceptable performance levels. Based on the Tank C-106 retrieval experience (CHG 1999), operational influences, such as uncondensed evaporation, may significantly affect the accuracy of available dynamic leak detection technologies.

5.1.2.2 Static Leak Detection

Static volumetric leak detection is used extensively in industry. Volumetric methods measure the liquid surface in a static tank and convert the level data to volume data from the known tank parameters. Leak detection is accomplished by calculating the rate of volume change over time and comparing this rate to a pre-determined "leak detection threshold" to determine whether the tank has an inflow, an outflow, or that the tank is sound (i.e., non-leaking). Volumetric methods are subject to error due to changes in bulk density of the waste, which occur during the period of measurement (e.g., dissolution of the salt and contained gas releases).

Differential pressure measurements are one type of sensor used by the DOE to measure liquid level and conduct leak detection tests (ORNL 1994). This method measures change in depth by measuring the change in the hydrostatic head above a pressure sensing port. Direct level-sensing instrumentation such as the ENRAF™ and FIC™ gauges are currently used in SSTs that have a continuous free liquid surface. They are well suited for the volumetric method in tanks with a measurable air-liquid interface. Tanks that do not have a free liquid surface may require alternative measuring devices.

In-tank volumetric technologies that measure the air-liquid interface, which can include adaptation of elements of the mass-based technology, are best suited for leak detection in large tanks because of the advantages they have over other technologies. These advantages include:

- Deployment readiness,
- Technology maturity,
- Accuracy,
- Ability to evaluate system performance,
- Life cycle cost, and
- Successful application in industry and at other DOE sites.

The performance data for leak detection with volumetric systems are based on data obtained in tanks with a free liquid surface. The ability of these methods of leak detection to accurately determine the presence of a sufficiently small leak (on the order of 1.8 gallons per hour) has not been determined in tanks without a liquid surface.

5.1.3 Leak Monitoring

If a release is detected during waste retrieval operations, the leak will be monitored in order to estimate the total volume lost. A leak volume estimate must be performed to

quantify the environmental impact resulting from a leak. The estimated leak volume will be incorporated into an updated RPE to recalculate the risk associated with the remainder of the tanks in the farm. Dynamic and static testing are applied to quantify a potential leak volume during retrieval operations. The limitations associated with leak detection, as discussed previously, apply to leak monitoring.

5.1.4 Leak Mitigation

The primary strategy for leak mitigation uses a retrieval technology that limits the liquid hydrostatic head, controls the rate of water addition and waste removal, and minimizes the retrieval time-at-risk during which a leak could occur. Water additions will not exceed the interstitial liquid level (ILL) (172 inches) of the tank in order to ensure the waste remains below a level at which the tank is known not to leak. In addition, the retrieval system will be designed and deployed to remove as much of the pumpable liquids as possible if a leak has been detected.

Waste retrieval from Tank S-102 is expected to require from 18 to 24 weeks to complete. Table 5-1 provides calculated total leak volumes for various leak rates and retrieval durations. For example, if an undetected leak of 2.0 gallon per hour (gal/hr) were to occur at the beginning of a 18-week-long retrieval campaign, the table shows that 6,048 gallons of liquid would be released during the 18-week period.

Table 5-1: Leak Volumes for Various Retrieval Durations with Constant Leak Rates

Leak Rate (gal/hr)	1 wk (gal)	6 wk (gal)	12 wk (gal)	18 wk (gal)	24 wk (gal)	30 wk (gal)
0.5	84	504	1,008	1,512	2,016	2,520
1.0	168	1,008	2,016	3,024	4,032	5,040
2.0	336	2,016	4,032	6,048	8,064	10,080
5.0	840	5,040	10,080	15,120	20,160	25,200
10.0	1,680	10,080	20,160	30,240	40,320	50,400
50.0	8,400	50,400	100,800	151,200	201,600	252,000

The non-catastrophic postulated leak volume (95 percent confidence) for Hanford SSTs is less than 1.8 gallons per hour (*A Scientific Basis for Establishing Drywell Monitoring Frequencies* [RHO 1981]). This analysis was reviewed again in 1998 and found consistent with SST leak data (LMHC 1999). This rate is based on estimated averages of leaks in the 1960s and 1970s from tanks with significant free liquids. Excluding catastrophic failures, 1.8 gallons/hour postulated leak volume is a much larger leak rate than would be expected today, particularly given the controlled, monitored addition and removal of water to and from the tank and interim stabilization of the SST's.

If a truly catastrophic failure of the tank were to occur, and no mitigating measures were implemented, the entire tank volume could eventually be released to the environment.

The maximum volume, which could be released under the hypothetical, worst-case scenario includes the tank inventory plus approximately 5,000 gallons of added water needed to support waste dissolution, is estimated at 452,000 gallons. Lessons learned indicate that catastrophic leaks are caused by past high heat operation or from improper design and construction. There is no evidence to indicate a catastrophic failure in Tank S-102 would occur.

Another consideration is that setting equipment to monitor for small leak volumes increases the potential for false alarms. False alarms will result in suspension of retrieval operations to validate the alarm, increasing overall retrieval duration, which in turn would increase the risk of leak volume. This approach is not consistent with the leak mitigation strategy. Figure 5-2 illustrates accumulated leak volumes using a 1.8 gal/hr leak rate. At a rate of 1.8 gal/hr, the leak loss performance criteria of 8,000 gallons would only be exceeded after a 186-day retrieval campaign. Both Table 1-1 and Figure 5-2 demonstrate that increased retrieval duration leads to potential increased leak loss, which in turn leads to increased risk to human health and the environment.

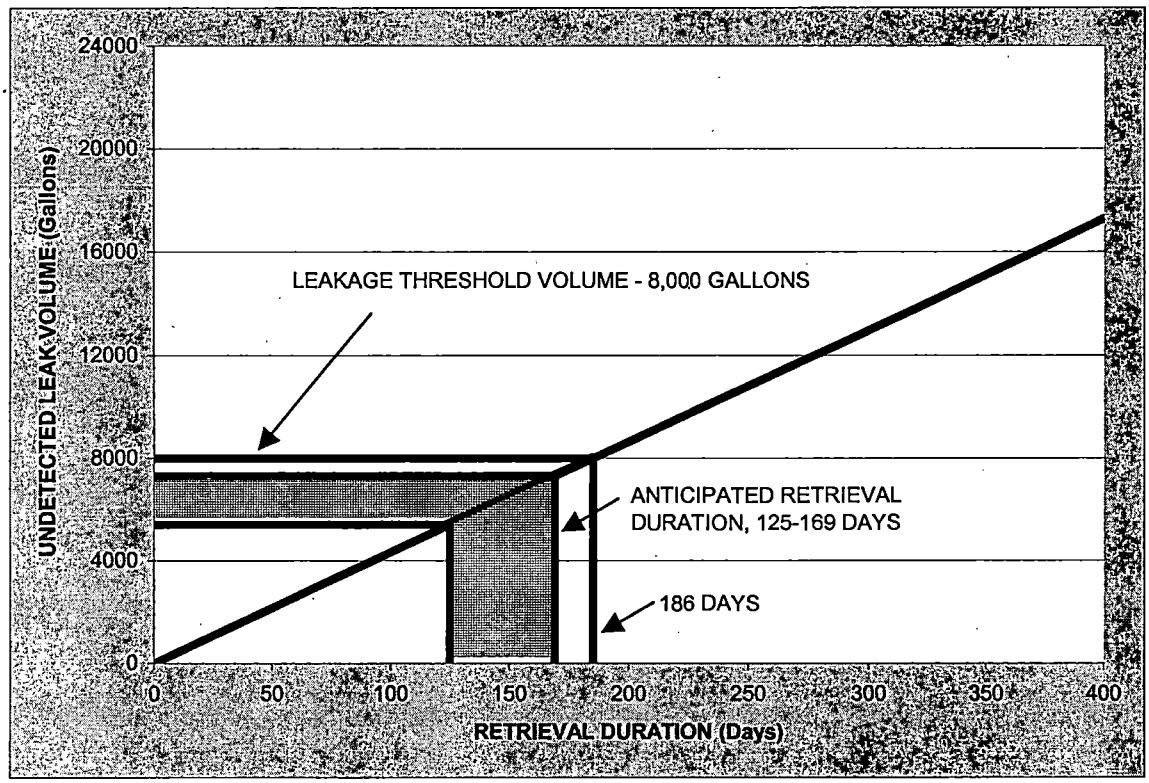

Figure 5-2: Undetected Leak Volume vs. Retrieval Duration At Loss of 1.8 Gal/Hr

Lessons learned (Appendix A) show no evidence of retrieval operations causing a tank leak, and the 95% probability leak rate for a non-catastrophic leak in an SST (1.8 gal/hr) would be undetectable. Therefore, the overall strategy for leak detection is:

1. Manage the amount of liquid in the tank,
2. Reduce the retrieval duration, and
3. Minimize activities that require suspending retrieval operations.

5.2 UNCERTAINTIES INFLUENCING LEAK DETECTION AND LEAK MITIGATION

Leak detection systems that can be integrated with this retrieval system have not undergone system performance testing to determine their performance in terms of probability of detection and probability of false alarm at a given leak threshold in the Hanford SSTs. System performance has been estimated based on the performance of systems in large underground petroleum storage tanks. By extrapolating available SST data and correlating it to the petroleum industry data, it is estimated that once the level has stabilized, a static leak test in a SST with a free liquid surface, will have a minimum leak detection rate in the range of 2 to 25 gallons per hour with a 95 percent probability of detection and 5 percent probability of false alarm. Similarly, based on petroleum industry experience, dynamic leak detection will have a minimum leak detection rate in the range of 20 to 250 gallons per hour with a 95 percent probability of detection.

The circumstances and uncertainties that result in less accurate leak detection include:

- Lack of a uniform free liquid surface,
- Changes in solution density as the waste dissolves,
- Uncertainties associated with the tank dimensions,
- Uncertainty of the waste characterization data and waste chemistry,
- Uncertainty of waste pore volume and capillary height,
- Uncertainty of soluble to non-soluble waste retrieval rates, and
- Uncertainty of interstitial liquid movement.

Understanding the performance of a leak detection method determines whether risk-based leak detection requirements can be met, as well as how the methodology is applied to meet the requirements (e.g., number of tests to be conducted or combined, number of in-tank parameters measured, and frequency of testing). The performance of each leak detection method or combination of methods will be determined in terms of the Probability of Detection and Probability of False Alarm expressed as a volume or volume rate using methods similar to American Society for Testing and Materials and EPA standard test procedures. To compensate for uncertainties in leak detection, the Tank S-102 retrieval design will minimize the hydraulic head, reduce the free liquid

inventory, reduce the available area where a leak could occur, and use static and dynamic leak detection methods.

5.3 TANK S-102 INTEGRATED STRATEGY FOR LDMM AND RETRIEVAL

An integrated LDMM and retrieval strategy will be employed for Tank S-102 in order to manage the risk posed by potential waste leakage during retrieval. Implementation of this strategy will be conducted in such a way as to not preclude future tank closure.

The environmental and programmatic risks posed by different retrieval technologies, tanks, and tank constituents vary significantly. To develop and implement a consistent and reasonable LDMM design concept, a risk-based approach has been used to establish quantitative performance requirements for individual tanks (see Section 3.0). When integrated with a retrieval technology, the risk-based approach establishes the minimum leak detection limits as a function of potential retrieval leak volume and residual waste remaining in the tank following completion of retrieval activities.

The risk associated with continued storage of waste in Tank S-102 is proportional to the total contaminants it contains (see Figure 5-3). If the tank waste is not retrieved, the risk is proportional to the curies trapped in the residual waste (447,000 gallons). A worst case leak scenario, based on a 1.8 gallon/hour leak rate, would be less than 7,400 gallons over the approximately 168 day retrieval campaign. The eventual release of all 447,000 gallons if the waste is not retrieved carries a much higher risk (a 100 percent probability and consequences 8,800 times higher than the residential farmer criterion of 10^{-5} ILCR) than the potential loss of 7,400 gallons that might occur during retrieval. The long-term risk of not retrieving the waste is greater than the risk associated with a 7,400-gallon retrieval leak, if it were to occur.

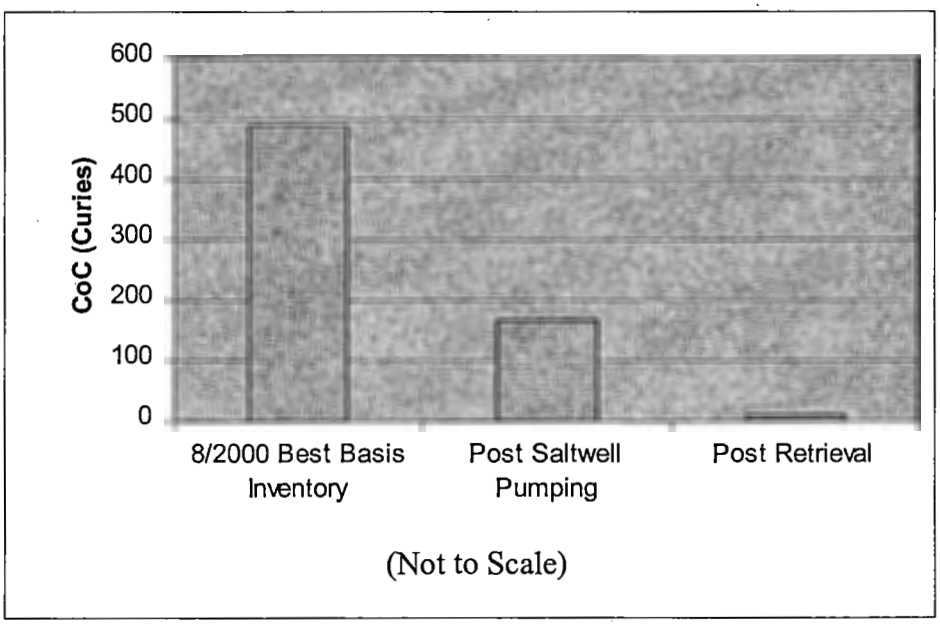

Figure 5-3: Tank S-102 Total Contaminants of Concern During Retrieval

The LDMM strategy for Tank S-102 will use best available leak detection, leak monitoring, and leak mitigation technologies and strategies economically achievable to reduce the risk to human health and the environment. However, leak detection and leak monitoring using the current best available technology require a free liquid surface within the tank to accurately detect and monitor a leak and relies on a free liquid surface to improve precision and reduce false indications at low volumes.

The retrieval technology selected for the Tank S-102 waste retrieval project will rely on the principles that:

- Manage the amount of liquid required for retrieval,
- Reduce the liquid volume in the tank,
- Incorporate a retrieval strategy that manages the free liquid surface and hydraulic head, and
- Minimize the time liquid is in the tank.

During active retrieval operations, the Tank S-102 retrieval and LDMM strategy minimizes the hydraulic head and reduces the wall area in contact with liquid to reduce the leak potential (maintains a liquid level below an established pre-Interim Stabilization ILL of 172 inches) to reduce the overall potential for a leak. Leak detection data for Tank S-102 has demonstrated that the tank is not leaking below the liquid level established by the interstitial liquid. Restricting the liquid hydrostatic head in the tank during retrieval operations improves leak mitigation. This reduces the driving force for leakage, resulting in a slower leak, if one should occur. In addition, as retrieval progresses and the waste level declines, the surface area of the tank walls available to form or reveal a leak site is also reduced. This is important because the declining area available to allow a leak reduces the probability that a leak will occur.

5.3.1 Strategies for Leak Detection

The Tank S-102 scoping-level RPE indicates that the 10-5 ILCR criterion is exceeded for the residential farmer scenario when the minimum retrieval residual waste of 4,920 gallons (99% of August 2000 BBI waste volume) is left in the tank, even with no leaks during retrieval. However, the risk of not retrieving the waste exceeds that criterion. If the tank is interim stabilized (has the pumpable interstitial liquid removed via saltwell pumping) and the rest of the waste remains in the tank, preliminary analysis shows that the long-term human health risk (to the residential farmer) is about 600 times higher than if the tank is retrieved.

As a result, the best practical and available leak detection methods will be used to minimize the potential for risk to human health and the environment. The LDMM strategy focuses heavily on mitigation of the potential for and consequences of a leak and use of accepted and available methods of leak detection.

Lessons learned from industry and the DOE complex (Appendix A) provide no evidence that retrieval operations have caused a tank leak, and the 95 percent probability leak rate for a non-catastrophic leak in an SST (1.8 gallons/hour) would be undetectable. Therefore, the overall strategy for leak detection is:

- Manage the amount of liquid in a tank, by maintaining the ILL at or below its starting level of 172 inches (prior to waste retrieval activities) during active retrieval operations;
- Minimize the liquid hydraulic head during active operations, i.e., the driving force for a leak during active operations;
- Evaluate process control data for the tank frequently while the waste is actively being retrieved for the possibility of a large leak release (dynamic testing);
- Use existing drywell and ground water monitoring wells as defense in depth for detection[1] and monitoring;
- Perform opportunistic static tests during the retrieval campaign. Opportunistic static tests would be performed when retrieval operations were shut down;
- Minimize activities that require suspending retrieval operations; and
- Use static leak detection if the dynamic or external tank leak detection system indicates a probable leak.

Logging of drywells will be employed prior to and after retrieval operations. However, radiation detected in a drywell (i.e., due to a leak) may be difficult to interpret for the following reasons:

- Lack of a reading may only mean that a release from the retrieval tank has not migrated to the well, and
- A positive reading may be the result of existing contamination or waste migration from another tank or ancillary equipment.

Due to this uncertainty, ex-tank methods using existing drywells will not be the primary method of leak detection. When used in conjunction with other leak detection systems, they can be helpful in assessing the existence and extent of a leak.

5.3.2 Strategies for Leak Mitigation

The leak mitigation strategy (i.e., reduction of leak potential) will use the following techniques for protection of human health and the environment.

- Control the time required for retrievalIf a leak occurs, the volume leaked will be proportional to the amount of time the leak site is below the drainable liquid level.
- Leak mitigation will be accomplished by managing the liquid inventory in Tank S-102 to limit the potential volume of waste that could leak. Minimizing the volume of liquid added to the tank during retrieval reduces the hydrostatic head, which is the driving force for a leak.

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[1] The present dry well and groundwater monitoring system is not designed for real time (i.e., instantaneous) detection and response, as time is required for waste to reach the area of influence of the dry well and for radiation data interpretation and analysis. Alternate ex-tank leak detection methods are being evaluated (see Section 5.7) and will be considered for use based upon the results of proof-of-concept tests.

- Maximize the rate of dissolution/collection. The mixing aspect of the Tank S-102 waste retrieval system will enhance the dissolution rate. The residence time of the waste solutions in the tank will be kept to a minimum. The water may also be heated to increase the solubility of the waste in the tank.
- Retrieve from an advantageous location. The system shall be located in such a way that it can pump from a low point in the tank if a leak should occur. This is a mitigation activity allowing removal of the greatest amount of liquid from the tank.

5.4 SYSTEM DESCRIPTION

The retrieval and LDMM systems described in this section represent a conceptual view of the systems currently planned for deployment in Tank S-102. Detailed design will enhance the definition of the system and may change the features described below. However, the final design shall comply with the requirements established in this document. Any subsequent changes will be established through the change control process described in Section 6.0.

5.4.1 Tank S-102 Retrieval System Description

The waste retrieval system is expected to consist of three centrally located charge vessels and two sets of nozzles inserted through the top of the tank (one set is located near the center of the tank and the second is located near the perimeter of the tank). Once deployed, the operational philosophy for the Tank S-102 WRS will be to retrieve the waste in a "center-out" approach. To accomplish this, the Tank S-102 waste retrieval campaign will be performed in a series of batches. The first step is to transfer the bulk of the drainable liquid left after interim stabilization. During the transfer mode, waste slurry is drawn into the charge vessels and then driven through an above-ground transfer line to SY-Farm and SY-102. Once a transfer is complete, the above ground transfer line is flushed. Flush water is directed back into Tank S-102 and serves as the new solvent batch for dissolving additional waste.

The leak mitigation strategy is to establish an ILL level as the maximum liquid level during the retrieval campaign. The ILL for this initial waste retrieval activity is 172 inches based on pre-Interim Stabilization liquid levels in the tank. Initial batch water additions will not exceed the solution volume removed on the previous pumping cycle. The central nozzles will perform the bulk of operations to enlarge the cavity around the fluidic charge vessels. As this cavity increases, the outer nozzles will be added to the operational strategy to reach areas that are shadowed from the central nozzles and to assist in cleaning the tank walls. The nozzles are directed at saltcake to break up and dissolve material. The circulation of slurry will enhance mass transfer for the dissolution of the saltcake and create a saturated solution. After a saturated solution has been achieved, the WRS will change from a mixing mode to a transfer mode and the cycle for the next batch is started. The bulk of the retrieval process will involve dissolution of saltcake waste. Near the end of the retrieval campaign, insoluble solids will represent a greater fraction of the remaining material and will require a slightly different operational strategy for their removal. To remove the insoluble solids, water is added to the tank via

the nozzles to push solid material towards the center of the tank for transfer from Tank S-102 to Tank SY-102. Pumping of waste concurrent to the water additions will maximize the recovery of solids suspended by hydraulic agitation and manage the volume of water in the tank at any given time.

The S-102 reference technology Power Fluidics™ system proposed for deployment at Tank S-102 is comprised of the following components: air compressor, valve skid, jet pump skid, fluidic pump assembly (including charge vessels and inboard nozzles), off-gas skid, outboard nozzle assembly, and control trailer (see Figure 5-4).

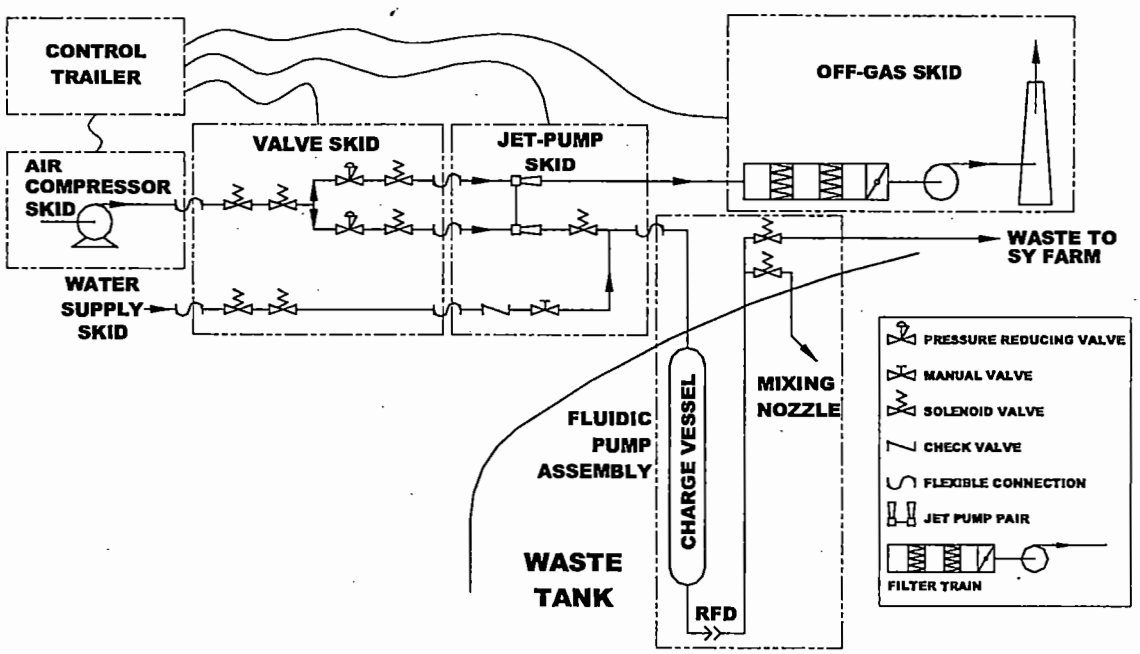

Figure 5-4: Tank S-102 Retrieval System (not to scale)

5.4.2 LDMM System Description

Two methods of in-tank leak detection will be used during the retrieval effort: dynamic and static. Dynamic leak detection uses tank level and transfer flow measurements to measure/calculate waste volume discrepancies between the SST being retrieved and the receiving DST (see Figure 5-5). Static leak detection uses discrepancies between level measurements taken at different points of time in the same tank and requires a halt in the retrieval effort to let the tank level achieve stasis (potentially over a period of days) (see Figure 5-6) and a free liquid surface to measure against. Drywells outside of Tank S-102 will be monitored to establish a pre-retrieval baseline for the SST and then periodically monitored to detect variations in radiation levels in the soil column.

The equipment and methods for LDMM will use the BATEA. Use of BATEA has been established by EPA in 40 CFR 415 (CFR, "Inorganic Chemicals Manufacturing Point Source Category"), which calls for use of BATEA for controlling effluents from inorganic chemicals point sources. Alternative equipment and methods under development or evaluation (see Section 5.7) will be employed at Hanford if they are available, shown to be an improvement, and found to be economically achievable.

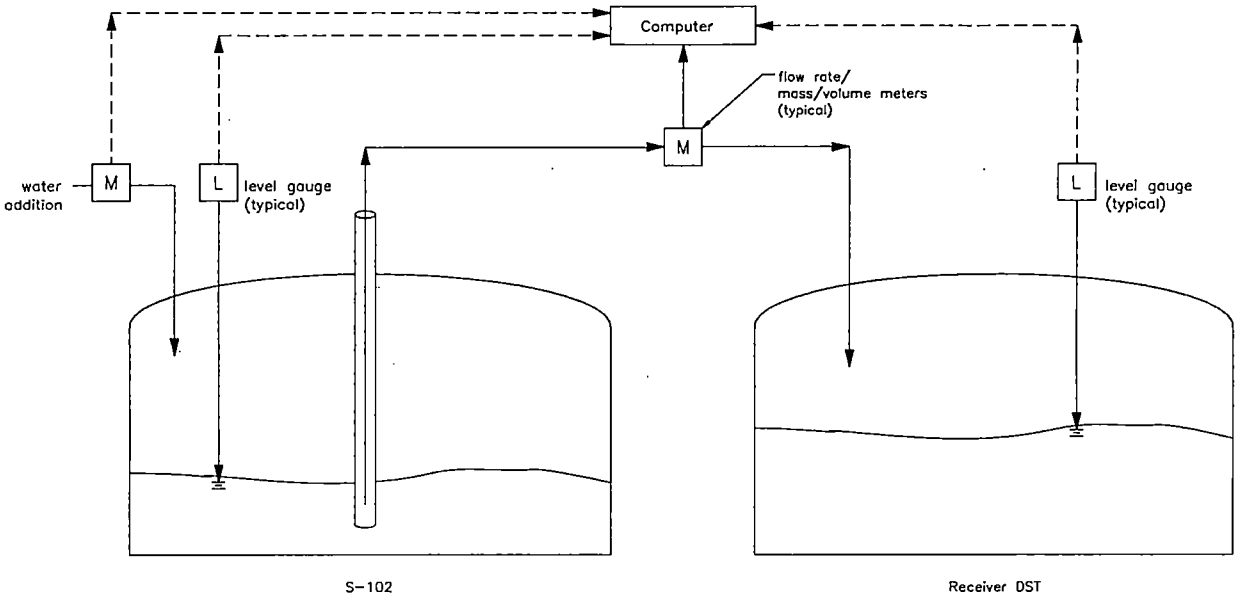

Figure 5-5: Tank S-102 Dynamic Leak Detection

(Based on Mass/Volumetric Flow & Tank Level)

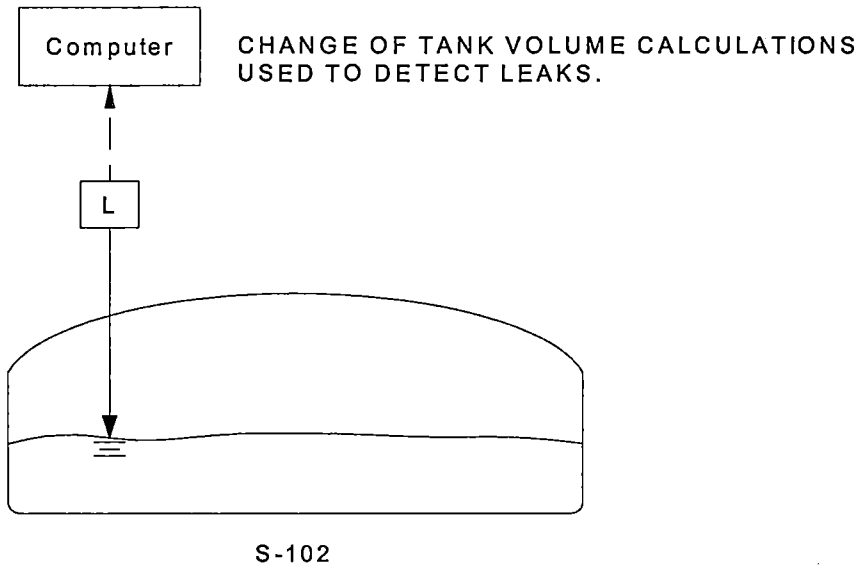

Figure 5-6: Tank S-102 Static Leak Detection

(Based on Changes in Tank Level Only)

Currently, the tank waste level is measured with ENRAF™ level instruments. The ENRAF™ instrument is mounted on a dedicated tank riser. The ENRAF™ is remotely controlled by a computer, which causes the instrument to raise and lower a displacer suspended on a stainless steel or platinum-iridium wire dispensed by a reel. The displacer is constantly weighed and the weight-sensing circuit can detect the difference between air, supernatant and sludge. The displacer wire dispensed length is measured via a rotary encoder on the reel. Changes in the waste level, greater than the uncertainties associated with the measurement error, are interpreted as a leak. This is currently defined as ½ inch, equating to a volumetric discrepancy of approximately 1,400 gallons (RHO 1981). Transfer flow measurements are done with volumetric/mass-flow instruments, which provide real-time data on volumetric and mass flow. Volumetric flows between Tank S-102 and the receiver DST can be compared with tank volumes calculated from tank levels. Differences outside of the instrument error bands and defined uncertainty ranges would indicate a leak. It is anticipated that the measurement will be performed at least daily after the liquid surface has been determined; however, timelines of detection for a potential leak will be dependent on potential leak rate. Any flush water additions or volume additions from other sources must also be accounted for in the volumetric balance calculations.

Leak detection is easily employed on the existing transfer lines, new transfer lines, and the receiving DST itself. Leak detection in the receiving DST will be performed primarily with the existing annulus leak detection. Unlike an SST, a DST has redundant protection against leakage (secondary encasement), which allows for using direct forms of leak detection, i.e., conductivity probes. The existing transfer lines and receiving DST

are encased and the encasement on each leg of the transfer route will terminate inside of a pit. Leak detectors, such as conductivity probes, will be employed in all interconnected valve and pump pits in the primary transfer system.

Transfer line leak detection may also be performed using volumetric/mass balancing. For example, flow meters placed at the inlet and outlet of the lines can be compared continuously for discrepancies greater than the anticipated measurement error and uncertainty ranges.

5.5 LDMM AND RETRIEVAL OPERATING STRATEGY

The operating strategy for performing LDMM and retrieval applies before, during, and after retrieval as described below. The strategy is consistent with the current level and maturity of the Tank S-102 retrieval design, as well as consistent with the functions and requirements established in this document.

5.5.1 Pre-Retrieval Operations

Figure 5-7 illustrates the liquid level in Tank S-102 (July 2002, (TWINS 2001)). The horizontal lines depict various start dates for saltwell pumping (March 15, 1999, May 12, 2002 and June 30, 2002). The liquid height in Tank S-102 prior to the May 12, 2002 start of saltwell pumping, 172 inches, will be the baseline.

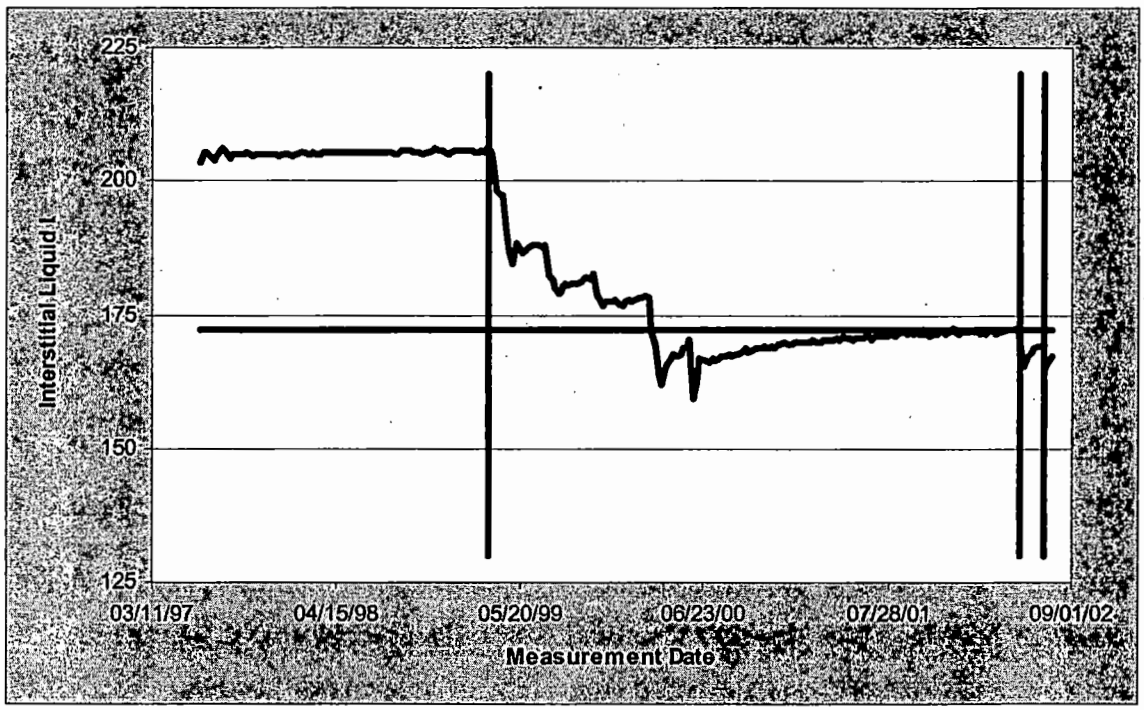

Figure 5-7: Tank S-102 Liquid Level

Liquid will continue be removed during the saltwell pumping phase. The ILL will vary from the baseline and the height of the liquid within the saltwell based on hydraulic continuity of the salt waste. It is assumed that approximately 35,000 gallons of drainable liquid will remain in the tank and approximately 200 gallons of supernatant will remain in the salt well at the conclusion of the saltwell pumping. In-tank leak detection and monitoring using existing equipment may be inoperable due to the lack of free liquid surface.

The pre-retrieval assessment required per Section 4.16 will be consistent with the Hanford Federal Facility Agreement and Consent Order Appendix H – Single Shell Tank Waste Retrieval Criteria Procedure and will:

- Establish an ex-tank baseline condition using gamma monitoring in existing drywells;
- Calculate the volume (liquid, solid, and total) for both Tank S-102 and the receiving DST;
- Measure/calculate Tank S-102 waste inventory via visual inspection or other mapping and survey techniques;
- Include an operational history review to look for evidence of releases;
- Include an operational/functionality review of existing leak detection instrumentation;
- Include a data review for drywell/borehole and Tank Farm Vadose Zone Project instrumentation and data; and
- Include a leak test and/or confirmation of "soundness" using active in-tank and ex-tank instrumentation following existing tank farm surveillance and monitoring programs and the tank leak assessment process (HNF-SD-WM-PROC-021, HNF-3747).

This pre-retrieval LDMM assessment will provide a baseline assessment of Tank S-102 conditions prior to retrieval.

5.5.2 Retrieval Operations

The overall retrieval operating strategy will consist of reducing the tank inventory and minimizing liquid hydrostatic head during retrieval operations, monitoring liquid inventories while waste is actively being retrieved (dynamic test), and monitoring liquid inventories if retrieval operations are intermittently suspended (static test). Minimizing the time at risk is also planned, so static leak tests may be coordinated with the time associated with staging waste from the 200 West Area DST receiver tank to an 200 East Area DST. Staging is required in order to have enough DST space to store the retrieved waste. Dynamic testing will be performed throughout the retrieval operations. Level measurements will be taken when the waste configuration and the location of the liquid surface is such that instrumentation can contact the liquid surface, i.e., a free liquid surface exists beneath a riser containing the level instrumentation. The opportunities for conducting leak tests will be established in a process control plan. Planning for static

testing will include taking advantage of opportunities, (such as DST staging described above), that arise when retrieval is shut down for another reason.

If a leak is indicated during retrieval operations, process control procedures will be implemented (see Figure 5-8). The first response to an indication of a potential leak will be to validate the instrumentation. If the validation process concludes that no leak is indicated, retrieval operations would start-up and continue under normal operating procedures. However, if a leak is validated, the operating contractor will notify DOE-ORP, which will in turn notify Ecology. The process control procedures will consider the leak volume limit, leak rate, and estimated duration to completion of retrieval operations when determining the appropriate response action. Potential response actions include: 1) modifying leak monitoring (e.g., implementing more frequent in-tank and/or ex-tank testing); 2) modifying operating conditions; 3) discontinuing adding or recycling liquids; 4) implementing emergency retrieval; or, 5) stopping all operations (see Figure 5-8). The response actions would then be implemented and, if appropriate, retrieval operations would continue under modified procedures through the completion of the retrieval activities. The requirements for implementation of leak response actions during retrieval operations will be established in the Process Control Plan that will be developed concurrent with the design of the retrieval and LDMM system.

5.5.2.1 Dynamic Leak Detection During Retrieval

Leak detection activities, during retrieval, will be performed via volume estimate calculations. At the conclusion of liquid removal operations, the liquid level height within the saltwell will be estimated via a Tank Volume Measurement System and a tank liquid inventory will be estimated. This will be compared with the estimated volumes of liquids added and removed. Since the assumed diameter of the saltwell is less than the location of the level indicator from center of saltwell (radius) it is not anticipated to be available for liquid level measurements on the first retrieval cycle.

Dynamic leak detection will be implemented during waste retrieval operations when the saltwell has expanded to encompass the level indicator. It will consist of liquid waste level measurements, including measurements required to compensate for short-term variations in the measurement signals, in both Tank S-102 and the receiving DST. In addition, flow measurements (also including other measurements required to compensate for short term variations) will be made in the transfer piping out of Tank S-102 and into the DST.

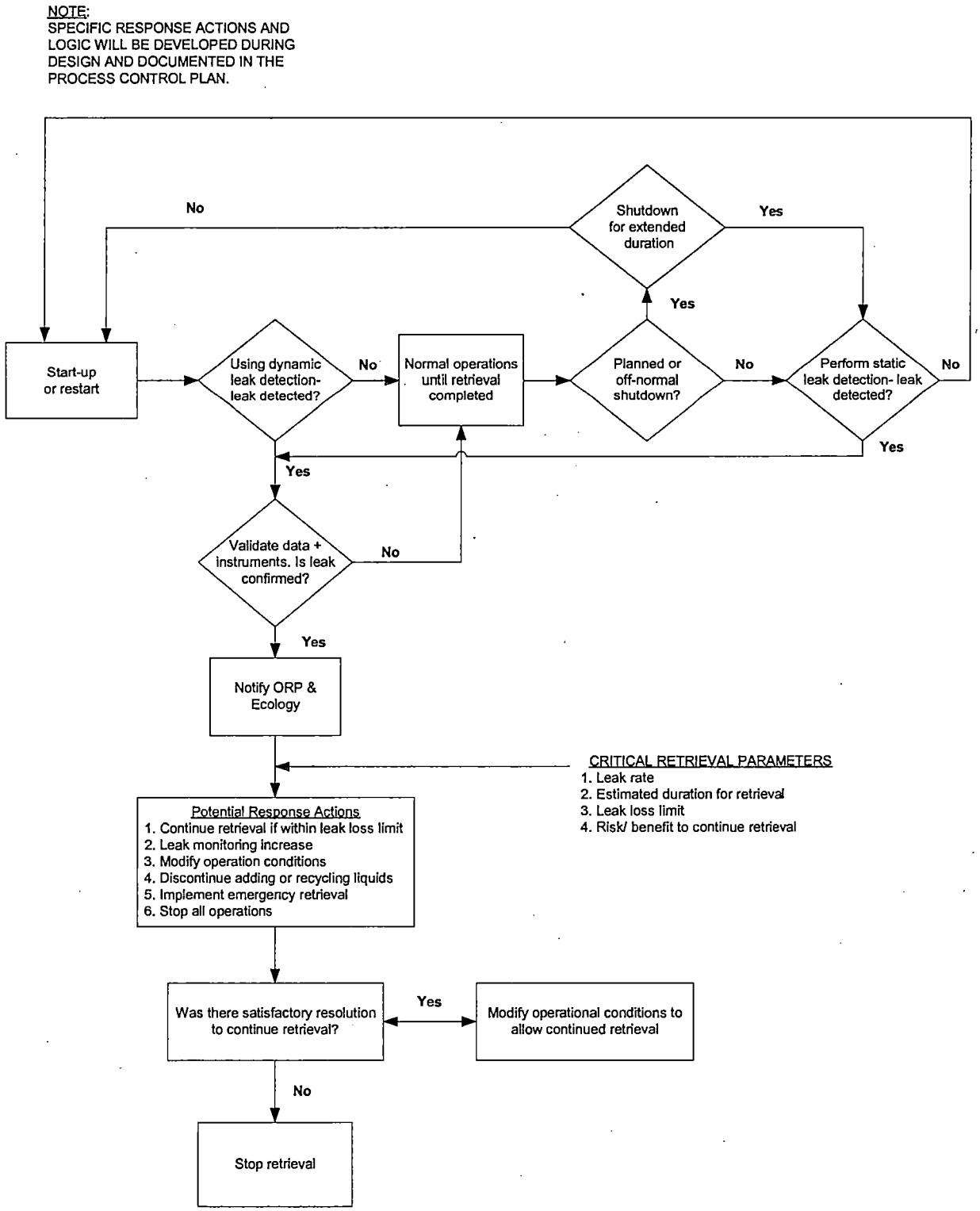

Figure 5-8: Retrieval/LDMM Operational Response Process Diagram

Table 5-2 provides a typical listing of the instrumentation that may be used for dynamic leak testing. The table describes the data and measurement functions for which it may be collected. Some instrumentation is already present. Some may be installed specifically to support retrieval.

Table 5-2: Instrumentation Requirements for Dynamic Leak Detection

Instrument	Type	Location	Function	Purpose
Level gauge	ENRAF™	Riser R-2 inside SST	Free liquid surface level inside SST	Direct waste level measurement
Thermocouple	TBD	Riser R-3 inside SST	Air temperature	Compensate for temperature-related instrument error
Thermocouple	TBD	Riser R-3 inside SST	Liquid temperature	Compensate for source material thermal expansion
Thermocouple	TBD	Outside the SST	Air temperature	Compensate for temperature-related instrument error
Pressure gauge	TBD	Outside tank	Barometric pressure	Compensate for source material expansion
Pressure gauge	TBD	Inside SST ventilation system	Static pressure	Compensate for source material expansion
Psychometrics	Calculation	Inside SST	Evaporation/ condensation	External inflow/outflow
Flow monitor	Rosemount	Output line	Measure liquid flow out of tank	Waste outflow measurement
Flow monitor	Rosemount	Input line	Measure flow into tank	Spray inflow measurement
Sensor and switch	TBD	N/A	Data acquisition and alarm	Data recording and processing

ENRAF™—ENRAF™-Nonius Series 854
N/A—Not applicable
SST—Single Shell Tank
TBD—To be determined

For dynamic leak detection, the retrieval system will be treated like a closed system consisting of the Tank S-102, the receiving DST, and the connecting double-contained transfer lines. Specific gravity in the recovery line may be measured and used to compensate/reconcile the recovery volume. The discrepancy between the inflow of water and outflow of waste from Tank S-102 will be compared to the volume in the DST (converted from surface level measurements) and the transfer line. Any discrepancy greater than the uncertainties in the volume calculations and estimates of Tank S-102 liquid inventory, including the error produced by all compensating measurements (e.g., thermal

expansion, dissolution, and solids loading) will be considered a leak in Tank S-102. This assumes that no leak is detected in the transfer line(s) or the DST. This assumption will be validated by periodic leak testing of the transfer lines and reviewed prior to the actual retrieval operations.

5.5.2.2 Static Leak Testing During Retrieval

A static leak test will require that all water additions and pumping be suspended for a period of time to allow the system to reach equilibrium and to conduct the leak detection test.

Once retrieval operations have been suspended, a waiting period will be observed to allow the liquids to gravity drain and reach equilibrium. The frequency and duration of the static test will be determined during the design of the retrieval system. Waste level data will be collected over a period of time (to be determined during performance testing) along with waste temperatures (to account for thermal expansion.) Table 5-3 provides a listing of the representative instrumentation that can be employed for static leak testing. The table also describes the data and the reason it is collected. Some instrumentation is already present in the tank farms. Other devices may be installed specifically to support retrieval.

Table 5-3: Instrumentation Requirements for Static Leak Detection

Instrument	Type	Location	Function	Purpose
Level Gauge	ENRAF™	Riser R-2 inside SST	Free liquid surface level inside SST	Direct waste level measurement
LOW	Hanford	Riser R-5	ILL level inside tank	Waste level measurement
Thermocouple	TBD	Riser R-3 inside SST	Air temperature	Compensate for temperature related instrument error
Thermocouple	TBD	Riser R-3 inside SST	Source material compensation	Compensate for source material thermal expansion
Thermocouple	TBD	Outside the SST	Air temperature	Compensate for temperature related instrument error
Pressure gauge	TBD	Outside tank	Barometric pressure	Compensate for source material expansion
Pressure gauge	TBD	Inside SST ventilation system	Static pressure	Compensate for source material expansion
Psychometrics	Calculation	Inside SST	Evaporation/ condensation	External inflow/outflow
Sensor and switch	TBD	TBD	Data acquisition and alarm	Data recording and processing

ENRAF™—ENRAF™-Nonius Series 854
ILL—Interstitial Liquid Level
LOW—Liquid Observation Well
SST—Single Shell Tank
TBD—To be Determined

The first response to an indication of a potential leak will be to verify that the instrumentation is functioning within its scope. If the validation process concludes that no leak is indicated, retrieval operations would start-up and continue under normal operating procedures. However, if a leak is validated, the operating contractor will notify DOE-ORP, which will in turn notify Ecology and process control procedures will be implemented. The process control procedures will consider the leak volume limit, leak rate, and estimated duration to completion of retrieval operations when determining the appropriate response action. Potential response actions include:

1. Continuing retrieval activities if there is no significant impact to risk;
2. Modifying leak monitoring (e.g., implementing more frequent dynamic monitoring or static testing);
3. Modifying operating conditions;
4. Discontinuing adding or recycling liquids;
5. Implementing emergency retrieval; and/or,
6. Stopping all operations (see Figure 5-8).

The response actions would then be implemented and, if appropriate, retrieval operations would continue under modified procedures through completion of the retrieval activities. The requirements for implementation of leak response actions during retrieval operations will be established in the Process Control Plan that will be developed concurrent with the design of the retrieval and LDMM system.

5.5.2.3 Drywell Monitoring During Retrieval

Drywells will be monitored periodically during retrieval operations to provide additional leak detection and monitoring capability. The frequency of drywell monitoring, the types of monitors to be used and the potential response actions to a leak will be established during the design phase of the project.

5.5.3 Post Retrieval

A post-retrieval LDMM assessment will be undertaken for Tank S-102 following completion of retrieval operations. This assessment will be consistent with the Hanford Federal Facility Agreement and Consent Order Appendix H – Single Shell Tank Waste Retrieval Criteria Procedure and includes:

- Reevaluate ex-tank conditions using monitoring in existing drywells and compare with the baseline condition,
- Measure/calculate Tank S-102 residual waste volume via topographical or other mapping and survey techniques, and
- Estimate residual waste composition.

When the Tank S-102 retrieval has been declared complete, an evaluation of the closure source term will be performed. If leak detection data does not indicate a leak occurred, no post-retrieval LDMM activities are planned. The SST closure work plan (not part of this project's scope) will specify any specific closure/post closure requirements. If a tank is shown to have leaked during retrieval, the present procedure (see Section 5.1.3) will address any follow-on actions. Post retrieval leak monitoring will be constrained to ex-tank subsurface conditions. Existing vadose zone contamination is being addressed under a separate program.

5.6 ALTERNATIVE LDMM TECHNOLOGIES

The Tank S-102 retrieval system will use the best available technology that is economically achievable for leak detection. During FY 2001, DOE/ORP sponsored screen testing and system demonstrations of 6 LDMM technologies that provide indirect leak detection outside the tank. As a result of this evaluation, the alternatives have been down-selected to three technologies that are currently undergoing system evaluation testing. They include:

- Electrical Resistance Tomography, Point Electrode Technology;
- Electrical Resistance Tomography, Long Electrode Technology; and
- High-Resolution Resistivity, Steel cased Resistivity Technique.

This testing and development of the down-selected technologies is needed to:

- Identify statistical ranges of performance to correlate performance of the system against the EPA standard of 95/5 percent (probability of detection/probability of false alarm);
- Develop potential performance characteristics of the system during anticipated operations of the retrieval systems and during possible leak scenarios;
- Define system configurations and deployment, and potential operational limitations; and
- Advance the maturity of the technology to a point where it can be integrated with the retrieval system and deployed.

If proof-of-concept and follow-on testing demonstrates that any of these technologies significantly decrease uncertainty associated with static and dynamic leak testing, they will be evaluated for inclusion in the Tank S-102 retrieval.

6.0 HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER FUNCTIONS AND REQUIREMENTS CHANGE CONTROL

This document is a HFFACO Primary Document requiring Ecology review and approval. Once approved, Section 4.0 of this document establishes the F&Rs for SST system LDM. Revisions to Section 4.0 will follow the criteria outlined in Section 9.3, "Document Revisions," of the HFFACO. Modifications to Section 4.0 will be assessed using existing criteria. Minor field changes to Section 4.0 (as discussed in Section 12.4 of the HFFACO) can be made by the person in charge of the particular activity, (i.e., the CHG Project Manager or equivalent). Minor field changes are those that have no adverse effect on the technical adequacy of the job or work schedule (i.e., does not impact completion of milestone commitments). Such field changes will be documented in daily logbooks (or equivalent) that are maintained by the project. Revisions/changes to Section 4.0 not considered minor field changes can be made through use of a change notice in accordance with Section 9.3, "Document Revisions," and Section 12.0, "Changes to the Agreement." Major changes to Section 4.0 (those requiring a change notice) or revisions to the plan are further defined by the following criteria:

- Significant change affecting public health or the environment,
- Evaluation of remedial alternatives (i.e., major changes to retrieval technologies and/or programmatic decisions that impact the technical adequacy of the project or impact work schedules),
- Protection of human health or the environment (i.e., exceeding maximum leak loss limits, or major design change to LDM criteria).

Upon approval of this Primary Document, an SST system list will be developed as a separate tank farm document. This document will:

- Describe SST system components,
- Identify the status of each component (i.e., active, inactive/not-in-use, interim stabilized, not interim stabilized, etc.),
- Identify LDM requirements associated with each component.

This document will not be subject to the change control process specified in this section. Changes to this document will be maintained and controlled in accordance with tank farm document control procedures.

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APPENDIX A
Lessons Learned Basis for Selection and Implementation of Retrieval and LDMM Technologies

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A lessons-learned summary was prepared to support the development of the functions and requirements (F&R) for retrieval of wastes from Hanford single-shell tanks (SSTs). A survey of technology application experience was conducted to identify lessons learned relevant to planned applications of retrieval technologies.

A.1.0 METHODOLOGY

Source information was taken from technical documents and communications with key personnel in the technical community from the DOE Complex, other Federal agencies, and the private sector. The information was screened for consideration and applicability to this retrieval activity. Considerations relevant to the 241-S-112, 241-C-104 and 241-S-102 retrieval activities were then formulated and presented in tabular format as illustrated below:

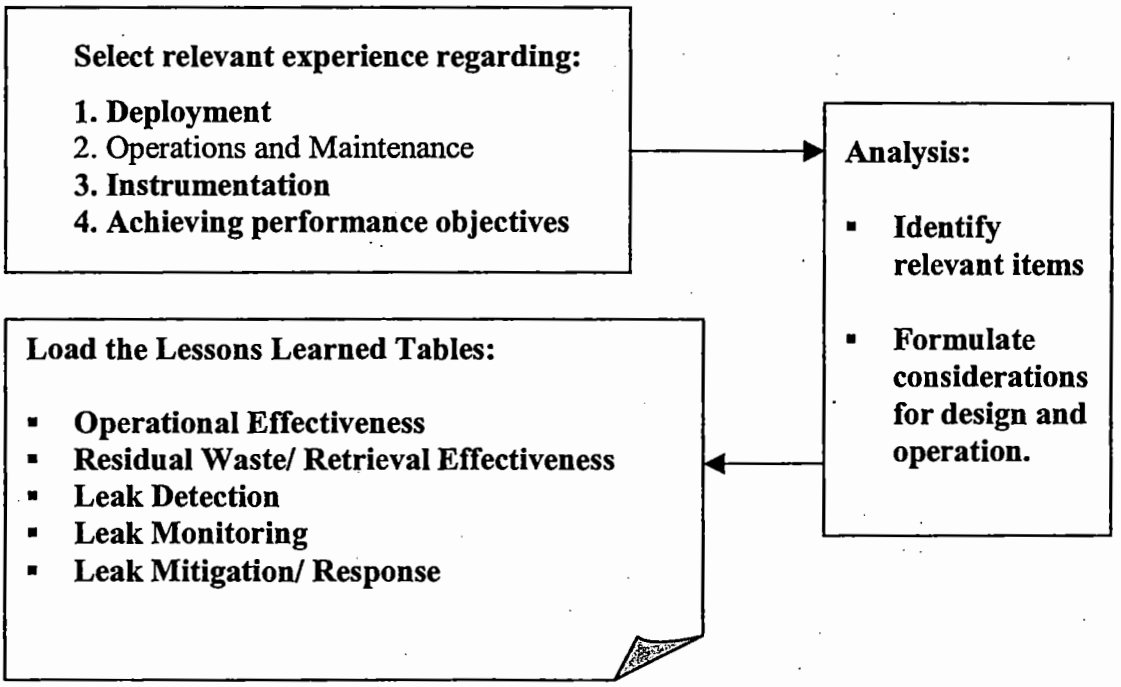

Figure A.1-1: Tanks S-112, C-104, and S-102 Retrieval Considerations

Although the selection process was primarily focused on confined sluicing, dissolution, and Leak Detection, Monitoring and Mitigation (LDMM) volumetric/mass balance systems supporting large-scale tank facilities; other applications also offered relevant information.

A.2.0 INFORMATION SOURCES

Candidate items with relevant technologies were identified. Key documents from these sources were reviewed and personnel contacted to acquire necessary information and to develop a basis to establish lessons learned for Tanks 241-S-112, 241-C-104 and 241- S-102 retrieval activities.

A.2.1 HANFORD TANK 241-C-106 RETRIEVAL

Project W-320 at the Hanford Site retrieved 187 kgal of sludge from Tank 241-C-106 (Bailey, 2000). The waste retrieval was accomplished using a past-practice sluicing technology in 24-hour batches with 12 hours between batches to perform heat load/transfer calculations. The heat load calculations also provided data for mass balance leak detection.

The mass balance technique employed during Project W-320 (Bailey, 2000 and LMHC, 1999) used both retrieval tank and receiver tank level measurements from sensors such as ENRAFs and FICs (Food Instrument Corporation liquid level monitors). This sensor data was used in combination with in-tank video and with characterization data to convert volume data to mass data. Mass data was run through an algorithm to compare how much sluiced material (by weight) went into the retrieval tank with how much waste material (by weight) came out of the retrieval tank.

This technique required liquid level interface measurements as well as shutdown of the retrieval operation to allow the tank waste level data to be acquired (this has been true for most technologies using in-tank measurements). Because some tanks have solid surface layers, it was necessary to "punch through" the layer for direct measurement of a liquid interface. Alternatively, measurements in the liquid observation wells, where available, could be taken using indirect measurement of the interface through neutron probe or gamma activity to estimate the volume moved between retrieval operations. As in any measurement of fluctuating quantities, "baselines" of level and level trends needed to be established and assessed for any observed change, before the data could be analyzed for "leaks," since normal and routine changes in inferred mass needed to be understood.

Flow rate-augmented mass balancing techniques have the potential to improve accuracy by measuring the rate at which liquids and slurries are transferred. Flow rate measurements were collected during the Tank 241-C-106-retrieval operation. When this data is analyzed, the benefits and limitations of flow rate-augmented data may be more evident. In cases where no liquid interface is measurable, such as might be found in tanks containing stabilized sludge, this technique has limited value.

Lessons learned during the retrieval included: 1) not flushing the tank with a supernatant that increase the risk due to mobile source term increase, 2) use at least two spray nozzles for better coverage, and position the pump as close to the tank bottom as possible. The sluicing was completed in 24 hour batches with 12 hours between batches to perform heat load /transfer calculations. The heat load calculations also provided data for mass balance leak detection (the primary leak detection method used during C-106).

A.2.2 OAK RIDGE GUNITE AND ASSOCIATED TANKS (GAAT)

The Oak Ridge Gunite and Associated Tanks (GAAT) project successfully completed waste retrieval on eight gunite tanks at the Oak Ridge National Laboratory between 1996 and 2000. The tanks include two 50-kgal gunite tanks in the North Tank Farm and six 140-kgal tanks in the South Tank Farm. Waste retrieval was completed for the last two tanks in fiscal year 2000.

Fluidic pulse mixing applications have been successfully carried out by AEA Technology Engineering Services, Inc., and reported in: Blackmon 2001; Danfelt 1998, 1999, 2000, and 2001; Dahl 1999; Kent 1998; AEAT 2001, 2001a, and 2001b; and TPA 2001a for ORNL tank retrieval activities.

The GAAT waste retrieval system consisted of the Modified Light-Duty Utility Arm (MLUDA), Confined Sluicing End Effector (CSEE), and the Houdini. The Houdini is a multifunctional, remotely operated crawler. Tank W-9 contained heavy sludge from previous waste consolidation efforts. A heavy-waste retrieval system consisting of an airlift system and heavy-duty pumps was used along with the three other technologies to successfully mobilize and transfer the wastes from the tank.

Leak detection and monitoring for the GAAT project was provided via an external tank monitoring system combined with internal tank volumetric techniques. The gunite tanks were monitored for a large sudden release by using the on-line level measurements that were monitored around the clock at the Waste Operations Control Center. Volumetric precision leak testing was accomplished by analyzing 48-hour data sets of tank level readings that were taken at one-minute intervals. This precision testing was conducted prior to waste retrieval operations to establish baseline conditions. Both the external leak monitoring system and the Waste Operations Control Center monitoring were used during waste retrieval operations.

The external leak monitoring system utilized the drywells adjacent to each tank to monitor the conductivity of the groundwater that naturally flows around the tanks. A significant increase in conductivity would indicate a potential release from a tank. The system worked because the groundwater conductivity was approximately two orders of magnitude (100 times) less than the conductivity of the fluids in the tanks. Field-testing showed that leaks on the order of 0.5 gallons per minute could be detected using the external drywell monitoring method. The method was deployed and used during all GAAT waste retrieval operations. The external drywell monitoring leak detection system has allowed the GAAT project to use several of the inactive tanks (W-8 and W-9) in the South Tank Farm for the temporary storage of sluiced material and supernatant liquids. This use has, in turn, resulted in significant cost avoidance and reduction in schedule by eliminating the need to construct new above-ground tanks and facilitating an efficient transfer of wastes out of the tanks (ORNL, 1998).

A.2.3 SAVANNAH RIVER TANK 19 HEEL REMOVAL PROJECT

At the Savannah River Site (SRS), long-shaft mixer pumps are being used for initial waste retrieval from the underground double-shell tanks, in Tank 19. Waste mixing and removal using the slurry pumps has left approximately 40 kgal of residual sludge as a waste heel in Tank 19. In

a joint effort between Westinghouse Savannah River Company and the Tanks Focus Area, the use of Flygt® Mixer technology is being demonstrated as a means to remove the waste heel from Tank 19 and other SRS tanks.

Two years of scale up and verification testing of the Flygt® Mixers were conducted at Pacific Northwest National Laboratory and the SRS TNX Test Facility. Following this effort, the third of three Flygt® Mixers was installed in Tank 19 on August 2, 2000. Leak detection in the SRS double-shell tanks is accomplished by monitoring the annular space between the inner and outer tanks with radiation monitors and electrical resistance leak detectors (SRS, 1995). Nine tanks have leaked in the past, and tank liquids were detected in the annular space via radiation monitors and annulus photography (SRS, 1995). The groundwater at the SRS typically ranges from ten to twenty feet below grade, and groundwater sampling is also used as part of the leak detection strategy.

A.2.4 HANFORD TANK 241-SY-101 SURFACE LEVEL REMEDIATION PROJECT

The 241-SY-101 tank contained nearly a million gallons of waste with a history of retained gases that were released during periodic rollover events. This had been remedied with the installation of a mixing pump in 1993. Subsequent to that time, the level of the crust began to grow, retaining ammonia, nitrous oxide, and hydrogen at an increasing rate. This presented critical safety issues requiring transfer and dilution of the waste. This Project deployed a submersible canned rotor transfer pump that was based on technology developed for cooling naval reactors. A temporary at-grade transfer line comprised of a flexible hose within a hose was used for the transfer from 241-SY-101 to 241-SY-102. The transfer line was compliant with established technical and regulatory requirements. With the conclusion of transfers and back dilution, the contents of 241-SY-101 were sufficiently changed to resolve this critical safety issue.

A.2.5 OTHER FEDERAL PROGRAMS AND PRIVATE INDUSTRY DEMONSTRATIONS

Other commercial nuclear, robotics development, and Federal programs have carried out activities that have provided relevant information for this lessons learned review. Examples include Cybernex (France) development of industrial systems to operate in hazardous environments (Fidani, 2001); Merpro Limited (United Kingdom) products for oil and gas treatment systems (Merpro, 2001a, b, c, and d); DOE/NASA collaborations to develop robotic systems for Chernobyl (Osborn, 2001); and Toshiba (Japan) development of robotic systems to deploy systems to conduct maintenance on nuclear power plant large pressure vessel fuel core support structures (Shimamura et al., 2001). The US-EPA has developed standards for leak detection on large petroleum tanks. Information is available regarding various types of remote or robotic systems operating in hazardous environments (Maresca, et al., 1993). The Salt Institute and Solution Mining Research Institute (and associated solution mining firms) and the National Petroleum Technology Office have information applicable to the dissolution retrieval (Salt Institute, 2001).

There were no specific DOE-observed private industry LDMM demonstrations in fiscal year 2000. The Strategic Environmental Research and Development Program (SERDP) sponsored an applied research project through Pacific Northwest National Laboratory. The applied research project was to perform non-intrusive characterization of dense non-aqueous phase liquids (DNAPLs) in the subsurface (Gauglitz, et al., 1995 and Gauglitz, et al., 2000). The results of the research indicated that short-lived radiotracers in partitioning interwell tests could detect fluid saturation in the subsurface. An adaptation of this approach has been proposed to quantify annual baseline soil moisture changes in the vadose zone immediately surrounding an underground storage tank as a leak detection technique. Previous studies have shown that under the ideal conditions of equilibrium partitioning, gaseous water-soluble tracers can quantify the water content in the vadose zone through an extension of earlier developments in partitioning tracers for delineating DNAPL contamination in aquifers and the vadose zone (Deeds, et al., 1999, Jin, et al., 1995, and Whitley, et al., 1999).

Preliminary field testing of six selected Ex-Tank LDMM technologies was conducted during fiscal year 2001 at the 105 A Mock Tank Site on the Hanford Reservation. This testing program was conducted to gather preliminary information on the detection capabilities of the six ex-tank leak detection technologies. These technologies consisted of Electrical Resistively Tomography (ERT), Cross Borehole Electro-Magnetic Induction (CEMI), High-Resolution Resistively (HRR), Cross Borehole Seismic (XBS), Cross Borehole Radar (XBR), and Partitioning Inter-Well Tracer Test (PITT). The preliminary test information will be used to down select the six technologies during FY2002 to one or two technologies for leak detection performance testing and integration into the tank waste retrieval program.

A.2.6 OTHER LESSONS LEARNED FROM HANFORD RETRIEVAL (118)(114)

Lessons learned from past sluicing activities have not been documented in a retrieval format. Tank C-106 was the first waste retrieval activities to provide a system of waste retrieval to meet regulators requirements of waste retrieval. Waste retrieval lessons learned have been documented to provide tank farms with past experience that will be used to improve systems prior to the initialization of other waste retrieval actives.

A.3.0 TABLES FOR DESIGN AND OPERATION CONSIDERATIONS

Lessons learned considerations for design and operation were recorded in one of five "topical" tables consisting of operating effectiveness, residual waste/ retrieval effectiveness, leak detection, leak monitoring, and leak mitigation/response; these are provided as Tables A-1 through A-5 respectively. Each entry is listed in the appropriate table along with the lessons learned, a statement regarding relevancy to Tank 241-C-104 and/or 241-S-112 retrieval activities, and reference documentation, with the associated project. Although this information was drawn from a variety of sources, industries, and applications, the "lessons" to facilitate successful deployment of the retrieval systems typically fell into one of the categories listed below:

1. Careful and complete documentation of applicable *functions and requirements* should be completed before the design activities are initiated. They should be managed to ensure effective flow-down to subcontractors. The Project should prepare a compliance matrix to verify that the deployed system satisfies all (100%) requirements.

2. Establish, communicate, and support a clearly defined *deployment strategy* at all levels of design, safety analysis, construction, test, and operations activities. Assign operations personnel to the design team.

3. Effective *system integration* to control all elements of the Project must be achieved with particular emphasis on *configuration management* of all safety and safety related items.

4. *System availability* analysis should be provided to verify compliance with the functions and requirements using the traditional reliability/availability methodologies. Reliability analysis tools can be used to provide needed maintenance and operational flexibility necessary to avoid the operational problems and performance issues experienced in recent tracked-crawler retrieval operations. Examples of known availability issues to address include: loss of in-tank camera visibility due to fogging, misting, and condensation; insufficient physical access to maintain instrumentation; pump and pipeline plugging; ineffective back flushing or screen clearing features; functional failure of the tracked vehicles; and fouling/failure and excessive contamination of tethered control cables.

5. Place the highest level of importance to the *system/operator interface* and associated operator training.

Table A.3-1: Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.1	"Batch-wise sluicing" operations resulting from overly restrictive authorization basis control, unreliable LDMM methods, and/or insufficient process control are not cost effective. These require repeated startup and shut down operations with line flushing and system lay-up. This results in extended operating scenarios that are labor-intensive and inefficient.	Design an integrated system to be capable of achieving performance criteria through continuous retrieval operations.	ORP W-320 Bailey, 2000. Vista 2000(119)
A.3.1.2	Overly restrictive controls imposed by authorization basis requirements can result in efficiency losses and extended outages when the need for maintenance or troubleshooting arises.	Design an integrated system to provide sufficient operational flexibility to: a) Operate within safety controls, environmental permits, and operating plans for the retrieval operation, and b) Conduct normal maintenance, calibration, and trouble-shooting as required.	ORP W-320 Bailey, 2000.
A.3.1.3	Waste tank cover gas grab samples were used as a basis to set unreasonably low limits for Volatile Organic Compound (VOC) emissions without consideration for organic compounds in the waste. During start-up operations limits for VOC and ammonia exceeded NOC prescribed limits.	Base environmental permits on credible "disturbed waste" characterization information appropriate for operation so that an overly conservative air permit information does not result in operational delays due to NOC issues.	ORP W-320 Bailey, 2000
A.3.1.4	Sluicer hydraulic drive systems over heated during the summer months due to inadequate cooling.	Provide adequate temperature control to ensure that components perform as required in the Hanford environment.	ORP W-320 Bailey, 2000.
A.3.3.4	Hold-up of liquid in the hose loop prevented air trapped in the pump impeller casing from moving up into the transfer line; this prevented priming of the pump.	Design flexible hoses and pipes to be self-draining after post-operation flushing and not prevent priming of the transfer pump.	ORP W-320 Bailey, 2000.
A.3.1.5	Overly flexible hoses together with excessive rotation resistance hose linkage resulted in kinking of slurry and sluice pump discharge lines. This caused the system to be inoperable when the pumps were lowered as the liquid level decreased in the tank. As a remedy, the system was operated at overly high liquid levels, which reduced the effectiveness of the sluicing operation.	Design flexible hoses to be the correct length and reinforced (or fitted with support devices) to ensure that rotary linkage performs effectively and no kinking will occur that would compromise the performance of the system	ORP W-320 Bailey, 2000.

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.6	Poor pump seal performance resulted in excessive quantities of seal gas in the slurry line flow meter used to monitor aqueous fluid streams in the transfer lines. These gas bubbles were indicated as SpGs below 1.0 (i.e., no flow with no slurry solids loading) and inaccurate estimates of volume transferred from the tank.	Design mass transfer instrumentation systems to mitigate the effects of retrieval system failures (e.g. entrained pump seal gas)	ORP W-320 Bailey, 2000.
A.3.1.7	Poor pump seal (and associated seal gas control system) performance resulted in continuous manual adjustment by operations of seal line pressures to maintain manufacturer's guidance for seal gas.	Make provisions for an appropriate pump seal fluid selection and seal pressure control system to minimize requirement for operator intrusion.	ORP W-320 Bailey, 2000
A.3.1.8	Jumper leaks resulted from misalignment for the sluicer assembly and associated equipment.	Use flexible joints on rigid jumper connections when correct alignment cannot be verified. Test all valves installed on jumpers before putting the jumper in service.	ORP W-320 Bailey, 2000
A.3.1.9	Leaks were discovered in a purchased three-way valve; the blocking function of this valve should have been tested before deployment in C-104	Cold test all fluid connections and components prior to deployment in the operating system.	ORP W-320 Bailey, 2000
A.3.1.10	Manual flushing after each sluicing batch required removal of cover blocks and the connection of flush water to a process jumper.	Provide the capability to flush slurry/supernatant-piping systems without excessive preparations or system modifications, and operator activity.	ORP W-320 Bailey, 2000.
A.3.1.11	Houdini-II maintenance systems (e.g., TMADS) and supporting equipment did not provide adequate features for effective maintenance. Examples include: ▪ Full-length hinges for access panels that were replaced with doors with positive compressive seals. ▪ No means to illuminate the interior of the robot maintenance compartment in a powered-down (safe) state. ▪ Some items (e.g. power supplies) should not have been located inside containment. ▪ Inadequate sealing of the bag-out port during decontamination spraying operations. ▪ Inadequate glove and reach access for required maintenance activities.	Maintenance enclosures, tooling, and access features should: ▪ Design closure panels to provide required containment and confinement features for operating, maintenance, stand-by, and decontamination modes. ▪ Provide a separate power supply for maintenance activities when retrieval system power has been locked out. ▪ Whenever possible, locate support equipment outside containment to facilitate servicing and maintenance. ▪ Provide sufficient access to fully maintain and repair equipment.	ORNL GTRP Burks, et al., 2001, & Falter, 1997

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.12	Houdini-II system suffered from inadequate planning and preparations to effectively address needed maintenance and repair activities.	Develop a reliability/availability –based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) methodology. Verify that all required design requirements have been met and anticipated maintenance activities can be achieved in a safe manner consistent with good ALARA principles.	ORNL GTRP Burks, et al., 2001, & Falter, 1997
A.3.1.13	MLUDA/Houdini: A complete understanding of the needed maintenance and support tasks was not established prior to design of the tank riser interface compartment (TRIC). This resulted in the need to retrofit and modify TRIC after the fact.	Establish a life-cycle operating profile for the system to be deployed and identify required maintenance and support functions and requirements to be included in the technical basis for the retrieval project.	ORNL GTRP Providence Group, 2001 & Falter, 1997
A.3.1.14	System integration issues with the deployment of the MLUDA/Houdini included: ▪ Failure of the tether cable system moisture protection seal; this limited the operation of the crawler to a maximum of 6-8 inches of sludge depth. ▪ Scarifying operations created aerosol-generated fog that rendered the cameras ineffective. ▪ Repeated hydraulic leaks due to incompatible hydraulic component fit-up. ▪ "Drifting" of the vertical positioning system due to use of hydraulic jacks. ▪ Inadequate strength capability of MLUDA during core sampling operations.	Systematically integrate project requirements to ensure performance objectives can be met with the deployed system of individual components and sub-systems. Examples would include: ▪ Adequate ventilation to ensure visual observation capability. ▪ Stable support systems with no excessive drifting during operations. ▪ Adequate hydraulic systems sealing capability. ▪ Reliable tether management process.	ORNL GTRP Providence Group 2001, & Falter, 1997
A.3.1.15	MLUDA maintenance systems (e.g. tank riser interface compartment or TRIC) and supporting equipment did not provide adequate features for effective maintenance. Examples include: ▪ Safety concerns that arose when the TRIC had to be open during testing of the gripper end effector (GEE) systems. This lead to a new design for GEE. ▪ Inadequate means to transfer tools and supplies to be transferred into TRIC.	Ensure that safety and ALARA requirements are addressed during design and deployment phases with particular emphasis on maintenance and support activities.	ORNL GTRP Providence Group, 2001 & Falter, 1997

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.16	Logistics of crawler/deployment system (Houdini/MLUDA) operation in the tank identified important issues to address: ▪ An operational/logistics strategy needed to be established to coordinate crawler and sluicer operations below each riser. ▪ The sluicer typically cleared out an area for the crawler to initially operate from.	Prior to initiation of design activities, establish: ▪ An operations and maintenance strategy for retrieval operations (contact or remote maintenance, etc.) ▪ Establish an operating strategy to coordinate crawler/sluicer operations. ▪ Include applicable features as system design requirements.	ORNL GTRP Providence Group, 2001 & Falter, 1997
A.3.1.17	Internal instrumentation should have been accessible without breaking containment.	Where feasible, provide direct access to instrumentation systems without breaking containment.	ORNL GTRP Providence Group, 2001 & Falter, 1997
A.3.1.18	Management and control of hydraulic fluids should have prevented oil from leaking into adjacent systems.	Provide engineered systems to safely manage hydraulic fluids under normal (operations and maintenance) and off-normal operations.	ORNL GTRP Providence Group, 2001 & Falter, 1997
A.3.1.19	The multiple control system screens were too complex and busy for efficient/effective operations.	Based on operational planning, integrate the control systems/user interface to provide effective means to conduct safe operations.	ORNL GTRP Providence Group, 2001 & Falter, 1997
A.3.1.20	Air conveyance development testing without water injection resulted in: ▪ " ... *approximately ¼ in. of material coating the hose walls. It was necessary to convey water intermittently to keep material from building up on the hose walls*". In spite of these precautions, the system still plugged up. "*At this point a decision was made to install water injection to the nozzle*". The " *technology is a sound option for waste retrieval with some modification to the basic [commercial] design.*" ▪ "*It became obvious during testing that a water injection system is imperative to prevent hose plugging while conveying undiluted sludge....*" A system utilizing a water injection device at the feed nozzle and additional injection units placed along the hose runs will be necessary.	If air conveyance is used, integrate water injection in the nozzle and the line. This is required to prevent sludge from building up on the walls and eventual plugging of the system.	Hanford Develop-mental Test Thompson, 1990

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.21	Deployment of a confined sluicing end-effector in the ORNL Tank needed to be carefully managed ▪ to avoid premature submersion and possible plugging of end-effector nozzles. Low-pressure flushing of nozzles was not possible during deployment prior to full deployment of the support system masthead. ▪ to control higher-pressure operation (>4,500 psi) which caused end-effector "bouncing" and position alarming and control system faulting. Tank wall scarifying, typically carried out at extremely high pressures, and was limited by MLUDA's ability to counteract pneumatic forces above 20,000 psi.	Possible plugging of end-effector nozzles should be addressed by: ▪ Carefully planning the deployment and operating sequence. ▪ Making provisions for in-tank recovery e.g. low-pressure flushing) in the event plugging does occur. High pressure operation should be addressed by ▪ Providing a means to counteract hydraulic loads and stabilize in-tank deployment structure to facilitate all phases of retrieval operations.	ORNL GTRP Lloyd, et al., 2001
A.3.1.22	Successful retrieval operations with MLUDA/Houdini were made possible due to built-in system flexibility. For example, back-drivable joints allowed Houdini to drag the sluicing end-effector to the desired location. Most equipment could be operated in multiple modes (e.g. local versus remote, manual versus automatic). This permitted operations to adapt to varying conditions, maintenance needs, and testing requirements.	See item A.3.1.18 where it states: *"Provide engineered systems to safely manage hydraulic fluids under normal (operations and maintenance) and off-normal operations."*	ORNL GTRP Lloyd, et al., 2001
A.3.1.23	The MLUDA/Houdini maintenance systems facilitated ready removal of key support system components to minimize hoisting and rigging, and space for lay-down while controlling contamination. Replacement of the retrieval system hose management assembly could be achieved without breaking tank vapor space containment. Decontamination of components during removal from the tank was achieved with "designed-in" elements integrated into the retrieval system. In addition end-of-shift flushing capability was also provided as part of the system.	See item A.3.1.16 where it states: *"Prior to initiation of design activities, establish:* ▪ *An operations and maintenance strategy for retrieval operations (contact or remote maintenance, etc.)* ▪ *Establish an operating strategy to coordinate crawler/sluicer operations.* ▪ *Include applicable features as system design requirements."*	ORNL GTRP Lloyd, et al., 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.24	Various weaknesses were identified during the MLUDA/Houdini deployment consisting of operator ergonomics, maintenance issues, instrumentation deficiencies, and control system faults; these included: ▪ Glove box location and configuration limited tool handling, retraction, and maintenance operations. ▪ Lengthy and demanding process to deploy the main handling system (10 cable and 3 hose connections) ▪ Limited range/rotation of cable and hose management systems required periodic disassemble and reassembly of equipment. ▪ Replacement of a cable was necessary – made possible only because of a spare conduit was included in the design. ▪ "Coriolis" (FE-204) flow meter was "completely ineffective" due to the highly dynamic 3-phase flow characteristics with significant "slugs" of air. ▪ Debris clogging the screen on the waste inlet. (However, this did prevent pump blockage.) ▪ Contamination traps in confinement box on tank riser. ▪ Inability to replace rupture disks. ▪ Poor seal design in the rotating end-effector. ▪ The control system was not capable of detecting a disconnected control cable; operations needed to de-energize and safely shut down system to conduct trouble-shooting activities.	See item A.1.1.16 where it states: *"Provide engineered systems to safely manage hydraulic fluids under normal (operations and maintenance) and off-normal operations."* ▪ Provide visual assess for inspections ▪ Provide temporary power for maintenance ▪ Provide a variety of end-effectors to achieve performance objectives ▪ Mount flow instruments in vertical orientation to eliminate air pockets ▪ Provide for signal and control cable disconnection detection alarms.	ORNL GTRP Lloyd, et al., 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.25	During testing of the EMMA (Manufactured by GreyPilgrim, LLC). GreyPilgrim robotic manipulator, *"barrels used to receive conveyed waste imploded"*. This was the result of an instantaneous seal being made between the end-effector and surfaces of a waste tray *"because of high vacuum created"*. A scalloped hard rubber shroud used to prevent contact between the scarifier and the waste surface did not function well. "*One solution is to redesign the skirt*". The possibilities include: ▪ Simple passive compliance via springs and contact shoe or caster to affect a compliant motion normal to the waste surface. ▪ A scalloped edge or other skirt design to allow proper airflow while maintaining contact with the waste surface. Other solutions might be: ▪ Active compliance proportional to ultra-sound surface distance feedback or vacuum sensor or tactile or capacitance sensor. ▪ Larger shroud (24"). ▪ Higher power blower. ▪ Hardened closed circuit digital cameras mounted at various points on arm to provide more information to operator." ▪ Use stronger drums. ▪ Use direct computer control of the e-stops to automate response instead of manual response.	Establish (verify) methods to control vacuum suction and prevent loss of control suction cup (end-effector) distance to hard surface. These might include a variety of distance control systems, suction cup configuration, and vacuum rating of the components prone to damage.	Hanford HTI GreyPilgrim, 1997
A.3.1.26	GreyPilgrim: Vacuum hoses "flattened along two locations and split in several others".	Size the retrieval system hoses for the maximum vacuum and better strength to prevent collapse and splitting under vacuum.	Hanford HTI GreyPilgrim, 1997.

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.27	GreyPilgrim: During testing, *"... it was observed that momentary setbacks or sudden stops in arm motion would lead to residual vibrations. These vibrations would generally take the form of free vibration response, a natural frequency of about 0.5 Hz, lightly damped (10 or 20%), and a peak-to-peak vibration of about 2 inches or so. This residual vibration is unacceptable for service unless it can be controlled. This could be mitigated by special operator action, which requires an extra skill. Another way to control this is through the control algorithm."*	Design and test the arm for the frequencies in the operation range and also design for proper vibration damping. To mitigate this effect, use experienced and well-trained operators and/or revise the control algorithm.	Hanford HTI GreyPilgrim, 1997
A.3.1.28	GreyPilgrim: Limitations of the Deployment System – Issues regarding actual underground storage tank applications include: ▪ The ceiling above the tank (head space) should allow enough motion for the elevator movements. ▪ Allow adequate space for the actuator and its movements. ▪ Provide adequate space in the actuator room. ▪ Allow enough room so the pivot could be fully utilized.	Design the system for adequate space for the elevator, pivot, and the actuator to be fully utilized.	Hanford HTI GreyPilgrim, 1997.
A.3.1.29	Cybernex (France): ▪ A vital element for safe robotic operations is real-time response for "force-feedback" or tracking system applications. This requires highly responsive, good quality feedback, frequently with fragile components, operating in a very hazardous environment. ▪ *"An ill-designed cable management system can significantly impair the capabilities to perform tasks efficiently."* Some systems are being developed with reduced (eliminated) cabling systems. RF spread-spectrum or ultra sound technologies are being used to exchange data between the vehicle and controller.	▪ Consider response time as a performance parameter for feedback for tracking or force-feedback applications instrumentation. ▪ Identify and control critical operational requirements. ▪ Effective cable (umbilical, tether) management is critical for successful deployment of a robotic system. Consider alternate technologies to communicate with the robotic (remote system) device.	Non-DOE Cybernetics Fidani, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.30	Toshiba (Japan): Low-cost, high reliability robots with fewer degrees of freedom with relatively simple control systems are used to perform dedicated tasks. Collectively, these components accomplish complex tasks normally requiring a robot with many degrees of freedom (DOF) and a complex control system.	High reliability performance at relatively low cost robotic systems can be deployed using task-specific sub-systems requiring simpler control systems as an alternative to complex expensive multi-degree of freedom systems. Note – integrate with FMECA activities identified in section A.3.1.12: *"...Develop a reliability/availability – based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) ...".*	Non-DOE Toshiba FDH, 1999
A.3.1.31	Development of the PIONEER crawler robot for Chernobyl applications identified several lessons learned and recommendations for future applications: ▪ Use of an on-board robot power distribution system would reduce the cross-section, weight, and stiffness of the tether. ▪ Place the highest priority on "operator ease" (e.g. remote viewing system).	Assess design trade-offs to enhance operability of remote system: ▪ Reduce tether weight and stiffness through careful selection of power distribution – even at the expense of robot weight and cost. ▪ Identify features early in the design phase to enhance operability of the system; manage these as high-priority objectives.	DOE/ NASA Chernobyl Osborn, 2001
A.3.1.32	Pipeline Unplugging Technologies were tested with the conclusion that several viable alternatives are commercially available. One innovative approach from Atlantic Group's Hydrokinetics used sonic resonance together with high-pressure water to clear plugged lines.	Integrate available pipe unplugging technology into the retrieval system as a contingency/recovery feature during operation.	DOE/ FL International University Sukegawa, et al., 2001
A.3.1.33	PNNL developmental, non-intrusive, ultrasound sensor to measure density in air-entrained waste slurries. Designed to operate in flammable gas environments, this system has completed several laboratory tests and is scheduled to be installed on Tank 241-SY-101 at Hanford.	Assess performance applicability of ultrasound density sensor for 241-C-104 retrieval operations. Integrate into design as appropriate.	DOE PNNL Bamberger, et al., 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.34	Provides an alternative to run-to-failure mentality typical of a "corrective" maintenance philosophy, which is in-appropriate where the consequence of failure is high [i.e. as in in-tank robotic applications such as 241-C-104]. Condition-based operations and maintenance (CBM) offers an approach less costly than preventive or predictive-based methods but more effective than corrective maintenance. Two key characteristics: ▪ Operations ownership in the need to recognize and correct the existence of an abnormal condition. ▪ Pro-active identification, through root cause analysis, of the fundamental stressors (parameters outside the design envelope) responsible for off-design conditions.	Consider planning to implement condition-based operations and maintenance (CBM) methodologies concurrently with conceptual and definitive design to establish relationships between failure modes, stressors that could lead to system failure. Select and integrate appropriate sensors into the retrieval system design activity. Note – integrate with FMECA activities identified in section A.3.1.12: *"...Develop a reliability/availability – based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) ...".*	DOE NERI Jarrel, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.35	SRS lessons learned from deployment of a prototype "bagless" transfer system: ▪ Reliability – Schedule pressures resulted a "business decision" not to conduct reliability tests. A "demonstration" unit became the production unit and materials and parts wore out. This resulted in unplanned down time for repairs. ▪ Defense in Depth – insufficient process administrative and engineered controls led to undetected quality problems during operation. ▪ Training – Although a large investment was made during trouble shooting of problems, learning-curve challenges could have been more effective managed if more time had been spent with "…in-depth component specific training …" From…. vendors..." In addition, operations and maintenance personnel should have been more involved with development, assembly, testing and troubleshooting. ▪ Resources – Too few engineers that were involved with deployment of the production unit stayed with the project through deployment and operation. This is a critical issue with first-of-a-kind development (or prototype) units.	▪ Develop project and deployment planning with due consideration for reliability testing and process quality assurance. ▪ Address operator and maintenance personnel training and retention of key technical staff through the transition to operations with project "corporate history" to solve problems. Note – integrate with FMECA activities identified in section A.3.1.12: *"...Develop a reliability/availability – based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) ... ".*	SRS Bayer, et al., 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.36	DNSFB TECH-30 identified several lessons learned which are applicable to any retrieval technology-based project: ▪ A comprehensive Preliminary Safety Analysis Report should be prepared to provide a basis for an integrated review of the facility design. This will avoid overly conservative assumptions, numerous activities to confirm the validity of early assumptions, and potential changes to the safety classification of components late in the project evolution. ▪ Thorough, timely, integrated design reviews during early phases of the project, including PSAR documentation, are necessary to avoid delays and excessive costs in later phases of the project. This should include development of matrices to assess compliance (design verification) with all applicable requirements. ▪ Effective implementation and management of quality assurance requirements for sub-contractors is necessary to avoid deficiencies with procured equipment (e.g. cleanliness requirements for valves, welding quality assurance) ▪ Preoperational test planning must ensure that appropriate rigor is provided to conduct and document tests. Emphasis should be placed on integrated tests rather than relying on tests of individual components and subsystems. Sufficient schedule should be provided to allow for recovery for failures or deficiency identification during testing.	Develop project design/development construction and deployment planning with due consideration for design reviews (i.e. verification – including testing), quality and technical requirements management, and preliminary safety analysis early in the evolution of the project. Note – integrate with FMECA activities identified in section A.3.1.12: *"...Develop a reliability/availability – based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) ...".*	DOE DNSFB Hanford DNFSB, 2001b

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.37	The Year 2000 DNSFB report to Congress identified a number of lessons learned-type items for DOE implementation based on specific DOE-complex experiences that are applicable to 241-C-104 retrieval: ▪ Project design criteria were not prepared at the outset of the project. ▪ Failure to maintain storage tank chemistry within specified limits. ▪ Failure to assign ***system engineers*** (subject matter experts) to all safety processes and systems with: 1. Requisite knowledge of system safety design basis and operating limits from the safety analysis. 2. Lead responsibility for the configuration management of the design. ▪ Failure to impose appropriate safety requirement through procurement contracts. ▪ Failure to impose industry standards for reliability requirements for safety-related instrumentation and control systems.	Develop project and deployment planning with due consideration for: ▪ Project design criteria ▪ Maintain operating safety criteria within limits. ▪ Technical management of system safety requirements and associated configuration management of the design. ▪ Management of flow-down of quality and safety requirement to sub-contractors. ▪ Reliability standards for safety-related instrumentation and control systems. Note – integrate with FMECA activities identified in section A.3.1.11: *"...Develop a reliability/availability – based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) ..."*.	DNSFB DOE-Complex DNSFB, 2001a & DNFSB, 2000
A.3.1.38	DNSFB recommendation for DOE criticality safety programs were for: ▪ More formalized and robust reviews to ensure requirements are met. ▪ Formalized surveillance, maintenance, and configuration control management process for those design features should be implemented.	Develop project and deployment planning with due consideration for: ▪ Criticality safety reviews. ▪ Configuration management, surveillance, and maintenance of criticality safety design features.	DNSFB DOE-Complex DNSFB, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.39	Rockwell Tank Farm experience from SST strontium retrieval operations in 1989-1990: ▪ Heavy duty, single-stage, centrifugal pumps built by Barrett Haentjens (Hazleton, PA) generally gave years of service under extreme operating conditions operating at 350 to 400 gallons per minute with SST heavy slurry. Bearings were water lubricated and completely isolated from the process liquids. ▪ Turbine-type pumps were used during final SST cleanout operations involving very low slurry concentrations, but were not suitable for the massive sludge transfers during normal sludge recovery operations. ▪ Pumps that provided long trouble free service in the AR-Vault transfer operation: single-stage, water-lubricated, centrifugal pumps, for sluicing and slurry transfer service; stainless steel, multi-stage, deep-well turbine pumps for clarified sludge. ▪ Standard Hanford deep-well turbine (TX-1) pumps were used to transfer thickened slurry. Service life was very short due to the abrasiveness of the slurry and the constant shaft and bearing stress produced by the powerful agitation in the tank and the resultant pump column flexing. Even heavy bracing of the pump columns could not alleviate the shaft breakage problem; the use of the standard pumps had to be discontinued.	▪ Applicable retrieval pump operational experience, which led to successful operations with heavy sludge and low-concentration slurries. Consider need to fully characterize material to be retrieved to ensure successful pump operation.	Hanford Tank Farms Rasmussen, 1980

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.40	During final SST sludge cleanout it became increasingly difficult to recover the sludge when the level in the tank decreased to a depth of 4 to 6 inches. More elaborate equipment and procedures were then required: ▪ Use of skirted, adjustable length slurry pumps to allow sluicing at the minimum liquid inventory essential for effective sludge recovery. ▪ Frequent in tank photography to chart sludge accumulation. ▪ Radiation monitors on sluice and slurry lines to measure sludge recovery. ▪ Carefully pre-planned sluicing strategies to move sludge toward the pump intake. ▪ Frequent sluicer direction changes to hit sludge concentrations from different angles. ▪ Fitting the intake of the slurry pumps with "funnels" to permit operation at low liquid levels. These funnels were massive enough to support the entire weight of the pump when necessary. High-pressure water nozzles were used to sluice the pumps into the sludge during initial installation. ▪ Aiming the sluicing nozzle precisely by means of a calibrated sluicer control unit calibrated head that provides for both horizontal and vertical adjustments and allows for accurate sluicing of the tank bottom area. The sluicer consisted of (1) high pressure water supply system, and (2) the nozzle aiming mechanism. ▪ The liquid level in the sluiced tank was kept as low as possible to maximize sluice stream penetration power.	Applicable retrieval pump operational experience: ▪ Sludge recovery technique for last 4-6 inched of tank bottoms. ▪ Instrumentation and surveillance methods to support retrieval. ▪ Sluicer positioning and operation.	Hanford Tank Farms Rasmussen, 1980

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.41	SST sludge recovery was closely monitored with a radiation probe on the slurry line. After 1-2 days of sluicing, the tank would be pumped down and photographed to determine progress and the need for further sluicing. In some tanks the tank bottom was cleared to bare metal. In some cases the particles were so large sluicing was required to literally wear particles down. Because of the heat producing strontium present in the tank infrared scanner was used in a system developed by Barnes Engineering Corporation to make temperature profile plots of the tank	Consider instrumentation and surveillance methods to support retrieval.	Hanford Tank Farms Rasmussen, 1980
A.3.1.42	Feature Tests of a pneumatic Needle Scaler were conducted with various simulated waste configurations and on steel and masonry surfaces. These tests indicated that devices of this type could provide effective tools to facilitate retrieval. Deployment of a linear scarifying end-effector was not successful due to deployment difficulties resulting from inadequate integration into the overall retrieval "system".	(See item A.3.1.14 regarding integration of required design elements into a system)	Hanford Tank Farms Squires, 1990 & Fitzgerald, 2001
A.3.1.43	Feature tests of Sine pumps indicated that the pump is capable of meeting the required pressure and flow at high viscosities. However, rapid wear with the soft (elastomer) components was experienced. Resolution of this will require additional development work. Feeding the pumps from the inlet hopper was another problem. Residue build-up on the interior hopper walls impeded flow of the product into the pump.	The SINE pumps (positive displacement - used in the food industry) are capable of meeting retrieval flow and pressure requirements including ability to pump very viscous materials, but will require development of improved elastomer components.	Hanford Squires, 1990a

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.44	The SRS structural integrity program conducted a comprehensive analysis of waste tanks and piping to assess past failures, failure mechanisms, and ageing effects. This resulted in some lessons learned applicable to SST retrieval activities. Many of these offer guidance for path-forward activities to avoid past system integrity issues that resulted on operational impacts and leaks to the environment.	Develop project and deployment planning with due consideration for: ▪ Chemistry controls to avoid corrosive conditions. ▪ Chemistry monitoring to verify operation within control limits. ▪ Procurement and system operation. ▪ Use inspection processes to ensure structural integrity. ▪ Operational controls to prevent piping failures resulting from typical failure modes such as stagnant water, stress corrosion cracking, pitting, etc.	SRS SRS, 1995
A.3.1.45	ORNL operation of the confined sluicing end effector (CSEE) in GAAT retrieved approximately 7,200 gal of supernatant above the sludge, 5,500 gal of sludge at the bottom of the tank, and 0.1 in of the scale from the tank wall. Less than 0.5% of the tank volume remained as a final residue waste. The retrieval of tank W-3 used 41,800 gal of water, which was added to the waste stream, at a ratio of 3.3:1. This includes water used by the jet pump, flushing operations, and equipment decontamination. Approximately one third of the water was used for scarifying operations and two thirds was from jet pump operations.	Develop project and deployment planning with due consideration for: ▪ Reduced water usage through careful coordination of the activities. ▪ Riser access to accommodate equipment (for this demonstration 24" for Houdini &12" for MLDUA) [see A.3.1.11-15] ▪ Accommodation of in-tank to access all tank locations. ▪ Verification that any additional tank dome loads is within safety allowable. ▪ The addition of a "holster" to provide temporary parking of the CSEE. ▪ Provisions for a means to clear the conveyance inlet screen. (Back flushing with low pressure is not effective and uses a significant amount of water.)	ORNL GATT TFA, 1999

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.46	The Hanford Tanks Initiative contracted to conduct feature tests designed to establish a better understanding of the technical challenge ahead for deployment of retrieval systems in tanks. ▪ The maneuverability of the tracked vehicle seemed to have an edge over the wheeled vehicle, whereas the wheeled vehicle seemed to have superior ability to get unstuck. The wheeled vehicle was superior to the tracked vehicle in dislodging and breaking up material. ▪ The complex control system in the wheeled vehicle needed to be redesigned to give the operator simpler controls. ▪ The tracked vehicle was jammed repeatedly with small rocks in its tracks; these were successfully un-jammed. A very hard object in a track created a failure mode from which recovery was difficult; the wheeled vehicle mobility and its ability to recover from a failed condition appear to be much better. ▪ A vehicle was weighed before and after decontamination where it was determined that 27 lbs of waste material was removed with 2 lbs remaining. Hold-up of material was worse for the tracked vehicle. ▪ It would be desirable to have multiple tank cameras, all equipped with zoom, pan, and tilt, so the operator could view the work area no matter where the vehicle was in the tank.	Applicable retrieval pump operational experience: ▪ Ensure that a tracked vehicle if used can be effectively maneuvered in the SST waste material, and decontaminated. ▪ Verify system availability (reliability/maintain-ability) will support deployment objectives; an effective means for recovery from faulted (stuck) conditions needs to be provided. ▪ Lighting and camera systems need to be able support operations throughout the tank and under all operating conditions (mist, fog, - see A.3.1.14 and 48) ▪ Operator training should be provided before deployment to ensure efficient in-tank operations and verify operator/ machine interface needs. (See A.3.1.35) Note – integrate with FMECA activities identified in section A.3.1.11: *"...Develop a reliability/availability – based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA) ...".*	Hanford HTI Berglin, et al., 1997

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.47	Hanford Tanks Initiative Vehicle Based Waste Retrieval (non-radioactive) Demonstration Report provided information from feature tests regarding in-SST vehicle operation: ▪ A 100-ft long umbilical was intentionally dragged against the simulated risers to prove the ability a Trac-Pump to negotiate riser obstacles. Minimum bend radius of the umbilical under power of the Trac-Pump was 3 ft. The turn radius of the Trac-Pump assembly was 8 ft. Fifty feet of 5-inch tank-car hose was retrieved and deployed 3 times. ▪ Solids concentration in the waste determined the amount of make-up water required; partial re-circulation of the discharged slurry could be used to minimize the amount of make up water required. A grinder type re-circulation pump could be used to further process the solids. ▪ The back flush system was tested by intentionally blocking the discharge manifold with salt cake; it was unplugged within 1 minute with a 13-gpm, 2000psi water jet. The second section was blocked with hardpan and took 3000-psi pressure to unblock it. ▪ Tests were conducted to identify additional features to facilitate assembly, maintenance, and decontamination. The need for a maintenance schedule was identified to verify that all necessary design features have been identified.	Applicable retrieval pump operational experience: ▪ Umbilical system operating characteristics. ▪ Re-circulating water utilization. ▪ Pump inlet back flushing characteristics. ▪ Design for maximum system operational availability.	Hanford HTI ESG, L.L.C., 1997

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.48	A comprehensive report is available documenting sluicing Hanford operations for 43 tanks from 1952-1957, 10 tanks from 1962-1978 as well as rail cars and several other S-farm tanks. This provides a history of sluicing operations including sludge and heel removal and information regarding equipment (including pumps) failure histories and clean-out time cycles. Of particular interest are the methods used to control fogging and misting to improve the visibility inside the tanks during operations.	Develop project and deployment planning using this operational and equipment performance history as a basis to make key conceptual and definitive design decisions. This would be useful information to support FMECA activities identified in section A.3.1.12: "*...Develop a reliability/availability-based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA)...*".	Hanford Tank Farms Rodenhizer, 1987
A.3.1.49	The Easily Manipulated Mechanical Arm (EMMA) used FMECA and RAM risk analysis methods as design tools. "*...The level of analysis and documentation has to commensurate with their relative importance to safety, risk, complexity of the activity, equipment life cycle, and their importance to the key functional goals. The Failure Mode and Effect Analysis (FMEA) and Reliability, Maintainability, and Availability (RMA) have been done systematically. ....., the probability and consequence of failures are evaluated and the risk factors are calculated for the systems, structures and components. Then the risk factors are translated to performance grade. With five grade levels, (PG-1 requiring the highest level of control and management), it has been determined that the deployment tower qualifies for PG-4 and the other systems and structures are PG-5. The system should provide a 10-year operating life with MTBF of 1,000 hr...*"	Use FMECA and RAM as design tools to meet functions and requirements. See also section A.3.1.12 "*.... Develop a reliability/availability-based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA)...*".	Huang, et al.

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.50	Resolution of the 241-SY-101 Surface Level Rise issue was achieved using traditional project management methods and tools. These consisted of planning the work, assigning a dedicated team, managing change control, tracking performance measures to closure, and documenting closeout of the work. Specific steps contributing to the success of this effort included: ▪ Assembling a dedicated project team with clear roles and responsibilities, schedule, and objectives. ▪ Measurable performance objectives. ▪ Characterization of interfaced and operational constraints. ▪ Rigorous and timely change control. ▪ Building consensus with client (including operations), oversight organization, and project team participants. ▪ Effective and frequent communication with team members.	Attributes for a successful project include: ▪ Defined scope managed through change control. ▪ Dedicated team, co-located, participating in frequent (daily) status meeting. ▪ Detailed WBS and resource-loaded schedule with no activity longer than 2 weeks. ▪ Cost estimated based on detail planning. ▪ Defined design process (including design verification). ▪ Pre-deployment testing of equipment and training of operators. ▪ Performance metrics defined and measured. ▪ Strict configuration management of the technical baseline (scope, schedule, technical basis). ▪ End state clearly defined and achieved.	CHG, 2001a and CHG, 2001b
A.3.1.51	The 241-AZ-101 Mixer Pump lessons learned identified items applicable to planned 241-C-104 retrieval: ▪ A realistic, resource-loaded schedule should be developed and staffed accordingly. ▪ Design issues that should have been addressed early impacted the reliability of the mixer test systems and equipment. ▪ Investing more resources (funding) up-front in the project would have resulted in fewer problems during testing.	Efforts need to be made to: ▪ Provide a realistic schedule, resource-loaded to provide realistic support to Project activities. ▪ Develop a cost estimate based on detail planning; provide staff resources accordingly. ▪ Implement a rigorous design process to ensure reliable system performance.	Hanford AZ-101 CHG, 2001b

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.52	Numerous applications of "Hydrotransport™" technologies based on TORE® systems have been successfully deployed in the petrochemical, mining, nuclear, and water utility industries. Typically these are used for water-oil/sludge separation and entrained solids removal. In some cases the removed solids are also cleaned using the same technology. A family of products is available to perform many functions to clean, trap, separate, and transport fluids or fluidized solids. Typical stream flow rates of 1300 GPM transporting >20 micron solids.	Thorough feature testing and process control system characterization is critical to successful operation of these systems. The TORE® principle of operation is based on a phenomenon know as a "processing" vortex core (PVC). Careful integration of these products into the design application is important to maximize the effectiveness of the chosen system. For example, solids removal may be required upstream of the separators. Liner materials must consider erosion due to fluid velocities.	Industrial Application Merpro Limited, 2001a, b, c, and d.
A.3.1.53	System plugging feature and pilot-scale testing of waste slurry transport equipment configuration was conducted to: ▪ Identify operating parameters and feed conditions that may cause solids formation and transfer line plugging. ▪ Establish correlation of observed data to enable prediction of slurry transport characteristics. ▪ Provide engineering data and technical recommendations.	Feature testing of equipment configurations provides necessary verification of key system design attributes. Specific findings established that feed temperatures (50° C and higher) and flow rates (>3 fps) were critical process control parameters to prevent plugging.	US-DOE funded University research Ebadian, 2001, and PNNL TFA, 2001
A.3.1.54	Solution mining information is available from the Salt Institute and Solution Mining Research Institute. These provide a resource for equipment suppliers, operational experience, technical resources, and independent reviews.	A large industrial community exists with a great deal of experience with the design, manufacture, and operation of solution mining systems. In addition, resources are available to provide consulting services and informational exchanges with the international salt mining industry.	Industrial Application Salt Institute, 2001
A.3.1.55	Parametric studies were completed and provide design basis information regarding leach times, brine production rates, and specific gravity.	Predictive performance models and operational experience is provided from multiple solution mining sites. These analytical tools and operational data may be useful to establish design basis requirements, design solutions, and subsequent operational control methods for SST retrieval.	Industrial Application Bauer, 1998

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.56	Laboratory tests results were used to assess modeling capability of computer simulations from ESP (Environmental Simulation Program). The results indicate that ESP predictions compare favorably with: ▪ Amounts of water required for dissolution ▪ Concentration of each constituent after it was dissolved.	Laboratory tests results are available to validate the results of dissolution models to establish critical attributes of salt wastes retrieved using dissolution technology.	Hanford Herting, 2000
A.3.1.57	Laboratory tests demonstrate that concentrated salt solutions can be produced and removed from dry salt tanks while maintaining minimum liquid inventory in the tank.	Dissolution of dry salt in tanks would be expected to: ▪ Not produce significant channeling if used with a sprinkler system dispersing water uniformly. ▪ Result in very high solution saturation levels, which may cause clogging of pumps and transfer lines. ▪ Cause preferential dissolution of salt species and corresponding depletion of hydroxide and nitride corrosion inhibitors; this may require the addition of additional hydroxide to the dissolution water.	SRS Wiersma, 1997
A.3.1.58	Laboratory tests of simulated waste were conducted to examine impact on in-tank corrosion controls resulting from various methods of dissolution retrieval. Water with and without inhibitors was added to saltcake and relationships established for various density gradient dissolution methods. These included: ▪ Drain-Add-Sit-Remove ▪ Modified Density Gradient ▪ Continuous Salt Mining Determinations were made regarding retrieval attributes and potential impact on tank corrosion controls.	There are important relationships between key process parameters for dissolution retrieval. Examples include: ▪ Rate of dissolution ▪ Degree of channeling or short circuiting ▪ Solution temperature ▪ Particular method of density gradient dissolution ▪ Retrieval rates ▪ Elevation of outlet lines ▪ Changes in corrosion inhibitor concentration. These should be evaluated and controlled to maintain required corrosion controls during retrieval.	SRS Wiersma, 1996

A.3.1.59	Deployment of the pulsejet mixing retrieval system utilized a modular, skid-mounted system and offered the benefit of a simple in-tank system requiring minimal maintenance. Some of the operational problems identified could be avoided in future deployments.	The pulsejet mixing system offers a proven technology with demonstrated successful retrieval. Specific items for consideration for improved performance include: ▪ Careful selection of in-tank nozzle configuration for waste characteristics. ▪ Sludge settling creating in-tank heels that were difficult to mobilize. ▪ Monitoring and control of mixing of mixing conditions compromised by inconsistent suction time data for the charger vessels. ▪ From Kent, 1998 executive summary text: *The use of on-line monitoring instrumentation for continuous measurement of density and solids of the slurry could likely have shortened mixing times, reduced operating costs, and provided greater assurance of adequate mixing.*	ORNL TFA, 2000a Kent, 1998 Dahl, 1999
A.3.1.61	Fluidic pulse jet mixer systems and components are commercially available and have been used in a variety of industrial/DOE –complex applications.	Maintainability and reliability information is available to establish maintenance planning and life-cycle reliability performance standards.	AEAT 2001, 2001a, and 2001b

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.62	Key requirements need to be specified in the contract instrument used to control purchased equipment and services. This will prevent typical in-process problems and avoid production delays. These include: ▪ Establishing service agreements to specify roles, responsibilities, policies and standards to enforce. ▪ Labeling standards consistent with client plant practices, specifying a suitable (e.g. weather proof and radiation/high-heat tolerant materials). ▪ Implications of working under 10CFR830.120 (QA Rule) requirements, certification of compliance by AEAT and sub-tier contractors, safety implications from various evolutions, change control, and potential impacts to USQ documentation. ▪ Requirements management: Flow-down of requirements to sub-tier contractors. Consider client-approved methods to use graded approach with emphasis on direct control of process fluid (slurry) elements. ▪ Operating, maintenance, and training manual standards need to be consistent with client plant standards (e.g. checklist format, page numbering, emergency event reporting, and alarm response). In addition, clear lines of authority need to be established to clarify subcontractor working relationships with the operating plant organization.	Implement service agreements with all contractors clarifying requirements associated with items such as: ▪ Labeling consistent with plant standards that are suitable for operating environment and safety practices. ▪ 10CFR830.120 requirements. ▪ Flow-down of requirements (e.g. traceability) to sub-tier contractors. Note: This of particular importance with the deployment of contractors employing "commercial practices" in SST retrieval operations. These contractors may not be fully cognizant of client expectations.	AEAT Danfelt, 2001 Blackmon, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.63	Ineffective interface management/control both between skids and between skids and existing plant structures is frequently the cause of system-level operational problems. Typical examples include: ▪ Unsuitable electrical cable management with inadequate length, restraint, and access for troubleshooting and maintenance. ▪ Poor junction box design with poorly secured terminal rails do not facilitate effective field wiring ▪ Inadequate weatherproofing of junction boxes resulted in unscheduled outages and costly field repairs. ▪ Inadequate specification of suitable inter-skid electrical and air duct connections. Unworkable "as designed" configurations and insufficient flexibility for field conditions applications. Most of the identified issues could have been prevented with effective walk-down of field conditions to validate design assumptions.	Establish a valid basis for design solutions based on as found field condition, integration and control of interconnecting systems that address known areas of concern consisting of but not limited to: ▪ Electrical cable management with sufficient cable lengths, cable restraints, and sufficient access for troubleshooting and maintenance. ▪ Effective junction box design with secured terminal rails to facilitate effective field wiring ▪ Weatherproofing of junction boxes. ▪ Effective specification of suitable inter-skid electrical and air duct connections.	AEAT Danfelt, 1998, 1999, and 2000 Blackmon, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.64	Inadequate trace heating and freeze protection for jet pumps and systems with condensate lines. Some cooling systems, designed for hot weather operation, over-cool components when operated at 35-40° F. Drain and flush lines froze up because they were not monitored when system was not being operated. In some cases trace heating systems failed to operate because tripped circuit breakers were not reset. Due to condensate issues with steam lines, electrical trace heat is considered a better alternative.	Trace heating and freeze protection for jet pumps and system condensate needs to be carefully managed during cool and cold weather operation. All drain and flush lines need to be monitored particularly when system is not being operated. Circuit breaker status should be monitored, drain valves open, and steam lines isolated. Consider use of electrical trace head instead of steam lines to avoid problems with condensate. Verify that flush lines are operable (not frozen) and provisions are made to modify fan-cooling systems for <40° F operation.	AEAT Danfelt, 1998, 1999 and 2001
A.3.1.65	Shipping, lifting, and handling requirements were inadequately specified and managed when design solutions were developed. The resulted in numerous issues related to supporting design calculations, safety factors, integration with client practices, unspecified handling loads during shipping/construction, flow-down of requirement to sub-tier contractors, and non-USA standards determined, after the fact, to be incompatible with domestic requirements. In one case a system was fitted with certified lift point only for vertical lifting. However, the component was shipped to the field horizontally.	Applicable shipping, lifting, and handling requirements need to be specified at the outset of the design process. This must address all lifting/handling scenarios for the life cycle of the equipment. They should begin with the fabrication process and be carried through to the planned disposal process. Consideration must be given to planned maintenance, operation, shipping, construction, installation, testing. A robust design solution must address combined loading cases with accepted (conservative) safety margins, clearances and weldments. Where applicable, fork life pockets should be provided	AEAT Danfelt, 1998 and 1999 Blackmon, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.66	Installation methods and requirements are typically not sufficiently addressed to avoid delays in the field. Anchor bolt interfaces were frequently a source of rework and lost time. Equipment anchored on the ground has been subject to depth limits (typically 3-inches). Applications deeper than 3-inches have required unplanned ground surveys, excavation permits, and associated environmental controls. Anchoring to existing facility floors or equipment can lead to poorly configured fastening arrangements with inaccessible anchoring bolts that are difficult to inspect and maintain. Welding to anchor equipment has frequently resulted in buckled floor plates.	Installation requirements and design solutions need to be carefully addressed at the outset of the project. Agreements with the client should be carefully documented and controlled. Anchoring methods need to be: ▪ Addressed early in the design solution ▪ Managed with interface controls ▪ Integrated with related evolutions with other contractor and the client facility.	AEAT Danfelt, 1998, and 2000 Blackmon, 2001
A.3.1.67	Post shipping inspections and associated turnover testing has frequently failed to identify damaged equipment and design integration issues. For example, shipping damage resulting in leaks and other hidden damage will effect performance and cause delays when identified after construction is completed.	Post-shipment inspections should be planned and addressed as a potential design constraint. For example: ▪ Consideration should be given to providing special restraint to complements during transport and handling. ▪ Provisions should be made in the design to facilitate post-shipment (in the field) leak and pressure testing. Design features need to be provided to facilitate access to and test of all areas of system functionality prior to turnover to Operations. The turnover schedule should provide for testing of all areas of system functionality.	AEAT Danfelt, 1998, and 2000 Blackmon, 2001

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.67	Deployment of retrieval and mixing system has identified a number of piping joint, gasket, assembly, and leak-recovery issues. These issues derive from less than adequate joint design and failure if shipping and installation inspection processes.	Piping joints using threaded joints (e.g. pipe threads) are less reliable than flanged joints and much more difficult to repair when leaks are detected. Sealants and gaskets need to be radiation resistant: ▪ Do not use Teflon-based materials (common with many "commercial practice" contractors). ▪ Use gasket materials such as Durlon 8500 instead of EPDM. Piping assembly should be thoroughly assessed as part of the design solution with full specification of assembly torques. Piping gaskets frequently are lost prior to field assembly or missing altogether after assembly. This could be remedied with: ▪ Better pre-shipment inspections. ▪ More effective field inspections. ▪ An effective spare parts inventory (e.g. provisions for lost/missing parts during construction.)	AEAT Danfelt, 2000 Blackmon, 2001
A.3.1.68	All new, used, leased equipment is frequently not provided with inspection/maintenance records and spares for critical parts.	Preventive maintenance schedules and spare parts for expected failures should be provided for all equipment necessary to maintain operations. Ideally this would be developed from a systematic RAM-type analysis. See also section A.3.1.12 "*.... Develop a reliability/availability-based maintenance strategy utilizing qualitative failure mode effects and criticality analysis (FMECA)...*".	AEAT Danfelt 1999

Table A.3-1 (cont'd): Operating Effectiveness

Section A.3.1	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.1.69	Electrical bonding and termination issues frequently result in construction and maintenance delays. These typically occur when field design changes are required when no provisions were made in the design to, for example, provide grounding points, route electrical lines and proper junction box configurations for termination.		AEAT Danfelt 1999

Table A.3-2: Residual Waste/ Retrieval Effectiveness

Section A.3.2	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.2.1	Sluicer performance in large waste tanks has not met expectations due to inadequate verification of performance prior to deployment. This has been compromised further due to "de-tuning" of the sluicer system in an attempt to: ▪ Reduce aerosols/evaporation resulting in gas in the mass flow meter ▪ Reduce moisture on the in-tank surveillance cameras Failure to systematically integrate various sub-systems will result in less than adequate performance of the retrieval system.	Verify (through modeling, reliability analysis, feature testing, or other suitable methods) that the design of the sluicer assembly will meet performance and maintenance criteria.	ORP W-320 Bailey, 2000
A.3.2.2	▪ Waste mobilization predictions based on core-sampling information have been determined to be invalid. ▪ Excessive dispersion (ineffective "straightening") of the sluice stream resulted in less than adequate performance.	Methods to mobilize tank waste need to be verified prior to acceptance of the final design for procurement. *C-106 core sample data indicated a hard heal that would be difficult to remove using sluicing retrieval. In actuality, the heal sluicing retrieval activities were able to remove a large amount of the heal. (120)	ORP W-320 Bailey, 2000
A.3.2.3	Although crawler system performance was severely limited due to reliability issues such as tether seal leaks, intermittent tether electrical problems and loss of one degree of freedom of MLUDA, the collective system was robust enough to achieve performance goals.	Provide redundant means to achieve performance goals through contingency planning and robust system design. [See associated FMECA recommendations in Table A-1]	ORNL GTRP Providence Group, 2001

Table A.3-2 (cont'd): Residual Waste/ Retrieval Effectiveness

Section A.3.2	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.2.4	Partial submersion of the confined sluicing end-effector offered the best means to avoid 3-phase (solid, liquid, gas) pumping. For the last 1-3 inches of waste retrieval, the Houdini collected and plowed "waves" of waste to the end-effecter.	Retrieval pumping performance and confined sluicing operation should be integrated to establish the design-basis operation profile to achieve performance objectives. (See also A.3.1.40 and A.1.3.41) *Applicable retrieval pump operational experience:* ▪ *Sludge recovery technique for last 4-6 inched of tank bottoms.* ▪ *Instrumentation and surveillance methods to support retrieval.* ▪ *Sluicer positioning and operation.*	ORNL GTRP Lloyd, et al., 2001

Table A.3-2 (cont'd): Residual Waste/ Retrieval Effectiveness

Section A.3.2	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.2.5	Various weaknesses were identified during the MLUDA/Houdini deployment consisting of ergonomics, maintenance issues, instrumentation deficiencies, and control system faults: ▪ Glove box location and configuration limited tool handling, retraction, and maintenance operations. ▪ Lengthy and demanding process to deploy the main handling system (10 cable and 3 hose connections) ▪ Limited range/rotation of cable and hose management systems required periodic disassemble and reassembly of equipment. ▪ Replacement of a cable was necessary – made possible only because of a spare conduit included in the design. ▪ Coriolos (FE-204) flow meter was "completely ineffective" due to the highly dynamic 3-phase flow characteristics with significant "slugs" of air. ▪ Debris clogging the screen on the waste inlet. (However this did prevent pump blockage.) ▪ Contamination traps in confinement box on tank riser. ▪ Inability to replace rupture disks. ▪ Poor seal design in the rotating end-effector. ▪ Inability of the control system to detect a disconnected control cable; need to de-energize and safely shut down system.	See item A.3.1.18: *"Provide engineered systems to safely manage hydraulic fluids under normal (operations and maintenance) and off-normal operations."* Also, provide: ▪ Visual access for inspections ▪ Temporary maintenance power inside and outside glove boxes. ▪ Various end-effectors to achieve performance objectives. ▪ Contamination and corrosion control in high-humidity environments. ▪ "Tune" end-effectors to achieve maximum performance per unit time (e.g. diverging verses converging jets). ▪ Trade off higher jet pressures for control of airborne mist. ▪ Umbilical management optimization (including decontamination and tensioning monitoring systems). ▪ Consider using crawler to position the end-effector. ▪ Establish realistic need to upgrade existing tank farm support systems.	ORNL GTRP Lloyd, et al., 2001

Table A.3-2 (cont'd): Residual Waste/ Retrieval Effectiveness

Section A.3.2	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.2.6	Item from Table A-1 *Operating Effectiveness applicable to Leak Detection*: A.3.1.54	A large industrial community exists with a great deal of experience with the design, manufacture, and operation of solution mining systems. In addition, resources are available to provide consulting services and informational exchange with the international salt mining industry.	Industrial Application Salt Institute, 2001
A.3.2.7	Item from Table A-1 *Operating Effectiveness applicable to Leak Detection*: A.3.1.59	Monitoring and control of mixing of mixing conditions may be compromised by inconsistent suction time data for the charger vessels. In addition, sludge settling may create in-tank heels that will be difficult to mobilize.	ORNL TFA, 2000a Kent, 1998

Table A.3-3: Leak Detection

Section A.3.3	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.3.1	A Gas Pressure Decay (GPD) method was used to test portions of the pressurized transfer piping of a Low Level Liquid Waste System at Oak Ridge National Laboratory (ORNL). This method analyzed the pressure decay rate of a gas introduced into the selected pipeline and expressed results in terms of an equivalent liquid leak rate. This system could measure a leak as small as .1 gal/hour with a probability of detection greater then 95% and a probability of false alarm less than 5%.	Could be a form of leak detection for the transfer lines provided the lines could be pressurized.	ORNL Starr, et al., 1993
A.3.3.2	Liquid integrity test of rusty carbon steel pipelines revealed sufficient integrity to allow GAAT to evaporator transfer. This allowed the project to use the pipeline avoiding the need for a new line resulting in savings in both cost and schedule.	Verify need for new, replacement lines prior to initiating design and fabrication of new equipment, test to determine if the exciting system is sound.	ORNL Ref. 98
A3.3.3	Items from Table A-1 *Operating Effectiveness* applicable to *Leak Detection*: A.3.1.12 A.3.1.16 A.3.1.17 A.3.1.31 A.3.1.34 A.3.1.35 A.3.1.37	▪ *Establish an operation and maintenance strategy and integrate detection system operation.* ▪ *Where feasible, provide direct access to instrumentation systems without breaking containment.* ▪ *Identify features early in the design phase to enhance operability of the system...* ▪ *Implement planning to establish condition-based operations and maintenance (CBM) ...* ▪ *Develop project and deployment planning with due consideration for reliability testing and process quality assurance.* ▪ *Address operator and maintenance personnel training and retention of key technical staff...* ▪ *Management of flow-down of quality and safety requirements...* ▪ *"...Develop a reliability/ availability-based maintenance strategy utilizing Micas ...".*	

Table A.3-3 (cont'd): Leak Detection

Section A.3.3	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.3.4	The performance standard for tank tightness testing is established by the U.S. Environmental Protection agency. The standard was developed to address tanks nominally 8,000 to 10,000 gals in capacity or less. To meet regulatory standards for tank tightness testing of petroleum fuel tanks, volumetric leak detection systems must be able to accurately compensate for thermally induced volume changes in the stored fuel. A field study was done to investigate the magnitude of these volume changes with the following results: • Current procedures used to compensate for temperature when testing smaller tanks will not suffice for larger tanks. • The number of temperature sensors must be sufficient that the volume of product in the liquid layer around each sensor is not to great • Duration of testing must be long enough to measure the fluctuation of temperature after additions or subtractions of product and that the precision of the temperature and level instrumentation is sufficient to measure a leak. • An accurate experimental estimate of the constants is necessary for converting level and temperature changes to volume. • A waiting period of approximately 24 hour after addition of product is required to equalize the temperature	Baseline information is required on the physical characteristics of the tank contents. Temperature sensors should be installed 3 inches from top of liquid and bottom of tank and every 6-12 inches through the liquid. Wait at least 24 hours for horizontal gradient in rate of change of temperature to dissipate. Use the most precise temperature and level measurement systems available. Measure the coefficient of thermal expansion experimentally. Determine the height to volume conversion factor level measurements to volume measurements experimentally.	US-EPA Maresca, et al., 1993

Table A.3-4: Leak Monitoring

Section A.3.4	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.4.1	Tank leak monitoring of the GAAT provide the following information • Stratification of waste in tanks caused stratification of conductivity readings used to determine a base line for external monitoring • For external leak monitoring utilizing dry wells, the dry wells should be clear of debris • During baseline activities for external tank leak monitoring utilizing waste conductivity, evaluate and document rainwater impacts.	Evaluate the overall conductivity of a tank for baseline and dry well conditions prior to insertion of conductivity instrumentation. Baseline information should be gathered over a period of time that would incorporate changes due to outside conditions (i.e. rain)	ORNL ORNL, 1996, ORNL, 1997, and ORNL, 1997a
A.3.4.2	An un-answered low-level alarm resulted in fines to ORNL. Indications for the liquid level in tank WC-9 dropped from about 1000 gallons to zero gallons within a 24-hour period due to instrumentation error. A low-level alarm sounded and was not addressed for 36 hours because "false alarms are common place". These false alarms tended to be ignored.	Design the system to operator interface to facilitate immediate response to all alarms; develop instrumentation to minimize false alarms	ORNL Ref. 98
A.3.4.3	A common method for the detection of small leaks in pressurized underground storage tank pipelines containing petroleum is based on monitored pressure in the line. It has been documented that changes in pressure, taking into account temperature variations, can detect a leak of less than one gal/hr. With sufficient information about the physical configuration of the system, the pressure history in the pipeline can be predicted. Establish a baseline prior to initiating retrieval operations. Characterization of the physical properties of the material to be retrieved is crucial to design and operation of a monitoring system.	Verify through analysis and testing that the level of waste characterization is appropriate for the leak monitoring system technology selected.	Industrial Application Maresca, et al., 1990

Table A.3-4 (cont'd): Leak Monitoring

Section A.3.4	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A3.4.4	Items from Table A-1 *Operating Effectiveness* applicable to *Leak Monitoring*: A.3.1.12 A.3.1.16 A.3.1.17 A.3.1.31 A.3.1.34 A.3.1.35 A.3.1.37	▪ *Establish operation and maintenance strategy and integrate detection system operation.* ▪ *Where feasible, provide direct access to instrumentation systems without breaking containment.* ▪ *Identify features early in the design phase to enhance operability of the system...* ▪ *Implement planning to implement condition-based operations and maintenance (CBM) ...* ▪ *Develop project and deployment planning with due consideration for reliability testing and process quality assurance.* ▪ *Address operator and maintenance personnel training and retention of key technical staff...* ▪ *Management of flow-down of quality and safety requirements...* ▪ *"...Develop a reliability/ availability – based maintenance strategy utilizing FMECAs ...".*	

Table A.3-5: Leak Mitigation/ Response

A.3.5	LESSON LEARNED FROM SOURCE/ REFERENCE	CONSIDERATIONS FOR DESIGN AND OPERATION	Source/ Reference
A.3.5.1	Pipeline (WC-10) at Oak Ridge National Laboratory was shut down due to delays in reporting a potential leak. The Tennessee's TDEC (state environmental agency) ordered ORNL to shut down in order to remediate the leak	Conduct regular liquid integrity tests and report results in a timely manner.	ORNL Ref. 98
A.3.5.2	An adversarial relationship between ORNL and TDEC was eased by open dialog regarding leak test program. Long standing mistrust between TDEC and MMES limited interactions. Leak Indication program for ORNL allowed open discussion of data and data collection facilities. This openness smoothed the MMES-TDEC relationship.	Provide a path for effective communication between regulators and technical staff.	ORNL Ref. 98
A3.3.3	Items from Table A-1 *Operating Effectiveness* applicable to *Leak Mitigation/Response*: A.3.1.12 A.3.1.16 A.3.1.17 A.3.1.31 A.3.1.34 A.3.1.35 A.3.1.37	▪ *Establish operation and maintenance strategy and integrate detection system operation.* ▪ *Where feasible, provide direct access to instrumentation systems without breaking containment.* ▪ *Identify features early in the design phase to enhance operability of the system...* ▪ *Implement planning to implement condition-based operations and maintenance (CBM) ...* ▪ *Develop project and deployment planning with due consideration for reliability testing and process quality assurance.* ▪ *Address operator and maintenance personnel training and retention of key technical staff...* ▪ *Management of flow-down of quality and safety requirement...* ▪ *"...Develop a reliability/ availability-based maintenance strategy utilizing FMECAs ...".*	

A.4.0 DOCUMENT SOURCE BIBLIOGRAPHY – FOR LESSONS LEARNED

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APPENDIX B
Retrieval Performance Evaluation for Single-Shell Tank S-102

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LIST OF TERMS

BBI	best-basis inventory
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CoC	contaminant of concern
DOE	U.S. Department of Energy
DST	double-shell tank
DWS	drinking water standard
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERPG	emergency response planning guideline
F&R	functions and requirements
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HLW	high-level waste
HWMA	Hazardous Waste Management Act
ILCR	incremental lifetime cancer risk
LCF	latent cancer fatality
LDMM	leak detection, mitigation, and monitoring
LLW	low-level waste
LWC	lost workday case
MCL	maximum contaminant level
MEI	maximally exposed individual
MTCA	Model Toxics Control Act
NRC	U.S. Nuclear Regulatory Commission
RCRA	*Resource Conservation and Recovery Act of 1976*
REDOX	reduction-oxidation
RPE	retrieval performance evaluation
SST	single-shell tank
TRC	total recordable case
TRU	transuranic

TSD	treatment, storage, and/or disposal
URF	unit risk factor
WMA	waste management area

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B.1.0 INTRODUCTION

This *Retrieval Performance Evaluation for Single-Shell Tank S-102* is written to document the results of a scoping-level retrieval performance evaluation (RPE) for waste retrieval from tank S-102 in the Hanford Site 241-S tank farm (S tank farm). The evaluation was performed as part of the requirements of Milestone M-45-05-T16 of the *Hanford Federal Facility Agreement and Consent Order* (HFFACO; Ecology et al. 1989). Milestone M-45-05-T16 calls for the development of a HFFACO functions and requirements (F&R) document for tank S-102 waste retrieval and leak detection, mitigation, and monitoring (LDMM) systems. This scoping-level RPE directly supports the tank S-102 F&R document. The HFFACO milestone further identifies that the scoping-level RPE will provide the following:

- Environmental and human health risk evaluation data/information associated with estimated waste volumes to be retrieved
- Environmental and human health risk evaluation data/information associated with the maximum volume that could leak during retrieval and the risk from residual waste
- Detail known and estimated radionuclide contamination and contaminant migration within the vadose zone as a basis of calculation.

The scoping-level RPE documented in this report considers human health risk and regulatory performance measures over a range of residual waste volumes and retrieval leakage volumes selected for tank S-102. Performance measures evaluated include short-term human health risk, impacts to groundwater, long-term human health risk, waste site intruder risk, and regulatory compliance. The results of the RPE analysis will be used to identify performance measures that influence the design and operation of the waste retrieval system. Examples of retrieval system requirements include retrieval leak volume limits considering residual waste remaining in the tank following retrieval, and residual waste volume limits based on risk or regulatory performance measures. These performance measures provide one of the inputs to the decision-making process that results in the retrieval system requirements identified in the F&R document. A range of volumes for both residual waste and retrieval leakage are evaluated to investigate the sensitivity of the performance measures to residual waste volumes or leakage volumes. The fundamental goal of the waste retrieval system for tank S-102 is to retrieve sufficient waste from the tank to meet retrieval criteria. The ideal goal of any waste retrieval effort would be to retrieve all of the waste in the tank with no leak loss to the environment. However, achievement of that ideal goal is highly uncertain given the conditions of the tanks, physical characteristics of the waste in the tanks, and the limitations of the waste retrieval system. Given this uncertainty it is important to develop a design and operating approach that provides estimates for risk-based performance of the tank at various points along the retrieval path and considers risk and regulatory-based performance measures.

Single-shell tank (SST) waste retrieval decisions and subsequent tank farm closure decisions are interrelated on a tank-by-tank and tank farm-by-tank farm basis. Because tank closure will be completed on a tank farm basis, all potential sources of contamination within the tank farms (past leaks, retrieval losses, and tank residuals) must be considered when evaluating long-term impacts

from the tank farm system. Near-term retrieval actions for individual tanks (i.e., inventory remaining in the tank following retrieval and retrieval leakage) could affect future waste retrieval decisions. Tank farm retrieval decisions are also interrelated with remediation and closure decisions of other non-tank sources in the Hanford Site 200 East and 200 West Areas.

This analysis focuses on tank S-102. The general approach involves definition of waste retrieval cases that span a range of retrieval leak loss and residual waste volumes. A range of leak-loss and residual waste volumes are considered to establish risk versus volume relationships for both retrieval leakage and tank residuals. The risk versus volume relationships are based on tank specific inventory since risk is a function of the contaminants present and their concentrations. Table B.1.1 lists the areas of analysis considered and provides a cross-walk of those areas to the corresponding section numbers that address technical approach, results of analysis, and conclusions for each tank.

Table B.1.1. Analysis, Approach, Results, and Conclusions Crosswalk

Area of Analysis	Technical Approach/ Description	Analysis Results	Conclusions
Retrieval cases	Sections B.3.2 and B.4.0	NA	Section B.6.0
Source terms	Section B.3.3 and the Attachment to this appendix		
Short-term human health risk	Section B.3.4	Section B.5.1.1	Section B.6.2.1
Groundwater impacts	Section B.3.5	Section B.5.1.2	Sections B.6.2.2 and B.6.3.1
Long-term human health risk	Section B.3.6	Sections B.5.1.3 and B.5.2.2	Sections B.6.2.3 and B.6.3.2
Intruder risk	Section B.3.7	Section B.5.1.4	Section B.6.2.4
Regulatory compliance	Section B.3.8	Sections B.5.1.5 and B.5.2.3	Sections B.6.2.5 and B.6.3.3

*Source term results, conclusions, and data needs are identified within each of the areas of analysis as appropriate.

NA = not applicable.

This RPE is not intended to set the minimum performance standard for the retrieval demonstration. The intent of the retrieval deployment in tank S-102 is to collect performance data and establish a technical basis for the limit of the technology and the performance characteristics (e.g., loss in retrieval efficiency) as a function of waste volume remaining in the tank. Tank and tank farm closure criteria (as they are understood today) are considered in an effort to remove enough waste with minimal leakage providing reasonable assurance that the tanks and the tank farm can be moved toward closure without having to plan for multiple waste retrieval campaigns.

It is recognized that addressing tank farm closure at this stage of the program is preliminary and will be revisited throughout the life of the retrieval program; however, because waste retrieval for tank farm closure is the primary driver for remediating the SSTs, it is important to evaluate the

relationships between tank waste retrieval and tank farm closure before, during, and after tank waste retrieval.

The RPE methodology will be used to provide risk-based performance data for use in defining retrieval system requirements in the F&R document. The performance measures evaluated will be used to support identification of the requirements for the LDMM systems in terms of required leak detection limits and response actions and the identification of requirements for the waste retrieval systems in terms of the extent of waste retrieval necessary to meet risk- and regulatory-based criteria.

B.2.0 BACKGROUND

In 1999 the U.S. Department of Energy (DOE) completed the RPE methodology for the AX tank farm, documented in *Retrieval Performance Evaluation Methodology for the AX Tank Farm* (DOE/RL-98-72), as a demonstration of the methodologies, data, and analysis necessary to support making tank waste retrieval and tank farm closure decisions required under the HFFACO. DOE/RL-98-72 includes an evaluation of a range of residual waste and retrieval leakage volume cases and post-retrieval actions that could be taken to remediate contaminated soil and close the tank farm. The methodology in DOE/RL-98-72 uses a systems approach that considers the entire tank farm when evaluating the cases relative to potential performance criteria. These relationships can then be used to support decisions on the extent of waste retrieval and the limits of retrieval leak loss.

In August of 2000, the HFFACO was modified via Milestone Change Package M-45-00-01A to reflect a revised strategy for SST waste retrieval activities. The revised strategy focuses on maximizing risk reduction by prioritizing the retrieval of waste from tanks with a high contaminants of concern (CoCs) inventory instead of focusing on maximizing the number of tanks entered for waste retrieval. The new strategy is also focused on demonstrating waste retrieval technologies in a variety of waste forms and tank farm locations to establish a basis for future work. To establish overall F&Rs for the waste retrieval demonstration systems, the need for overarching F&R documents has been identified. The F&R documents define the requirements for how the waste retrieval systems will be designed and operated. The major elements of the HFFACO F&R document along with the HFFACO milestones leading up to waste retrieval for tank S-102 are shown in Figure B.2.1. HFFACO Milestone M-45-05-T16 specifies how the F&R document for tank S-102 should include scoping-level RPEs that provide human health risk evaluations associated with waste volumes to be retrieved and the maximum volumes of waste that could leak during waste retrieval operations. Milestone M-45-05A specifies the tank S-102 waste retrieval goal as retrieval of 99% of the August 2000 best-basis inventory (BBI) (BBI 2000) tank contents by volume, with approximately 490 curies of long-lived mobile radioisotopes retrieved to safe storage.

B.2.1 SETTING

The 200 West Area (Figure B.2.2) is located on a plateau about 8 km (5 mi) south of the Columbia River. The 200 West Area housed facilities called separations plants that received and dissolved irradiated fuel (from the 100 Areas) and then separated out the plutonium. Operations at the Hanford Site resulted in production of liquid, solid, and gaseous wastes. Most wastes resulting from Hanford Site operations have had at least the potential to contain hazardous and radioactive materials. From an operational standpoint, radioactive wastes were originally categorized as high-level waste (HLW) or low-level waste (LLW) depending on the level of radioactivity present. HLW was first stored in large underground SSTs. Portions of the contents of some of these tanks have since leaked into the soil, either directly from the tanks or from associated transfer piping. In later years HLW was stored in double-shell tanks (DSTs), from which waste has not leaked into the soil. However, in a few instances, releases have occurred from the transfer piping within DST farms, contributing to near-surface vadose zone contamination.

Figure B.2.1. Tank S-102 Waste Retrieval Demonstration Milestones

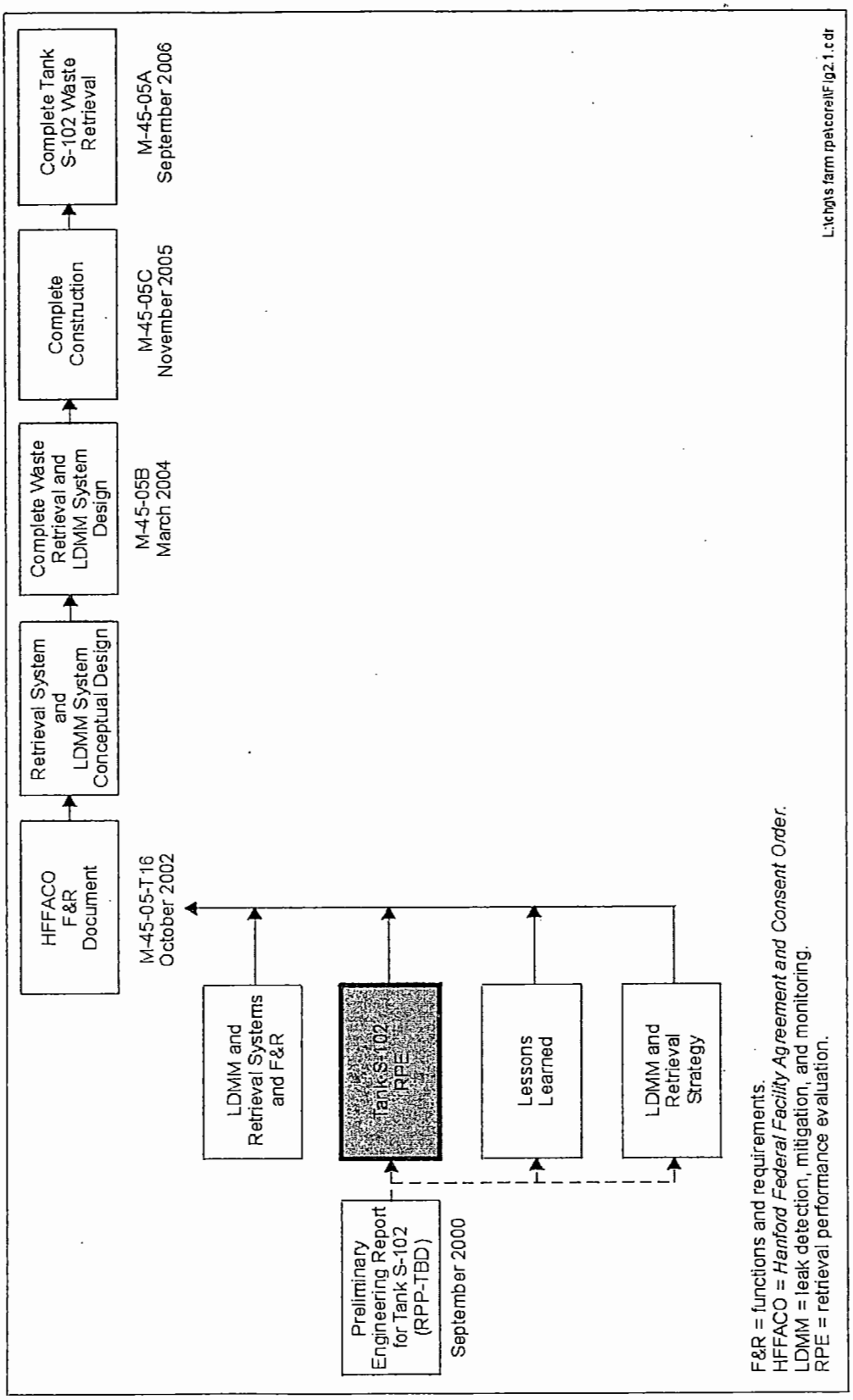
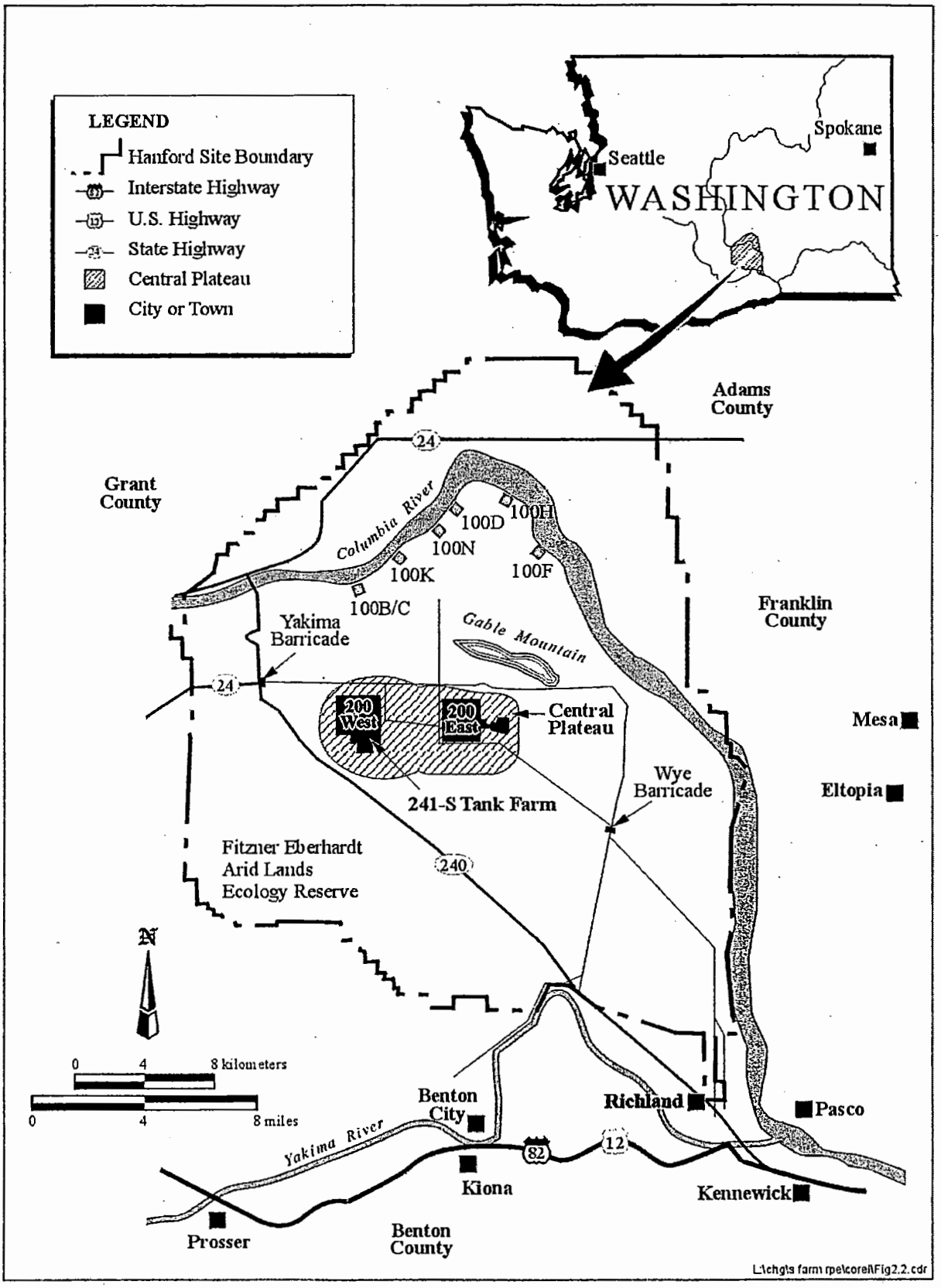


Figure B.2.2. Hanford Site Map and Vicinity



B.2.2 FACILITIES DESCRIPTION

This section contains descriptions of the S tank farm and tank S-102. Definition and description of ancillary equipment are also provided.

B.2.2.1 S Tank Farm

The S tank farm is located in the southern portion of the Hanford Site 200 West Area, near the Reduction-Oxidation (REDOX) Plant (Figure B.2.3). The S tank farm contains 12 SSTs, each with a 2,869,000 L (758,000 gal) capacity; waste transfer lines; leak detection systems; and tank ancillary equipment. The SSTs are 23 m (75 ft) in diameter. The S farm SSTs are approximately 11.4 m (37.3 ft) tall from base to dome. The sediment cover from the apex of the dome to ground surface is approximately 2.5 m (8.0 ft) at the S tank farm. All of the tanks have a dish-shaped bottom (Figure B.2.4). Information and data regarding the S tank farm facility description are taken from historical tank content estimate (WHC-SD-WM-ER-352).

The tanks in the S tank farm received REDOX Plant waste, which was allowed to self-boil or self-concentrate through evaporation of liquid. The S tank farm was built between 1950 and 1951. S tank farm operations began in 1951. The tanks were filled with liquids by 1953; however, the waste in the tanks began self-boiling in the summer of 1952 because of the radioactive decay heat load in the REDOX Plant wastes. A surface condenser was installed in 1953 to concentrate the waste and provide more tank space. The vapor condensate was disposed of in nearby cribs. Liquid levels in the tanks fluctuated during the next 20 years and then the tanks filled rapidly with solids. The change can be attributed to the startup of the 242-S Evaporator because the tanks were used as receivers for evaporator waste products. When the tanks were filled with solids, little could be done with technology that had been developed to increase the service lives of the tanks. The tanks were removed from service in the late 1970s and early 1980s (WHC-SD-WM-ER-352). Tank S-104 is the only tank in the S tank farm that is assumed to have leaked.

The S farm SSTs are treatment, storage, and/or disposal (TSD) units operating under interim status pending closure. Following waste retrieval, the S tank farm will be closed in accordance with "Closure and Postclosure" (WAC 173-303-610) under the Washington State "Hazardous Waste Management Act" (HWMA) and HFFACO Milestone M-45-00.

B.2.2.2 Tank S-102

Tank S-102 was filled with REDOX Plant waste between 1953 and 1965. The tank was removed from service in 1980. Tank S-102 is categorized as a Flammable Gas Facility Group 2 tank for hydrogen/flammable gas. Tank S-102 is classified as a sound tank and contains 1,900,000 L (492,000 gal) of waste, which includes 337,000 L (89,000 gal) of pumpable liquid (HNF-EP-0182, Rev. 150).

Figure B.2.3. Location Map of S Tank Farm and Surrounding Facilities in the 200 West Area

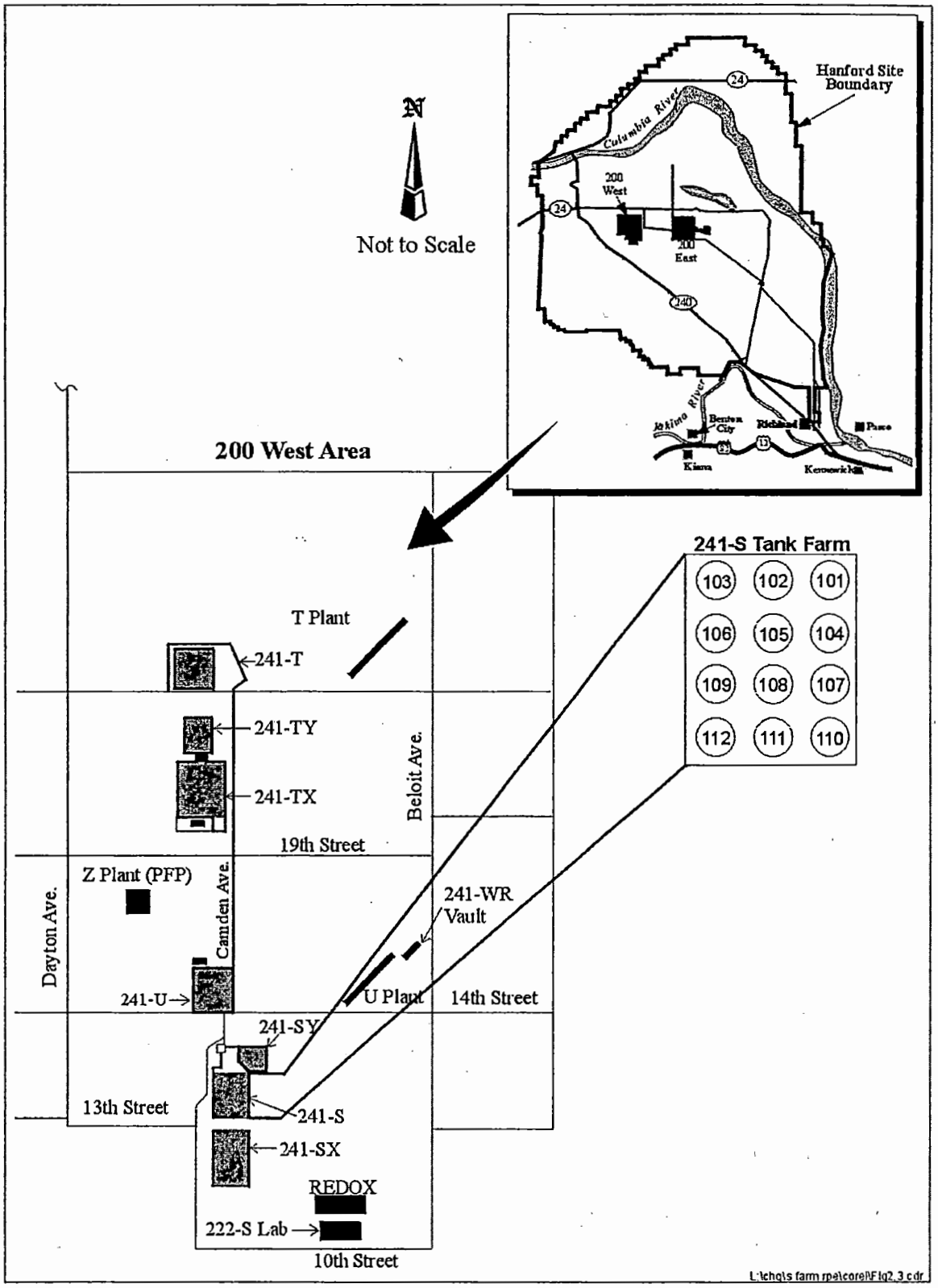
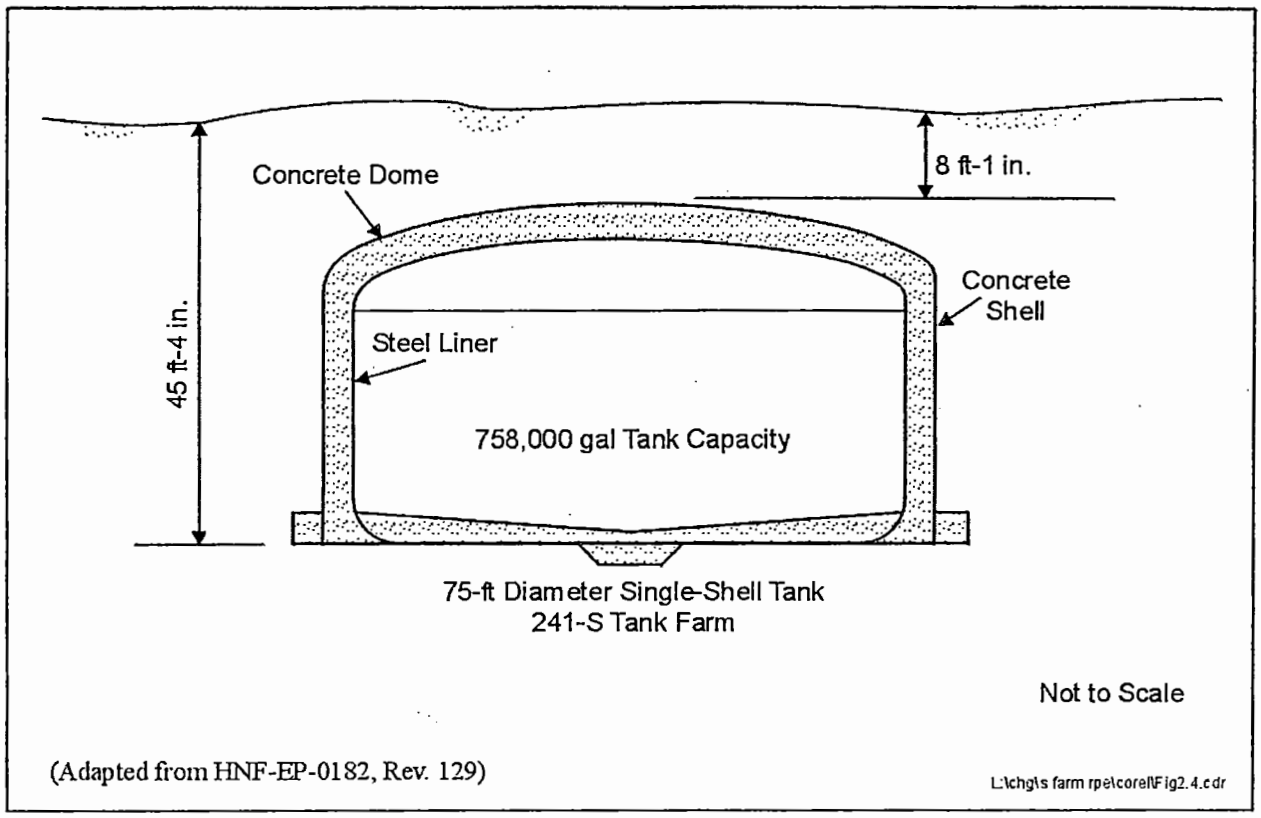


Figure B.2.4. S Farm Tanks



B.2.2.3 Ancillary Equipment

Ancillary equipment is defined as structures, piping, and equipment outside of waste tanks but associated with tank farm operations. Most of the ancillary equipment in the S tank farm was abandoned in place when the S farm tanks were taken out of active service. Evaluating ancillary equipment is an important component of closure strategy evaluations because the equipment represents a potential source term for worker exposures (if the equipment is removed) or long-term human health risk (if the equipment is left in place). S tank farm ancillary equipment includes the following:

- Surplus buildings and other surface facilities
- 72 drywells
- Tank riser penetrations
- Direct-buried piping, encased piping, and ventilation elements
- Pump pits, sluice pits, and valve pits associated with individual tanks
- Other valve pits, jumper pits, diversion boxes, and structures.

Potential sources of contamination include residual waste in the transfer lines, sluicing lines, valve pits, and pump pits. There is currently insufficient data available to assess the contaminant inventory in the ancillary equipment and, therefore, this contamination source was not included

in the calculation of long-term risks. This approach is reasonable for this scoping-level RPE to support retrieval decisions for tank S-102. Inventory estimates for the ancillary equipment will be needed for future performance evaluations of closure options.

B.3.0 TECHNICAL APPROACH

The value and response of risk and regulatory measures to variations in two main system parameters are the primary focus of this RPE. These two parameters are residual waste volume and retrieval leakage volume. Evaluation of the residual waste volumes supports the definition of the waste retrieval system requirements while evaluation of retrieval and potential leak loss volumes supports definition of the LDMM system requirements.

Section B.3.1 provides an overview of the technical approach. Section B.3.2 describes the approach used to identify specific waste retrieval cases for analysis. Section B.3.3 describes the approach used to develop contaminant inventory estimates for past leaks, retrieval leakage, and residual waste for each of the waste retrieval cases. Sections B.3.4 through B.3.8 describe the approach used for the five areas of analysis included in this RPE. Using the technical approach described in this section, performance measures for each case are calculated for four areas of analysis including short-term human health risk, groundwater impacts, long-term human health risk, and inadvertent human intruder risk. The results of these calculations are presented in Section B.5.0. The fifth area of analysis involves comparing the case-specific performance measures against the appropriate regulatory standards and identifying where regulatory uncertainty exists.

The methodology described for establishing waste retrieval and leak loss criteria for tank S-102 involves performing a baseline risk assessment of the S tank farm. In developing the approach for contaminant transport modeling it became apparent that four individual cross-sections were needed to capture the differences in past leaks and tank-specific inventories.

B.3.1 OVERVIEW OF THE TECHNICAL APPROACH

The RPE process was developed as a decision-making tool to support tank waste retrieval and tank farm closure decisions using a systems approach that considers contributions from multiple sources (i.e., past leaks, retrieval leakage, and residual waste) across a number of performance measures. The RPE methodology is an iterative process that can be applied before designing the waste retrieval system to develop criteria for the extent of waste retrieval and leak loss. After retrieval the methodology can be used to evaluate performance measures using actual retrieval and leak loss data. The technical approach includes integration with related Site activities (e.g., Tank Farm Vadose Zone Project). The current application of the RPE focuses on developing waste retrieval and leak loss criteria for tank S-102 within the S tank farm. The following tank farm performance measures are assessed.

- **Short-term human health risk** (Section B.3.4) – Health risk to workers and the public from chemical and radiological exposures that is expected to occur during routine remedial actions (e.g., waste retrieval) or that could result from postulated accidents, injuries, and fatalities resulting from industrial accidents.

- **Groundwater impacts** (Section B.3.5) – Impacts resulting from contaminant release and migration to the groundwater are assessed and compared to regulatory standards.

Groundwater quality impacts are evaluated at the tank farm boundary over a 10,000-year period of interest beginning at present.

- **Long-term human health risk** (Section B.3.6) – Human health risk to future Site users that would exist after completion of waste retrieval (post-remediation) and implementation of tank farm closure. Long-term human health risk analysis involves evaluation of health risks resulting from exposure to contaminated groundwater. CoCs to long-term human health risk are those that are persistent and mobile in the environment.

  A 10,000-year period of interest was used for calculating long-term human health risk based on the lifestyle of a residential farmer and an industrial worker. This time period was selected for the following reasons.

  - Classification of the residual waste under *Radioactive Waste Management* (DOE O 435.1). If residuals do not meet the 'waste incidental to reprocessing' criteria a determination from the U.S. Nuclear Regulatory Commission (NRC) will be required, based in part on demonstrating protection of human health and the environment over a 10,000-year period.

  - Future requirements for assessing tank closure will consider the 10,000-year period.

  - Based on previous analyses, the maximum long-term risk impacts from tank residuals are expected to occur 1,000 to 10,000 years following closure.

- **Inadvertent human intruder risk** (Section B.3.7) – Health risk to future Site users who could inadvertently drill through the tank following closure and loss of institutional control at 100 years after closure. A comparison of the residual waste inventory to NRC waste classification criteria is also made to support a regulatory evaluation of the planned approach for reclassification of the residuals as incidental waste. CoCs to the inadvertent human intruder include isotopes of cesium, strontium, tin, and transuranics (TRUs) that would remain in the tank.

- **Regulatory compliance** (Section B.3.8) – Applicable and appropriate regulatory requirements have been identified including areas where open issues and specific quantitative performance measures exist.

The best available data for tank S-102 and the S tank farm were used to provide calculations for each performance measure. Where data were unavailable or highly uncertain, assumptions were developed to complete the analysis. The major assumptions are defined in the following methodology sections. Those assumptions were based on engineering judgment following a review of available data or information from other Hanford Site, DOE complex, or non-DOE remediation programs.

Application of the RPE methodology to the evaluation of tank S-102 and the S tank farm includes the following components:

- A conceptual model of the tanks and S tank farm system (e.g., tank farm components, sources of contamination, engineered systems, and the natural environment) to analyze the potential implications of SST waste retrieval
- Waste retrieval cases that span a range of residual waste and retrieval leakage volumes that will be used to develop risk versus volume relationships
- Risk assessment to assess short- and long-term human health risks
- Comparison of the waste retrieval cases to requirements established by federal and state regulations and the HFFACO.

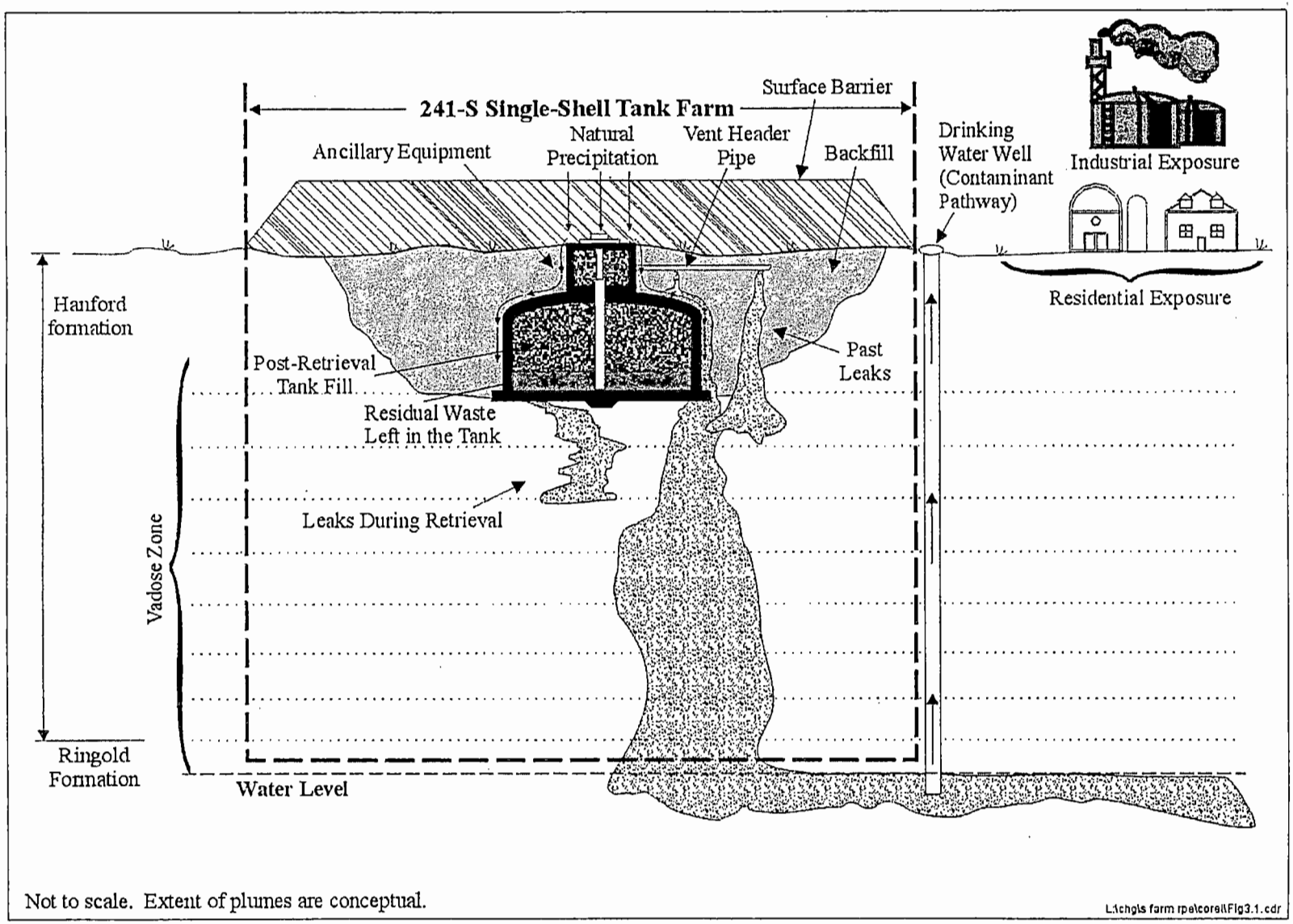
Sections B.3.1.1 through B.3.1.4 outline how each of these components are applied in the tank S-102 evaluation.

B.3.1.1 Conceptual Model of the S Tank Farm

SST waste retrieval decisions and subsequent tank farm closure decisions are interrelated on a tank-by-tank and tank farm-by-tank farm basis. They are also interrelated with other decisions regarding remediation and closure of a number of other waste sites in the 200 Areas.
This analysis focuses on tank S-102 within the context of the S tank farm. Considering the tank farm conceptually as a whole provides a means to evaluate the performance measures at a tank-farm level while also evaluating performance measure changes resulting from variations in residual waste and retrieval leakage parameters for specific tanks of interest. The conceptual model is depicted in Figure B.3.1 and includes the following.

- The S tank farm including tanks and soils within the tank farm boundary and from the surface to the groundwater.
- All waste sources within the S tank farm including:
  - Contamination in the vadose zone from tank leaks
  - Potential releases to the environment during waste retrieval activities
  - Releases to the environment from residual waste potentially remaining in the tank farm following completion of waste retrieval and assumed closure actions.
- Long-term degradation of the tanks and assumed tank closure system.
- Migration of mobile contaminants from the tank farm through the vadose zone and groundwater.
- Residential farmer and industrial worker scenarios and resulting human health impacts from contaminants that may have migrated beyond the tank farm boundary. Human health impacts from inadvertent intrusion into the residual tank waste are also included in the analysis but to preserve clarity are not depicted in Figure B.3.1.

Figure B.3.1. S Tank Farm Conceptual Model for Long-Term Human Health Risk and Groundwater Impacts



The conceptual model shown in Figure B.3.1 identifies source terms, transport pathways, and exposure pathways that could be under investigation by other Site projects (e.g., Tank Farm Vadose Zone Project, Groundwater/Vadose Zone Integration Project). Efforts to integrate this RPE with other projects were made to provide consistency in approach and methodology. The S tank farm is under the *Resource Conservation and Recovery Act of 1976* (RCRA) Corrective Action Program so there is a direct need for integration at the S tank farm. The past leak inventory for the S tank farm developed by the Tank Farm Vadose Zone Project (RPP-6285) was adopted for this RPE.

Figure B.3.2 depicts the waste sources, release mechanisms, exposure pathways, and receptors for all impacts analyzed in this RPE. Figures B.3.1 and B.3.2 also serve to illustrate much of the scope of this document, which includes evaluations of impacts associated with all past leak releases, potential future releases from the tanks during retrieval and post-closure, and intrusion into the tanks during post-closure. The scope of this document does not include the impacts associated with immobilization and disposal of the waste once it has been retrieved from the tanks.

B.3.1.2 Use of Waste Retrieval Cases

The approach used to evaluate performance measures for tank S-102 was to identify a number of specific cases that cover a range of retrieval leakage volumes and residual waste volumes. The performance measures for tank S-102 were coupled with performance measures for tank S-112. This allowed for the analysis of a myriad of contributing factors in order to ascertain waste retrieval performance for the entire S tank farm. These cases are evaluated against an assumed standard level of retrieval performance in the remaining 10 S farm tanks. Short-term risks are evaluated with retrieval activities for the S farm tanks of interest. Groundwater and long-term human health impacts are evaluated on a cross-sectional basis for the farm as well as on an individual tank basis. Inadvertent human intruder risks are evaluated on a tank basis.

B.3.1.3 Performance of a Risk Assessment

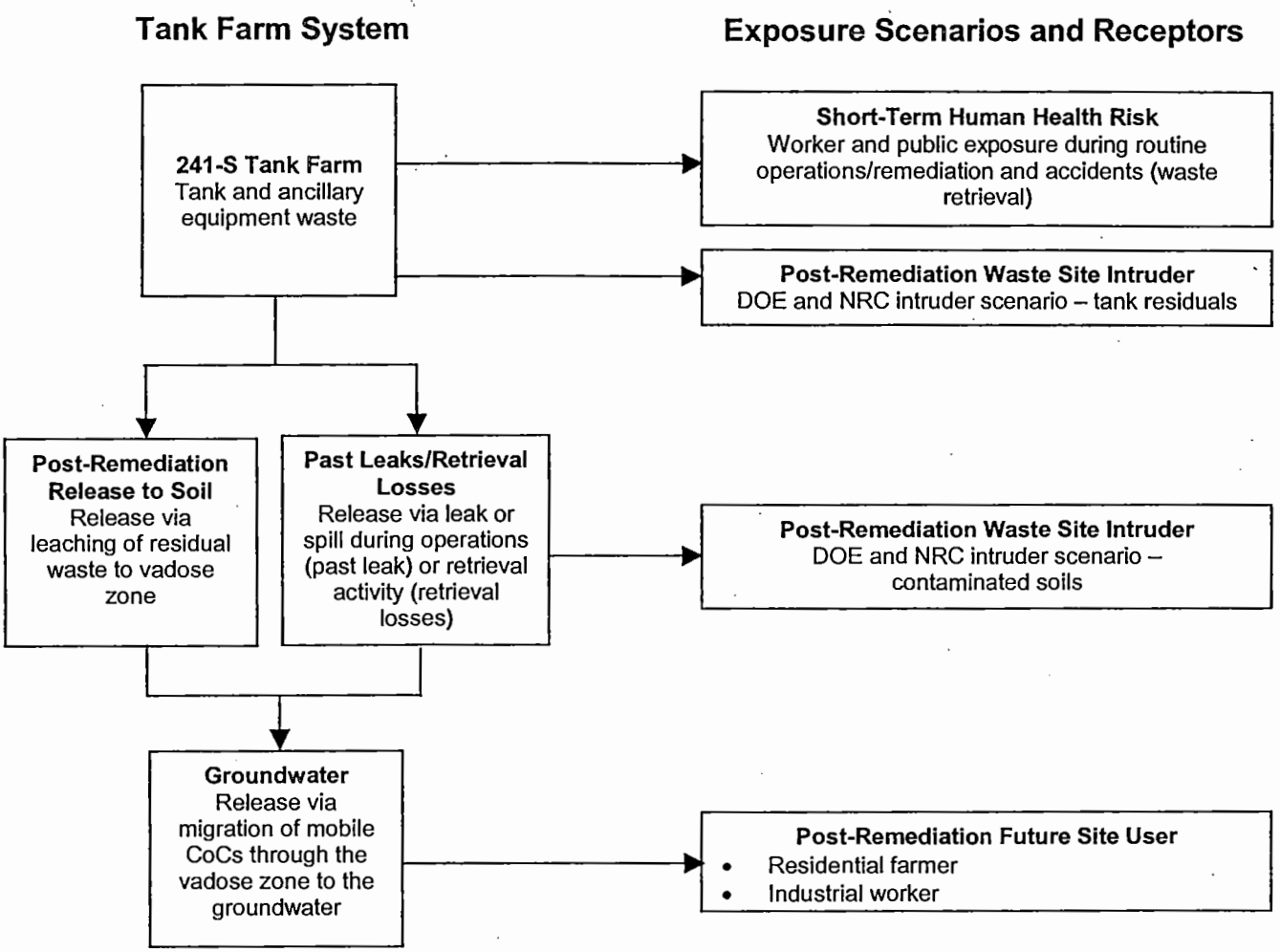
Waste retrieval actions for tank S-102 are evaluated and accident and routine conditions considered. The dominant pathways for short-term exposure include air releases and direct exposure.

Long-term human health risk is calculated based on exposure through the groundwater pathway. Exposure through other pathways (i.e., air and direct contact) would be limited by the tank closure system design and the surface barrier. Thus, contaminant migration through the vadose zone into groundwater and from groundwater to receptors is determined the dominant exposure pathway to future Site users located outside the tank farm boundary.

A numerical model is used to simulate the migration of contaminants through the vadose zone to the groundwater and in the groundwater to the tank farm boundary for each of the major source term components (e.g., past leaks, retrieval leakage, residual waste).

A human intruder into the residual waste following tank farm closure may limit the ability to close some tanks based on the residual waste inventory left in the tanks following waste retrieval. To address this issue, waste site intruder analyses are conducted using both DOE and NRC intruder scenarios.

Figure B.3.2. Evaluated Waste Sources, Release Mechanisms, Exposure Pathways, and Receptors



Receptor Exposure Pathways

Short-Term Human Health Risk				Long-Term Human Health Risk		Long-Term Human Health Risk Future Site User (Post-Remediation)	
Pathway	Involved Worker	Noninvolved Worker	Public	Waste Site Intruder*		Residential Farmer	Industrial Worker
				NRC	DOE		
Inhalation	✓	✓	✓	NA	✓	✓	✓
Direct Exposure	✓	✓	✓	NA	✓	✓	✓
Groundwater Ingestion				NA		✓	✓
Food Ingestion			✓	NA	✓	✓	
Soil Ingestion				NA	✓	✓	
Dermal (Water)				NA		✓	✓

*The NRC intruder scenario is based on concentration limits of CoCs in the waste.
CoCs = contaminants of concern.
DOE = U.S. Department of Energy.
NA = not applicable.
NRC = U.S. Nuclear Regulatory Commission.

B.3.1.4 Regulatory Compliance

Waste retrieval and future tank farm closure is driven by federal and state regulatory requirements and the values of stakeholders and Tribal Nations. Requirements for waste retrieval and tank farm closure include federal and state regulations associated with management, treatment, and disposal of chemical and radiological wastes.

B.3.2 IDENTIFICATION OF WASTE RETRIEVAL CASES FOR ANALYSIS

Ten waste retrieval cases are identified for this evaluation, as shown in Table B.3.1. Each case assumes specific values for retrieval leakage volume and residual waste volume for tank S-102 and the remaining S farm tanks. The cases were developed by varying one of the system components (i.e., retrieval leakage or residual waste volume) so that results could be compared and risk-versus-volume relationships developed. Because the long-term performance measures associated with closure are evaluated for a tank farm, each waste retrieval case identifies an assumed endstate for tank S-102 and for the remaining S farm tanks. Because the RPEs for tanks S-112 and S-102 are being developed in parallel, the cases identified in Table B.3.1 were developed to address both tanks. The specific retrieval leak and residual waste volumes used to develop the cases are intended to provide impacts over a range of volumes and not to select one of the cases for implementation. It is important to note that to provide results over a range of inputs, some of the cases identify residual waste volumes and retrieval leakage volumes that would not meet the objectives of the tank S-102 retrieval technology demonstration or the HFFACO interim retrieval goal for tank S-102. The purpose of the analysis is to evaluate how the performance measures change as the residual and retrieval leakage volumes change.

The two major components identified in Section B.3.1, retrieval leakage and residual waste volume, were combined to form the waste retrieval cases analyzed. Other elements of the cases are assumed fixed. That is, the same past leak inventory estimate is used for each case, and all cases assume an enhanced RCRA Subtitle C barrier is constructed over the tank farm for closure.

The approach used to develop waste retrieval strategies resulting in volume retrieved and leak loss assumptions is based on the fiscal year 2000 preconceptual engineering studies conducted for tank S-102 (RPP-7819).

Table B.3.1. Summary of Waste Retrieval Cases

Case	Residual Volume Remaining Following Retrieval			Retrieval Leak Loss			Interim Barrier
	Tank S-102 (gal)	Tank S-112 (gal)	Remaining S Farm Tanks (gal)	Tank S-102 (gal)	Tank S-112 (gal)	Remaining S Farm Tanks (gal)	
1	2,700	2,700	2,700	0	0	0	N
2	2,700	2,700	2,700	8,000	8,000	8,000	N
3	1,300	2,700	2,700	8,000	8,000	8,000	N
4	2,700	6,000	2,700	8,000	8,000	8,000	N
5	27,000	27,000	2,700	8,000	8,000	8,000	N
6	2,700	2,700	2,700	0	0	8,000	N
7	2,700	2,700	2,700	4,000	4,000	8,000	N
8	2,700	2,700	2,700	40,000	40,000	8,000	N
9	2,700	2,700	2,700	8,000	80,000	8,000	N
10	2,700	2,700	2,700	0	8,000	0	Y

Note: 2,700 gal represents the HFFACO interim retrieval goal of 360 ft^3 for the 100-series single-shell tanks.

To obtain liters multiply gallons by 3.785.

The tank S-102 waste retrieval action is intended to show the capability of a technology to retrieve waste from tanks containing both sludge and salt cake waste. It is anticipated that the effectiveness or efficiency of the retrieval system will drop off as the amount of waste remaining in a tank decreases resulting in greater cost and worker health risk per volume of waste retrieved. The practical limit for when the retrieval system has reached the limit of the technology will be defined in the HFFACO F&R document. Milestone M-45-05A specifies the tank S-102 waste retrieval goal as retrieval of 99% of the tank contents by volume with approximately 490 curies of long-lived mobile radioisotopes retrieved to safe storage.

Conservative assumptions are made for the various tank farm case elements so as to not underestimate the long-term human health risk contribution from the remaining S farm tanks. The assumptions made for the remaining S farm tanks are not intended to describe the planned approach but to develop a conservative basis for evaluating long-term human health risk for the S tank farm. For all but one of the waste retrieval cases it is conservatively assumed that each of the tanks leaks during waste retrieval.

B.3.3 SOURCE TERM INVENTORY ESTIMATES

The RPE evaluates three source terms:

- **Past leaks** – Contamination that is currently in the tank farm soil as a result of tank leaks or spills that have occurred in the past

- **Retrieval leakage** – Contamination released to the soils during the waste retrieval operations
- **Residual waste** – Contamination remaining in the tank following waste retrieval operations.

Identification and quantification of source terms are necessary to evaluate both the short-term impacts to human health during routine remediation activities and accidents and the long-term impacts resulting from releases to the tank farm soils. Releases of concern for evaluating long-term impacts include past leaks and spills, potential releases that may occur during waste retrieval, and the eventual release of residual waste remaining in the tanks following closure. The past leak source term encompasses a range of events that have resulted in the release of contamination to the vadose zone, including transfer line leaks, tank overfills, and leaks originating from the failure of the steel-liner-concrete-shell system. Once in the vadose zone contaminants are subject to the influence of transport processes that tend to drive contaminants toward the groundwater, which is the main source of long-term exposure. Source terms of concern for short-term human health risk assessment (both routine and accident) are predominantly in the form of air emissions. Source terms of concern for intruder scenarios are based on inventories of TRU waste and other isotopes of concern from a direct exposure or ingestion pathway caused by an inadvertent intrusion into a waste tank.

The first step in developing source terms involves developing inventory data for the waste retrieval cases. Inventory estimates were developed for each of the major long-term human health risk source term components; past leaks; potential retrieval leakage ranging from 15,000 L (4,000 gal) to 300,000 L (80,000 gal); and residual waste volumes ranging from 4,900 L (1,300 gal) to 100,000 L (27,000 gal). The inventory estimates are provided in the Attachment to this appendix.

B.3.3.1 Past Leak Estimates

The inventory associated with past leaks at or around tank S-104 (i.e., the only leaking tank at S tank farm) has been evaluated for the S tank farm as a part of the waste management area (WMA) S-SX RCRA facility investigation process (RPP-6285). This inventory comprises an estimate of contaminant inventory currently in the vadose zone. The distribution of this inventory as a function of depth was then estimated in the modeling data package for the WMA S-SX field investigation report by the Tank Farm Vadose Zone Project (RPP-6296).

In support of the WMA S-SX field investigation report (RPP-7087), the past leak inventories for cesium-137, technetium-99, nitrate, and chromium are presented as soil concentrations as a function of depth. This estimate does not include all of the CoCs utilized in the contaminant transport and long-term human health risk analyses.

B.3.3.2 Retrieval Leak Loss Estimates

The chemical and radiological inventories associated with the waste retrieval cases were estimated as a part of this task and are presented in the Attachment to this appendix. A range of

potential retrieval leakage volumes are evaluated to support development of LDMM F&R. The time and duration of the assumed retrieval leakage events were developed using available retrieval sequence data (RPP-7087). The major assumptions made include the following.

- Leak loss rates would be constant throughout the retrieval period.
- Leak loss occurs uniformly around the outer edge of a tank base. It is assumed that the retrieval leakage will be released over a 1.5 m (5 ft) wide ring circling the base of the tank. This corresponds to an area approximately equal to 25% of the tank base area. This assumption is based on engineering judgment and review of available data on potential leak mechanisms at the Hanford Site (WHC-EP-0722) and failures of similar waste tanks at the Savannah River Site (DP-1358). Review of Hanford Site past tank leaks at tank T-106 (WHC-EP-0332) and tank SX-115 (BNWL-CC-701) indicate that tank leak area can be localized. An assumed leak area equal to 25% of the tank base area is considered appropriate given that tank S-102 has not leaked in the past. If a leak were to occur during waste retrieval the most likely reason for tank failure would be corrosion of the tank steel liner. If corrosion-related failure of the steel liner were to occur it would likely occur at multiple sites throughout the tank. This and the assumption that two probable leak paths out of the concrete tank shell are near the outer edge of the tank base supports the assumption of uniform leakage around the perimeter of the tank base. The two probable leak paths out of the concrete shell are (1) through the construction joint where the tank sidewall meets the base or (2) through cracking in the tank base along the outer edge resulting from vertical loads imposed by the tank sidewall.

Leak loss, if it occurs, will be proportional to retrieval time. The current schedule used as a planning basis for waste retrieval has recently been updated to reflect the strategy of using tank S-102 for technology demonstration for fluidic mixing. Table B.3.2 identifies the current waste retrieval schedule from the 2000 retrieval sequence update (RPP-7087). The start date and duration indicate the time over which the tank is assumed to leak.

Table B.3.2. Retrieval Schedule for Tank S-102

Tank	Start Date	Duration (days)
241-S-102	1/3/2006	168

Source: RPP-7087.

The concentration of CoCs in leak loss was developed using the current BBI (Hale 2001) and tank-specific wash factors (HNF-3157). The amount of water required to retrieve the waste is estimated using waste transfer constraints for both 5 molar sodium and 10 wt% solids in the retrieved slurry. The larger of the calculated water volumes is then used to calculate the concentration of individual contaminants in the retrieval liquid. The resulting concentrations multiplied by the retrieval leak loss volume provides the retrieval leakage inventory for the individual waste retrieval cases.

B.3.3.3 Residual Waste Estimates

The contaminants that would remain in the tanks after waste retrieval constitute the residual waste inventory. Release of the residual waste is evaluated assuming that the integrity of a tank degrades over a period of 500 years after which recharge water from infiltrating precipitation is assumed to enter the tank, dissolve the residual waste, and drain out into the surrounding vadose zone through cracks in the tank.

The starting point for calculating residual waste inventories is the BBI estimates for each tank. BBI estimates are derived from the best data sources available. These sources include sample results, model output, historical waste transfer logs, engineering judgments, and calculations.

Two methods were used to develop residual waste inventory estimates for the S farm tanks, based on retrieval assumptions. For tank S-102, the retrieval method is either not expected to agitate the existing sludge or may have only localized agitation of the sludge. Consequently, wash factors (HNF-3157) were not applied to the existing sludge before mathematically reducing the heel volume. Other tanks in the S farm were assumed to undergo thorough mixing of the existing sludge with retrieval fluids, and wash factors were applied to the sludge prior to mathematically reducing the sludge heel volume. These methods are similar to calculation methods used and uses the same starting data currently used by the Hanford tank waste operation simulator model to simulate all of the tank farm waste retrieval operations from waste retrieval. Calculation details are found in the Attachment to this appendix.

B.3.3.4 Ancillary Equipment Inventory

The contaminant inventory currently in the abandoned S tank farm ancillary equipment is of interest in calculating the total long-term impacts from the tank farm under a landfill closure type scenario. This inventory would add to the inventory remaining in the tank farm from tank residuals and contaminated soils and would contribute to the closure source term. There is currently insufficient data available to develop a reasonable estimate basis for the contaminant inventory in the ancillary equipment; therefore, an estimate of this inventory was not developed for this RPE. This is believed to be reasonable for this scoping-level RPE because of the following.

- The ancillary equipment inventory will likely be relatively small in comparison to the residual waste inventory remaining in the tanks following retrieval.
- This RPE is targeted at establishing retrieval requirements for initiating waste retrieval efforts in the S tank farm. Future updates to the RPE will allow additional information to be incorporated as it becomes available (e.g., ancillary equipment inventory, actual residual waste inventories, leak loss estimates).
- The risk allocation methodology provides for balancing the risk from an individual tank within the context of the tank farm and the ancillary equipment inventory can be accommodated as one of the other sources in the tank farm.

B.3.4 SHORT-TERM HUMAN HEALTH RISK

The intent of the short-term human health risk analysis is to estimate the potential health impacts from both accident and normal (nonaccident) conditions resulting from various tank residual scenarios for the S tank farm during waste retrieval activities. The analysis identifies the spectrum of potential accidents associated with construction and operation activities. The hazards associated with these activities include potential occupational hazards resulting in physical trauma, radiological exposure resulting in latent cancer fatalities (LCFs), and toxicological exposure resulting in toxic or corrosive health effects. Initiating events that could result in hazardous health effects may include natural phenomena, human error, component failure, and spontaneous reactions. Health risks during normal conditions include anticipated exposure to radiation fields and radiological and chemical releases to the atmosphere during normal waste retrieval activities.

All waste retrieval cases in this evaluation assume that an enhanced RCRA Subtitle C barrier will be constructed over the S tank farm for closure. Because the short-term human health risk associated with closure activities would be common to all the cases it would not be a good differentiator and is therefore not evaluated.

Retrieval leak losses are assumed to occur at or near the base of a tank. It is not anticipated that the subsurface leaks at the base of a tank would result in an atmospheric release (in the short-term) nor would the ionizing radiation have an appreciable health risk to the workers. While it may be possible that retrieval leaks could result in atmospheric release of volatile compounds, such releases are not likely to contribute significant risk given the depth of the release and the low volatile content of the tank waste. For this reason the short-term human health risk from retrieval leak loss is not evaluated.

B.3.4.1 Occupational Injuries, Illnesses, and Fatalities

The number of injuries, illnesses, and fatalities resulting from waste retrieval activities is calculated based on currently available incidence rates applicable to waste retrieval activities. The number of injuries, illnesses, and fatalities from construction or operations is calculated by multiplying the total person-years required to support the activity by the incidence rates.

B.3.4.2 Radiological Risk from Accidents

Radiological risk is expressed as the number of LCFs resulting from accidents in which people are exposed to radiation fields or radiological constituents released to the atmosphere. The probability of an accident occurring also is evaluated. The methodology used to identify and quantify radiological risk from accidents involves the following steps.

Step 1. Accident identification. Potential hazards associated with retrieval activities will be identified from existing preliminary hazard analyses and other safety documents. The hazards will be reported in a tabular format showing, for each accident, the barriers within the facility that prevent or mitigate the consequences of the accident, a rough estimate of the magnitude of

consequences of the accident assuming that the listed preventive barriers fail, and the estimated likelihood of the accident occurring.

Step 2. Accident strategy selection. The accident with the highest risk will be screened for further analysis to determine, as accurately as possible, the consequences and probability of occurrence. The risk of a given accident is the product of the consequences of the accident and the estimated likelihood of the event occurring. Screening for the highest-risk accidents follows the same methodology as outlined in Section 3.3.2.3.5 of *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports* (DOE-STD-3009-94).

Step 3. Accident sequence quantification. The frequency of occurrence of the selected accidents is taken from referenced documents where available. Where accident frequencies are not available they are estimated.

Step 4. Source term development. The source term is the respirable fraction of inventory from which the receptor dose is calculated. The source term is developed based on the inventory that could be released to the environment from an accident. The major reduction factors that control the source term are considered in the evaluation. The reduction factors will include damage ratios, airborne release fractions, airborne release rates, leak path factors, and respirable fractions. Use of the reduction factors will be dependent upon the nature of the accident (i.e., energy of accident at impact, waste form, and effectiveness of mitigating barriers). Exposure resulting from direct exposure to radiation under accident conditions also is evaluated. Direct exposure is the direct gamma radiation dose rate to a receptor.

Step 5. Atmospheric Dispersion Coefficients. The atmospheric dispersion coefficient (χ/Q) values are generated using the GXQ computer code following the methodology outlined in *Atmospheric Dispersion Models for Potential Accident Consequence Assessment at Nuclear Power Plants* (NUREG 1.145). The meteorological data used by the GXQ code is in the form of joint frequency tables. The joint frequency data used are taken from data collected at the Hanford Site meteorology tower in the 200 West Area (Figure B.2.3). The atmospheric dispersion coefficient values are used in equations to calculate the radiological dose experienced by the noninvolved worker and general public receptors as a result of inhaling radioactive materials. Ingestion of radioactive materials also will be included for the general public receptor dose.

Step 6. Receptor determination. Potential health effects from radiological exposures are estimated for three subsets of populations and maximally exposed individuals (MEIs) in those populations. The dose to a receptor depends on the location of the receptor relative to the point of release of the radioactive material. The involved workers are those involved in the proposed action and are performing work at the facility. Those workers are assumed to be in the center of a 10 m (33 ft) radius hemisphere where the airborne released material has spread instantaneously and uniformly. The noninvolved workers are those that would be on the Hanford Site but not involved in the action. Those workers are assumed to extend from 100 m (330 ft) out to the Hanford Site boundary. The general public is assumed to be located at the Site boundary to a distance of 80 km (50 mi) from the point of release. The Hanford Site boundary used in the analysis is the adjusted Site boundary that excludes areas designated as part of the Hanford Reach

National Monument (65 FR 7319). Those areas include the North Slope, the Hanford Reach of the Columbia River, and the Fitzner-Eberhardt Arid Lands Ecology Reserve. The Site boundaries are as follows:

- North: Columbia River, 0.4 km (0.25 mi) south of the south river bank
- East: Columbia River, 0.4 km (0.25 mi) west of the west river bank
- South: A line running west from the Columbia River, just north of the Energy Northwest leased area, through the Wye Barricade to Highway 240
- West: Highway 240 and Highway 24.

Step 7. Radiological dose assessment. The inventory involved in each accident is evaluated to determine the activity concentrations. The activity concentrations are converted to unit liter dose, or gram, factors. The GENII computer code (PNL-6584) is used to generate a single unit liter dose factor for each composite source term for a 70-year dose commitment period. The receptor doses are given in terms of committed effective dose equivalents. The unit liter dose factors are used with the appropriate atmospheric dispersion coefficient and the source term to determine the radiological dose to the involved worker, noninvolved worker and general public receptors.

Step 8. LCF risk development. The likelihood that a dose of radiation would result in a fatal cancer at some future time is calculated by multiplying the receptor dose by a dose-to-risk conversion factor. Conversion factors are predictions of health effects from radiation exposure. The dose-to-risk conversion factors used for estimating LCFs from low doses of radiological exposure and from high doses are consistent with those taken from *1990 Recommendation of the International Commission on Radiological Protection* (ICRP 1991). They are summarized as follows.

- **Involved worker and noninvolved worker**. 4.0×10^{-4} LCF/rem for low doses less than 20 rem and 8.0×10^{-4} LCF/rem for doses greater than or equal to 20 rem.
- **General public**. 5.0×10^{-4} LCF/rem for low doses less than 20 rem and 1.0×10^{-3} LCF/rem for doses greater than or equal to 20 rem. The dose-to-risk conversion factors for the general public accounts for the presence of children.

B.3.4.3 Chemical Exposure from Accidents

Potential acute hazards associated with exposure to concentrations of postulated accidental chemical releases are evaluated using a screening-level approach for the receptors. This involves directly comparing calculated exposure point concentrations of chemicals to a set of Hanford Site-specific air concentration screening criteria known as emergency response planning guidelines (ERPGs) (Dentler 1995). The ERPGs, as developed by the American Industrial Hygiene Association, are specific levels of chemical contaminants in air designed to be protective of acute adverse health impacts for the general population. The ERPGs are defined as follows.

- **ERPG-1** – The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse effects or perceiving a clearly defined objectionable odor.

- **ERPG-2** – The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their ability to take protective action.

- **ERPG-3** – The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

Determining the accidents to be used in the analysis, the source term, atmospheric dispersion coefficients, and the receptor location follows the same methodology as applied to radiological risk from accidents.

B.3.4.4 Radiological Latent Cancer Facility Risk from Routine Exposure

Involved worker exposure is a combination of exposure from inhalation and direct radiation. Involved worker dose rates are estimated based on time, distance, and shielding considerations associated with the various tasks. Noninvolved workers and general public exposure are estimated by determining the expected routine radiological releases during retrieval and closure. Exposure to the noninvolved worker is assumed to be from inhalation and external radiation from the plume continuously throughout the year and from deposition of radionuclides on the ground. The exposure pathways for the general public are assumed to be inhalation, external exposure from submersion in a plume, and ingestion of contaminated farm products. The involved workers are assumed to be located in the radiation zone. The noninvolved worker population is assumed to be located 100 m (330 ft) from the point of release out to the Hanford Site boundary. The general public population includes people located within 80 km (50 mi) of the Hanford Site boundary.

The GENII computer code (PNL-6584) is used to calculate the dose. The LCF risk is then calculated by multiplying the receptor dose by a dose-to-risk conversion factor (ICRP 1991).

B.3.4.5 Chemical Hazards from Routine Exposure

The nonradiological chemical intake (dose) is estimated for the involved worker, noninvolved worker, and general public according to the U.S. Environmental Protection Agency (EPA) methodology used in DOE/RL-98-72.

To estimate the potential noncarcinogenic effects from exposure to multiple chemicals, the hazard index approach is used consistent with the EPA methodology that was used in DOE/RL-98-72. The hazard index is defined as the summation of the hazard quotient (calculated dose divided by the reference dose) for each chemical and route of exposure. A total hazard index less than or equal to 1.0 is indicative of acceptable levels of exposure.

The potential carcinogenic or incremental lifetime cancer risk (ILCR) (i.e., the cancer risk from fatal and nonfatal cancers) from exposure to carcinogenic chemicals is calculated by multiplying the cancer slope factor for each chemical by the exposure intake of each chemical. Carcinogenic risk is assumed to be additive and is estimated by summing the upper-bound incremental cancer risk for all carcinogenic chemical emissions. Federal and State regulatory action levels require that ILCR be kept below 1×10^{-4} and 1×10^{-5}, respectively.

B.3.5 GROUNDWATER IMPACTS

Contaminant releases from the S farm tanks were modeled using a two-dimensional, cross-sectional model of the vadose zone and a portion of the underlying aquifer. The lateral extent of the cross-sections was fence line to fence line, the east-west boundaries of the S tank farm. The cross-section containing tank S-102 (referred to as the S-101 cross-section) passes through the centerline of tanks S-101, S-102, and S-103. These three tanks are located along an east-west line at the north end of the S tank farm. The S-101 cross-section was the primary focus for determining tank-specific long-term performance measures for tank S-102. Three additional cross-sections were also modeled to evaluate the performance of tank S-102 within the context of the S tank farm. Vertically, the cross-sections extend from ground surface downward completely through the vadose zone and include the upper 5 m (16 ft) of the aquifer. Each contaminant source term (i.e., past leak, retrieval leakage, and residual waste) was modeled separately. The period of interest is from January 1, 2000 to January 1, 12000 for an overall period of 10,000 years.

The deterministic approach taken in this document is based on the approach that was developed for concurrent RCRA facility investigation/corrective measures study investigations at the S tank farm, which adopted reasonably conservative best-estimate parameter values. The data on which the deterministic calculations are based are summarized in *Modeling Data Package for S-SX Field Investigation Report (FIR)* (RPP-6296). The means by which contaminants are transported in the vadose zone and groundwater are the same for all 10 waste retrieval cases analyzed. Assumed recharge rates; geologic stratigraphy; structure (i.e., clastic dikes); hydrogeologic properties; and contaminant transport properties are developed in RPP-6296.

Individual calculations (i.e., numerical model simulations) were performed in the S-101 cross-section evaluation for retrieval leak losses and residual waste. There were no past tank releases to consider for the S-101 cross-section because none of the three tanks in the cross-section are known to have leaked. Impacts from the tank S-104 past leak were included as part of the evaluation of composite impacts from potential releases from all tanks in the S tank farm. The contaminant flux through the vadose zone from each of the two sources enters the underlying aquifer and moves in an easterly direction at a prescribed gradient. Contaminant concentrations in the aquifer are then determined at the easterly tank farm boundary (fence line) as the average concentration in the 5 m (16 ft) aquifer thickness.

The CoCs for this RPE are largely consistent with those used in DOE/RL-98-72. These CoCs are as follows:

- **Radionuclides**: carbon-14, selenium-79, technetium-99, iodine-129, and the uranium series

- **Chemicals**: nitrite, nitrate, chromium, and uranium.

This CoCs subset was selected for inclusion in DOE/RL-98-72 based on a screening analysis that indicated these constituents would be highly mobile in the vadose zone and groundwater and would contribute approximately 95% of the total groundwater pathway long-term human health risk. Chromium has been identified as a CoC in the RCRA facility investigation/corrective measures study process and is included as a CoC for this analysis.

The concentrations of three contaminants were calculated with the flow and transport model. These were technetium-99, nitrate, and uranium-238. The concentration of the remaining CoCs (selenium-79; iodine-129; carbon-14; chromium; nitrite; and uranium-234, -235, and -236) were then estimated by scaling the calculated concentrations to the ratio of the inventory for each source term.

As described in RPP-6296, the approach to assessing the groundwater impacts for releases from the cross-section began with developing a vadose zone and saturated zone conceptual model and associated assumptions based on best available data and analysis. This conceptual model was then expressed numerically based on the best available data and information. After this step, the migration of contaminants through the vadose zone and the underlying aquifer to the east fence line of the tank farm were calculated for the 10 waste retrieval cases.

The STOMP numerical model (PNNL-12028) was used to implement the calculation of flow and transport in the vadose zone and saturated zone. All simulations were comprised of steady-flow and transient components, where flow fields developed from steady-flow components were used to initialize the transient simulations. The characteristics of the two source terms (i.e., retrieval losses and residual waste) were made a part of the model inputs. These characteristics include the mass and solubility of the contaminants, their locations within the model domain, and timing of their release. The two source terms were evaluated separately so that the impact of each could be readily determined. Based on the principle of superpositioning, the source terms were then added to form composite time-versus-concentration curves.

B.3.6 LONG-TERM HUMAN HEALTH RISK

This section describes the methodology used for assessing long-term human health risk. The approach for this risk assessment is consistent with the overall RPE approach established in DOE/RL-98-72. The primary objectives of the long-term human health risk assessment for this RPE are as follows:

- Support the development of risk-based retrieval performance criteria for the tank S-102 waste retrieval system (i.e., retrieval leakage and residual waste volume limits)

- Provide the basis for the design criteria for the tank S-102 LDMM systems.

Long-term human health risk refers to the risk of health effects to a hypothetical future site user from exposure to tank waste contaminants remaining onsite following the completion of waste retrieval and tank farm closure actions. Groundwater is considered the principal pathway (excluding inadvertent intrusion) for post-remediation human exposure to tank waste at compliance points outside of the tank farm boundary. The exposure pathways used in this assessment are therefore based on withdrawal and use of groundwater via wells.

B.3.6.1 Source Term

The waste retrieval cases evaluated for this RPE are similar to the release scenarios evaluated in DOE/RL-98-72 and include a single best-basis past leak release and retrieval leakage and residual waste release variations. A common closure endstate is assumed for all cases (i.e., stabilized tank and enhanced RCRA Subtitle C barrier).

Multiple release cases are not of interest for the past leak source term because the long-term human health risk from S farm past leaks will not be affected by waste retrieval systems performance. In contrast, multiple release scenarios *are* of interest for the retrieval leakage and residual waste source terms because those variations provide the data needed to develop relationships between risk and volume. The risk-to-volume relationships are the basis for determining risk-based retrieval performance criteria (i.e., volume limits for retrieval leakage and residual waste).

Because the regulatory unit for closure decisions is the tank farm and not the individual tank, impacts need to be understood within the context of S tank farm impacts. Source inventories are therefore developed for all tanks in the S farm. Source inventories are estimated individually for the past leak, retrieval leakage, and residual waste source terms. Source inventories are developed by estimating contaminant-specific source concentrations and then multiplying by the source volumes of interest. Source concentrations are assumed not to vary with variations in release volume. Discussion of source term inventory development is provided in Section B.3.3.

B.3.6.2 Contaminant Transport

Following release from the source, contaminants would travel through the vadose zone and into the unconfined aquifer. Once in the aquifer, contaminants would travel with the regional groundwater flow toward the Columbia River. A vadose zone and groundwater contaminant transport analysis was performed using the methodology described in Section B.3.5. Results of the analysis provide groundwater CoC concentrations at the S tank farm boundary over a 10,000-year assessment period.

To support the development of tank-specific retrieval performance criteria, a range of waste retrieval cases were analyzed. The cases analyzed were selected in part to ensure that the resulting long-term risk data would be sufficient to bracket a range of regulatory action thresholds (e.g., the 1×10^{-4} federal and 1×10^{-5} state criteria for excess lifetime cancer risk).

B.3.6.3 Exposure

The principal receptor scenarios used for this RPE are taken from *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement* (DOE/EIS-0189) analysis and include the residential farmer and industrial worker scenarios. Both scenarios were adapted for use in DOE/EIS-0189 from scenarios described in *Hanford Site Risk Assessment Methodology* (DOE/RL-91-45). Both scenarios involve multi-pathway groundwater exposures based on hypothetical future land uses and activities.

The residential farmer scenario represents exposures associated with the use of the land for residential and agricultural purposes. This scenario is a slight modification to the residential scenario described in DOE/RL-91-45; it includes all of the exposure pathways for the residential scenario plus most of the food ingestion pathways described in the DOE/RL-91-45 agriculture scenario. The residential farmer scenario includes using groundwater for drinking water (ingestion rate of 2 L/day [0.5 gal/day]) and other domestic uses as well as for irrigation to produce and consume animal, vegetable, and fruit products. The exposures are assumed to be continuous and include occasional shoreline-related recreational activities, which include contact with surface water sediments. A composite adult is used as the receptor for some of the exposure pathways. The composite adult is evaluated using child parameters for 6 years and adult parameters for 24 years, with total exposure duration of 30 years. Body weights of 16 kg (35 lb) for a child and 70 kg (150 lb) for an adult and a lifetime of 70 years are assumed.

The industrial worker scenario represents exposures to workers in a commercial or industrial setting. The receptors are adult employees assumed to work at a location for 20 years. A body weight of 70 kg (150 lb) and a lifetime of 70 years are assumed. The scenario involves mainly indoor activities, although outdoor activities (e.g., soil contact) also are included.
The groundwater exposure pathways for this scenario include drinking water ingestion (1 L/day [0.2 gal/day]), dermal absorption during showering, shower-water ingestion, and inhalation. These exposures would not be continuous because the worker would go home at the end of each work day (i.e., after eight hours). The scenario is intended to represent nonremediation workers assumed to wear no protective clothing.

Analysis of the state of Washington "Model Toxics Control Act" (MTCA) Method B and Method C exposure scenarios (WAC 173-340-720) is also included in this RPE to allow for comparison to risks being assessed for past tank leaks and releases at SST WMAs under the RCRA Corrective Action Program (DOE/RL-99-36). The MTCA risk assessment criteria apply only to nonradioactive contaminants. Method B and Method C exposure scenarios essentially assume unrestricted and restricted use of groundwater, respectively, and are based on ingestion of drinking water (with an inhalation correction factor for volatile chemicals).

It is important to note that all of the scenarios require an assumption that groundwater wells are drilled at the downgradient S tank farm boundary and used as a water supply for the receptors.

B.3.6.4 Risk

Long-term human health risk is calculated for this RPE using a unit risk factor (URF) approach consistent with the approach used for the DOE/EIS-0189 and DOE/RL-98-72 analyses. A URF is the risk associated with exposure to one concentration unit (e.g., risk per pCi/L for radionuclides in groundwater) of a given contaminant in a given exposure medium for a given human exposure scenario. Risk is calculated in the URF approach as the product of the URF and the contaminant concentration at the receptor for the exposure medium of interest. In developing retrieval performance criteria, the contaminant concentration values used are the peak groundwater CoC concentrations at the S tank farm boundary. The URF values used for this analysis are contaminant- and scenario-specific groundwater URFs taken from Appendix D of DOE/EIS-0189. The URFs for the residential farmer and industrial worker scenarios are listed in Table B.3.3. The human health impact measures given by the URFs are ILCR for radionuclides and carcinogenic chemicals, and hazard index for noncarcinogenic chemicals. ILCRs differ from LCFs in that ILCRs are total cancers (nonfatal and fatal) and LCFs are fatal cancers.

Table B.3.3. Groundwater Pathway Unit Risk Factors

Constituent	Units	Industrial Worker[a]	Residential Farmer[b]
C-14	ILCR per Ci/mL	5.23E+06	6.06E+08
I-129	ILCR per Ci/mL	9.33E+08	1.29E+10
Se-79	ILCR per Ci/mL	3.22E+07	2.87E+08
Tc-99	ILCR per Ci/mL	7.11E+06	2.61E+08
U-233	ILCR per Ci/mL	3.03E+08	1.38E+09
U-234	ILCR per Ci/mL	3.00E+08	1.34E+09
U-235	ILCR per Ci/mL	2.98E+08	1.37E+09
U-236	ILCR per Ci/mL	2.85E+08	1.27E+09
U-238	ILCR per Ci/mL	2.84E+08	1.28E+09
NO2	Hazard quotient per g/mL	9.92E+03	3.73E+04
NO3	Hazard quotient per g/mL	6.20E+03	7.59E+06
Cr	Hazard quotient per g/mL	3.31E+06	1.14E+07
U (Total)	Hazard quotient per g/mL	3.52E+06	1.41E+07

[a]Source = DOE/EIS-0189, Appendix D, Tables D.2.1.21 and D.2.1.23.
[b]Source = DOE/EIS-0189, Appendix D, Tables D.2.1.18 and D.2.1.20.

ILCR = incremental lifetime cancer risk.

The basic expression for risk using a URF approach is:

$$R_{S(x,y,t)} = \sum C^{i}_{S(x,y,t)} \cdot URF^{i}_{R} \qquad \text{Eq. B.1}$$

Where:

$R_{S(x,y,t)}$ = risk from source term S at point of compliance x,y,t

$C^{i}_{S(x,y,t)}$ = groundwater concentration at point of compliance x,y,t for contaminant i released from source term S

URF^{i}_{R} = groundwater URF for contaminant i and receptor scenario R

x,y = horizontal location coordinates

t = time.

The summation in Equation B.1 represents addition of the contributions from all CoCs in a given source term. The hazard quotient from each non-carcinogenic chemical CoC is summed to give a total hazard index while the ILCR from each carcinogenic chemical CoC and radionuclide CoC

is summed to give a total ILCR. The addition of contributions from the past leak, retrieval leakage, and residual waste source terms gives the composite risk for a given tank. The addition of composite risks for all tanks gives the composite risk for the tank farm.

Equation B.1 is used to calculate human health risk for all release cases included in the contaminant transport analysis. Additional cases for retrieval leakage and residual waste volumes intermediate to those included in the modeling runs are likely to be of interest for establishing risk-to-volume relationships. For these cases, risks are estimated by interpolation using a linear approximation.

Risk-based retrieval performance criteria (i.e., retrieval leakage limits and extent of retrieval requirements) are developed by plotting the peak human health risk values calculated for the various release scenarios against either retrieval leakage volume or residual waste volume. The risk values plotted can be either source-term specific or composite values. Plots using tank-specific risk and volume data are of interest because they provide the primary basis for determining retrieval performance criteria for tank S-102. Plots using risk and volume data for the entire S tank farm are also of interest because they provide a sense of how quickly the S tank farm risk performance will change with departure from the baseline retrieval leakage and residual waste assumptions. The overall objective is to provide a range of combinations of residual waste volume and retrieval leak loss volume that would allow the tank S-102 composite risks to maintain compliance with certain risk-based regulatory standards.

B.3.6.5 Risk Allocation

To evaluate retrieval leakage within the context of tank farm risk, a risk allocation method is used. The methodology used involves selection of a risk threshold (i.e., 1×10^{-5}) and developing a risk budget for retrieval leakage. The methodology includes the following steps:

- Calculate the risks on a tank farm basis from past leaks and spills
- Calculate the risk budget for the tank farm by subtracting the risk from past leaks from the risk threshold
- Calculate a risk budget for tank S-102 by apportioning the tank farm risk budget by the fraction of the S tank farm waste volume contained in tank S-102.

Tank S-102 currently contains 1.86 million L (492,000 gal) of waste (HNF-EP-0182, Rev. 150). The S tank farm currently has 19.2 million L (5.09 million gal) of waste. Therefore, tank S-102 contains 9.6 % of the waste in the S tank farm. Using this methodology, the risk budget for tank S-102 is equal to 9.6 % of the tank farm risk budget.

B.3.7 INTRUDER RISK

The methodology used for assessing impacts to an inadvertent human intruder is consistent with the approach used in DOE/RL-98-72. The intruder analysis addresses tank S-102 impacts only. The purpose of the intruder risk assessment is to support an analysis of compliance requirements and waste classification issues related to tank S-102 waste retrieval and tank farm closure. Impacts to an intruder are examined based on scenarios and requirements established in DOE regulations (DOE O 435.1; Frei 1996) and NRC regulations (10 CFR 61) related to LLW disposal.

B.3.7.1 U.S. Department of Energy Intruder Scenario

DOE demonstrates protection of an inadvertent human intruder through site-specific performance assessments using a 100 mrem/yr chronic dose standard and a 500 mrem acute dose standard (DOE O 435.1). The scenarios used in this RPE are consistent with those used in DOE/RL-98-72 and are based on the intrusion model in *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Burial Grounds* (WHC-EP-0645). Well driller and post-drilling resident scenarios are used. These scenarios were selected based on their applicability to the deep contamination sources (i.e., soil contaminated by retrieval leak loss and tank residual waste) involved in this analysis.

Contaminant transport is not considered for this analysis. Contaminants are assumed to be exhumed during well drilling and spread over the surface of certain land areas. The intruder receives radiation exposures because of proximity to and use of these contaminated surface areas. Exposures are calculated using unit dose factors. The analysis considers radionuclide contaminants only. The radionuclides used are consistent with those used for the DOE/RL-98-72 analysis. These radionuclides were selected because their half-lives are greater than five years and they have been shown in past performance assessments to dominate intruder doses (DOE/EIS-0189).

The source is calculated as the total activity in curies of each constituent exhumed and made available at the surface. The well is assumed to be drilled through the residual waste in tank S-102 and into the underlying soil column down to the aquifer. The source is calculated based on the tank S-102 residual waste volumes and the contaminated soil from retrieval leakage. The source (Ci_{exh}) from tank S-112 and tank S-102 is calculated using the following equation:

$$Ci_{exh} = Ci_{tnk} \cdot \left[r_{well} \div r_{tnk}\right]^2 \qquad \text{Eq. B.2}$$

Where:

Ci_{tnk} = total activity of each radionuclide of concern in tank S-102
r_{well} = radius of the well or 0.15 m (0.5 ft)
r_{tnk} = radius of tank S-102, or 11.4 m (37.5 ft).

The source activity (Ci) is then multiplied by a unit dose factor (mrem/yr/Ci) for each receptor (well driller and post-drilling resident) to produce the receptor dose (mrem/yr). Unit dose factors

are calculated for a unit activity (Ci) for each constituent based on the exposure conditions defined for each receptor. The well driller dose is from 40 hours of external exposure to the exhumed contaminants. The following is assumed of post-drilling resident:

- Lives on a 2,500 m^2 (0.62 ac) parcel of land over which the exhumed waste has been spread
- Grows a variety of vegetables on the land
- Obtains 25% of total vegetables consumed from this garden.

The post-drilling resident ingests small amounts of contaminated soil each day (100 mg/day [0.004 oz/yr]) and the total ingestion is 37 g/yr (1.3 oz/yr). The annual inhalation and external exposures are based on the post-drilling resident spending 1,800 hours in the garden and 4,380 hours in the house. The remaining 2,580 hours are spent elsewhere away from the intruder site.

Table B.3.4 presents the unit dose factors for each radionuclide of concern in the exhumed waste under the previously listed exposure conditions for the well driller and post-drilling resident scenarios. These dose factors are calculated using the GENII computer code (PNL-6584) and are the same as those used in DOE/EIS-0189. The unit dose factors are calculated for 100 years from tank closure, corresponding to the time of assumed loss of institutional control. Total dose for each receptor is calculated as the sum of the doses from each radionuclide.

Table B.3.4. Intruder Scenario Unit Dose Factors at 100 Years from 1998

Radionuclide	Dose Factor	
	Well Driller (mrem per Ci exhumed)	Post-Drilling Resident (mrem/yr per Ci exhumed)
Strontium-90	6.93E-01	8.42E+01
Tin-126	2.13E+03	6.93E+03
Cesium-137	6.13E-01	2.03E+02
Plutonium-238	8.29E+01	2.82E+02
Uranium-238	5.49E+01	2.15E+02
Plutonium-239	2.04E+02	6.96E+02
Plutonium-240	2.00E+02	6.91E+02
Americium-241	1.01E+03	3.27E+03
Plutonium-241	6.42E+00	2.21E+01

B.3.7.2 U.S. Nuclear Regulatory Commission Intruder Scenario

The current Hanford Site planning basis assumes that once HLW has been retrieved from a tank the residual waste would be classified as incidental waste (i.e., non-HLW) and thus not be

subject to NRC licensing authority. The residual waste would then be disposed of in place as LLW in accordance with the requirements of DOE O 435.1. The NRC has proposed using several criteria for making incidental waste determinations for DOE HLW tank closure. One of these criteria is that the residual waste be incorporated in a solid form at concentrations that do not exceed Class C LLW limits.

The NRC divides LLW into four classes and sets different disposal requirements for each class (Class A, Class B, Class C, and Greater Than Class C). Class C LLW has the most stringent disposal requirements for near-surface burial. Greater Than Class C waste requires special disposal methods and approval from the NRC on waste form and disposal configuration. The NRC uses the Class C upper concentration limits for individual radionuclides to determine waste classification and demonstrate protection of an inadvertent human intruder. The NRC derived the Class C concentration limits based on calculated doses to an inadvertent human intruder. The Class C upper limits are the waste concentrations that would not exceed either a 500 mrem radiation dose to the whole body or bone or a 1,500 mrem dose to other organs under an intruder construction or agriculture scenario (SAND98-2104). The Class C upper concentration limits are provided in Table B.3.5.

Table B.3.5. Class C Low-Level Waste Upper Concentration Limits

Long-lived Radionuclides	Class C Upper Limits	Short-lived Radionuclides	Class C Upper Limits
Carbon-14	8 Ci/m^3	Nickel-63	700 Ci/m^3
Carbon-14 in activated metal	80 Ci/m^3	Nickel-63 in activated metal	7,000 Ci/m^3
Nickel-59 in activated metal	220 Ci/m^3	Strontium-90	7,000 Ci/m^3
Niobium-94 in activated metal	0.2 Ci/m^3	Cesium-137	4,600 Ci/m^3
Technetium-99	3 Ci/m^3		
Iodine-129	0.08 Ci/m^3		
Alpha emitting transuranic with $t_{1/2} > 5$ yr	100 nCi/g		
Plutonium-241	3,500 nCi/g		
Curium-242	20,000 nCi/g		

Source: 10 CFR 61.

To determine the waste classification for the residual waste in tank S-102 and to demonstrate protection of the inadvertent human intruder, the residual waste concentrations are compared with the concentration limits shown in Table B.3.5. Because the residual waste will contain multiple radionuclides, the sum-of-fractions for the individual radionuclides is used.

The grout-averaging approach involves calculating contaminant concentrations assuming the residual tank waste is stabilized using in-tank grouting. The grout is assumed to be uniformly mixed with the residual waste and the concentration of the combined residual waste and grout is used in estimating the solidified waste concentration. Consistent with the approach used for the

DOE/RL-98-72 analysis, the amount of grout that would need to be added to tank S-102 to allow the residual waste to meet the Class C limits is estimated using the methods of *Regulatory Closure Options for the Residue in the Hanford Site Single-Shell Tanks (SSTs)* (SAND98-2104) for each of the residual waste cases analyzed.

B.3.8 REGULATORY COMPLIANCE

Hanford Site tank waste and SST and DST facilities are regulated through the federal RCRA, the Washington State HWMA, and their implementing requirements. The Washington State Department of Ecology (Ecology) is authorized to implement HWMA requirements in lieu of federal program requirements pursuant to RCRA. EPA retains authority for oversight of the state hazardous waste program and for elements of RCRA not yet authorized. Regulatory requirements applicable to Hanford Site tank wastes and tank waste systems include, but are not limited to, those specifying requirements for waste designation, permitting, storage, treatment, disposal, response to releases, and site closure (Fitzsimmons and Clarke 2000).

Regulations that may affect waste retrieval performance issues are addressed in this report. The methodology is to:

- Identify the potentially applicable regulations
- Develop a list of quantitative and qualitative performance measures
- Compare strategy and option performance against the measures
- Develop conclusions regarding ability of strategies to comply
- Refine performance measures based on regulations, analyses, and conclusions
- Identify data needs and uncertainties to support future analysis and decision making.

Statutory, regulatory, and permit requirements relevant to the retrieval and disposal of tank waste, contaminated soils, as well as tanks and ancillary equipment are described in Section B.3.8.1. The regulatory compliance of the tank S-102 waste retrieval approach is addressed in Section B.3.8.2.

B.3.8.1 Relevant Regulations and Requirements

Relevant federal and state statutes and regulations are addressed in the following sections.

B.3.8.1.1 Federal Statutes and Regulations. Table B.3.6 summarizes federal requirements that may apply to waste retrieval and endstate analysis associated with establishing waste retrieval performance measures. A more complete discussion of federal regulations is provided in Appendix D of DOE/RL-98-72.

The following summary of federal statutes and regulations that affect tank waste retrieval and closure is excerpted largely from *Regulatory Closure Options for the Residue in the Hanford Site Single-Shell Tanks* (HNF-3428). Three federal entities have the majority of regulatory authority for the disposal of radioactive waste: EPA, DOE, and NRC. Each entity has codified various laws, orders, directives, guidance documents, and branch technical positions that govern the various types of radioactive waste.

EPA has the authority to write standards, DOE has authority to write and enforce standards for radioactive wastes from atomic energy defense activities, and NRC has the authority to write and enforce regulations for disposal of commercially-generated LLW and for disposal of HLW. However, regulatory authority may depend on whether the radioactive waste has yet to be disposed or the waste has already been released to the environment (e.g., a spill or leak). EPA has the lead role for writing regulations. DOE and NRC regulations and orders must be consistent with EPA standards. There are many notable exceptions to these generalizations (HNF-3428).

Nuclear energy became subject to federal regulation with the passing of the *Atomic Energy Act of 1946*. With amendments the act later became the *Atomic Energy Act of 1954*. Through the *Atomic Energy Act of 1954*, Congress gave control of the production and use of fissile materials to the Atomic Energy Commission. The *Atomic Energy Act of 1954* has been amended a significant number of times.

Table B.3.6. Relevant Federal Statutes and Regulations

Federal Statutes and Regulations	Relevance
Resource Conservation and Recovery Act	Establishes requirements for the identification, generation, treatment, transportation, storage, and disposal of hazardous waste including mixed waste.
Federal Facility Compliance Act	Requires all federal facilities (e.g., the Hanford Site) to comply with RCRA and establishes requirements for DOE facilities pertaining to mixed waste.
Atomic Energy Act	Establishes the jurisdiction of federal and state agencies to regulate radioactive materials and provides requirements for such regulations.
Nuclear Waste Policy Act	Provides for development of repositories for disposal of HLW and spent nuclear fuel.
Clean Air Act	Regulates emissions of radioactive and nonradioactive pollutants from stationary sources.
Safe Drinking Water Act	Establishes standards for drinking water and groundwater protection.
Toxic Substances Control Act	Regulates toxic chemicals, specifically PCBs and asbestos.
Clean Water Act	Regulates discharges to and quality of surface water bodies (e.g., the Columbia River).
Occupational Safety and Health Act	Regulates safe and healthful working conditions.
Comprehensive Environmental Response, Compensation, and Liability Act	Provides emergency response, reporting, and cleanup requirements for uncontrolled release of contaminants.
National Environmental Policy Act	Requires analysis of potential impacts to human health and the environment of any major federal action.

DOE = U.S. Department of Energy.
HLW = high-level waste.
PCB = polychlorinated biphenyl.
RCRA = *Resource Conservation and Recovery Act of 1976.*

When the EPA was created in 1970 by Reorganization Plan Number 3, President Nixon transferred the functions of the Atomic Energy Commission for establishing generally applicable environmental standards for the protection of the environment from radioactive materials "in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive material." Thus EPA was granted the authority to set release standards but not to implement the release standards. Later, Congress granted EPA authority to address cleanup of radioactive materials under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) to regulate air emissions of some radionuclides. Congress also asked EPA to certify DOE compliance with "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" (40 CFR 191) and "Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR 191 Disposal Regulations" (40 CFR 194) for the disposal of TRU wastes in the Waste Isolation Pilot Plant.

In 1974, the *Energy Reorganization Act of 1974* redirected federal energy efforts. The Atomic Energy Commission was abolished and replaced by the NRC and the Energy Research and Development Agency (which was later abolished and became DOE). Section 202 of the *Energy Reorganization Act of 1974* also gave the NRC licensing authority for facilities used primarily for the receipt and storage of HLW. Under this Section 202 authority NRC licenses the disposal of HLW.

The *Nuclear Waste Policy Act of 1982* established federal responsibility for the development of repositories for the disposal of HLW and spent nuclear fuel. The *Low-Level Radioactive Policy Amendments Act of 1985* established DOE responsibility for the disposal of commercially generated wastes with radionuclide concentrations exceeding the limits established in "Licensing Requirements for Land Disposal of Radioactive Waste" (10 CFR 61) for Class C LLW (i.e., Greater Than Class C LLW). These amendments require NRC to license the DOE facility for disposal of commercially-generated Greater Than Class C LLW.

NRC has regulatory responsibilities under the *Atomic Energy Act of 1954* for establishing standards for the disposal of radioactive waste. NRC has established regulations for low-level radioactive waste that can be disposed of in near-surface disposal sites (10 CFR 61) and for high-level radioactive waste requiring disposal in a geologic repository (10 CFR 60). Under authority of the *Atomic Energy Act of 1954*, EPA has promulgated standards for managing and disposing of spent nuclear fuel, HLW, and TRU waste (40 CFR 191). EPA standards for managing and disposing of LLW are not yet finalized (40 CFR 193).

The *Atomic Energy Act of 1954* authorizes DOE to establish standards to protect health or minimize dangers to life or property for activities under DOE jurisdiction. Through a series of DOE orders, an extensive system of standards and requirements has been established to ensure safe operation of DOE facilities. The most relevant of these is DOE O 435.1, which establishes requirements for managing DOE HLW, TRU waste, LLW, and the radioactive component of mixed waste.

According to definitions in *Radioactive Waste Management Manual* (DOE M 435.1), HLW is the highly radioactive waste material resulting from the reprocessing of spent nuclear fuel and other highly radioactive material that is determined to require permanent isolation. TRU waste is radioactive waste containing more than 100 nanocuries of alpha-emitting TRU isotopes per gram of waste, with half lives greater than 20 years. Low-level radioactive waste is radioactive material that is not HLW, spent nuclear fuel, TRU waste, byproduct material (as defined in Section 11e[2] of the *Atomic Energy Act of 1954*), or naturally occurring radioactive material. Therefore HLW is defined by source (i.e., spent nuclear fuel); TRU waste is defined by isotope concentration and half-life; and LLW is defined by what it is not (i.e., it is not HLW, spent fuel, TRU waste, or byproduct material).

DOE M 435.1 is organized into four chapters. Chapter I contains requirements and responsibilities applicable to all radioactive waste types and delineates responsibilities for radioactive waste management decision-making at the complex-wide and Field Element levels. Chapter II contains requirements applicable to HLW; Chapter III discusses TRU waste; and Chapter IV discusses LLW.

Chapter II of DOE M 435.1 includes a discussion of general requirements for disposal of HLW. NRC determines whether HLW resulting from reprocessing spent nuclear fuel is considered incidental to reprocessing. If it is incidental it is not HLW and is managed under DOE regulatory authority in accordance with the requirements for TRU waste or LLW, as appropriate. The NRC uses either the citation or evaluation process to determine whether spent nuclear fuel reprocessing plant waste is managed as LLW, TRU waste, or HLW. Waste incidental to reprocessing by citation includes spent nuclear fuel reprocessing plant wastes that meet the description for proposed Appendix D of "Policy Relating to the Siting of Fuel Reprocessing Plants and Related Waste Management Facilities" (10 CFR 50). These radioactive wastes are the result of reprocessing plant operations such as, but not limited to, contaminated job wastes including laboratory items such as clothing, tools, and equipment.

Determinations that any waste is incidental to reprocessing by the evaluation process must be documented. Such wastes may include spent nuclear fuel reprocessing plant wastes that will be managed as LLW and meet the following:

- Have been processed to remove key radionuclides to the maximum extent technically and economically practical
- Will be managed to meet safety requirements comprable to the performance objectives in 10 CFR 61
- Will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C LLW as set out in 10 CFR 61.55, or will meet alternative requirements for waste classification and characterization as DOE may authorize.

The waste may be managed as TRU waste and meet the following:

- Have been processed to remove key radionuclides to the maximum extent technically and economically practical
- Be incorporated in a solid physical form and meet alternative requirements for waste classification and characteristics as DOE may authorize
- Be managed pursuant to DOE's authority under the *Atomic Energy Act of 1954* in accordance with Chapter III of DOE M 435.1.

A second set of laws and guidance documents is applicable to cleanup of radioactive wastes. Of these laws, the CERCLA and the regulations created to implement the statute are the broadest. CERCLA provides EPA with authority to address releases and threatened release of hazardous substances, including radioactive wastes. The EPA CERCLA Program has created a system to designate the highest priority sites for cleanup, and those sites are National Priorities List sites. The Hanford Site is on the National Priorities List.

RCRA establishes requirements for generators and transporters of hazardous waste and also establishes a specific permit program for TSD of hazardous waste. For purposes of this report, RCRA covers the statute and all amendments including *Hazardous and Solid Waste Amendments of 1984,* the *Federal Facility Compliance Act of 1992*, and *Land Disposal Program Flexibility Act of 1996.* RCRA creates cradle-to-grave regulations for the generation, identification, transportation, and TSD of hazardous waste; RCRA imposes requirements on all persons including DOE agents that perform regulated activities. EPA regulations implementing RCRA are found at "Hazardous Waste Management System" (40 CFR 260 through 40 CFR 280).

B.3.8.1.2 Washington State Statutes and Regulations. Ecology and the Washington State Department of Health administer Washington State environmental requirements applicable to tank waste retrieval and tank farm closure actions. Those requirements are described in the following sections.

B.3.8.1.2.1 Hazardous Waste Management Act. The HWMA and its implementing regulations, "Dangerous Waste Regulations" (WAC 173-303), implement RCRA in Washington State. The HFFACO provides the framework for applying the state's requirements for dangerous waste TSD units at the Hanford Site. WAC 173-303 specifies requirements for design, permitting, operation, closure, and post-closure of dangerous and mixed waste management sites, including the tank farms. There are some differences between Washington State dangerous waste regulations and federal hazardous waste regulations. The state definition of dangerous waste includes more types of waste than does the federal definition of hazardous waste. For example, the state regulations do not exclude source, special nuclear, and byproduct material from the definition of dangerous waste (Rosenthal 1997). Washington State also designates specific types of state-only dangerous waste, including extremely hazardous waste, that is subject to more stringent regulations (Rosenthal 1997). Other differences exist between the state and federal regulations on contained-in determinations, closure, and corrective actions.

The SSTs are classified as HWMA TSD units that contain hazardous waste as defined by either the characteristics of the waste (e.g., toxicity, corrosivity) or as designated hazardous

through listing. In either case, because the SSTs contain dangerous waste, these units are managed as TSD units. Because the SSTs were in operation on the date they became subject to RCRA regulations, they were granted interim status (i.e., Part A permit) (WAC 173-303-400) to operate until Ecology determines that a final status permit must be issued (i.e., Part B permit). The SSTs do not comply with the interim status standards but continue to operate under interim status through the HFFACO. The SSTs must undergo closure and are being allowed to remain under interim status rather than being required to comply with final status standards (including final status permit). Final status post-closure permitting is a likely end-state for the SST farms.

B.3.8.1.2.2 HFFACO Requirements. The HFFACO establishes an action plan for cleanup that addresses priority actions, methods for resolving problems, and milestones. The HFFACO sets milestones to achieve coordinated cleanup of the Hanford Site and provides for the enforcement of these milestones to keep the program on schedule. In addition, the HFFACO establishes the applicability of RCRA and CERCLA and their amendments to the Hanford Site. In 2000 the HFFACO was amended to adjust near-term milestones, target dates, and associated language governing SST waste retrieval and tank farm closure activities prior to September 30, 2006 (i.e., modifications necessary to achieve compliance with federal and state hazardous waste requirements). DOE has committed to comply with requirements of the HFFACO related to management of Hanford Site tank waste and tank farm closure.

As described in the HFFACO, the agencies determined that the tanks will be closed under WAC 173-303-610 regardless of permit status. These regulations specify closure and post-closure requirements. DOE is required to submit a closure plan for the SST farms (not individual tanks) for approval by Ecology. If all of the dangerous waste cannot be removed or decontaminated, DOE will submit a post-closure work plan and a RCRA Part B permit application for Ecology approval. Upon completing the closure action for each SST TSD unit, the RCRA permit will be amended to indicate that the applicable unit has been closed (DOE/RL-89-16).

HFFACO Milestone M-45-00 declares the SSTs as unfit for use. According to WAC-173-303-640 the SSTs are deemed unfit-for-use tanks based on secondary containment and/or inability for tank integrity assessment, the tanks must be removed from service immediately, and the owner or operator must take mitigating actions. This regulation further specifies that neither dangerous wastes nor treatment reagents may be placed in a tank system if they could cause the tank, its ancillary equipment, or the containment system to rupture, leak, corrode, or otherwise fail. Therefore, additions of water and waste into SSTs are prohibited under the *Washington Administrative Code* and RCRA. However, a rationale for the addition of liquids to the SSTs can be made under the RCRA Part A permit for SSTs (DOE 1996):

> Treatment of the mixed waste in the SST system occurs when solids and interstitial liquids are separated and/or cooling liquids are added. These treatment processes involve, but are not limited to, mechanical retrieval, sluicing, and saltwell pumping of the mixed waste.

Based on past-practice sluicing operations for tank waste retrieval, water or waste has been added to enable the waste to be pumped out of a tank. DOE, EPA, and Ecology recognize the

need to remove the waste and that concessions or waivers from the regulations will be necessary to facilitate retrieval and disposal of SST waste and closure of the tank farms.

DOE has met some of the requirements for unfit-for-use tanks. After 1980 all SSTs were removed from service. Through the interim stabilization program pumpable liquids have been removed from almost all of the SSTs, and the remaining tanks will be pumped by fiscal year 2004 (DOE 1996). DOE will need to obtain from Ecology either (1) a waiver for the addition of water or DST supernate for waste retrieval on a tank-by-tank basis or (2) a universal waiver for the entire SST system.

DOE O 435.1 states that unless demonstrated to the contrary, all HLW shall be considered radioactive mixed waste and subject to the requirements of the *Atomic Energy Act of 1954* and RCRA. Hanford Site high-level radioactive tank waste contains hazardous, characteristic, and/or listed wastes under RCRA. To address potential differences between the requirements of RCRA and the *Atomic Energy Act of 1954*, DOE, EPA, and Ecology anticipate in the HFFACO that "the TSD units containing mixed waste will normally be closed with consideration of all hazardous substances, which includes radioactive constituents." However, the potential exists for conflict between the regulations for the hazardous and the radioactive components of the waste.

HFFACO Milestone M-45-00 links tank waste retrieval and tank farm closure. According to Milestone M-45-00:

> Closure will follow retrieval of as much tank waste as technically possible, with tank waste residues not to exceed 360 ft^3 in each of the 100 series tanks, 30 ft^3 in each of the 200 series tanks, or the limit of waste retrieval technology capability, whichever is less.

New requirements of the HFFACO through Change Package M-45-00-01A modify the agreement to achieve compliance with federal and state hazardous waste requirements. The near-term strategy for SST waste retrieval activities shifts from focusing on maximizing the number of tanks entered for retrieval (regardless of waste volume or content) to a focus on scheduling the retrieval of wastes from those SSTs with a high volume of CoCs. These contaminants are defined as mobile, long-lived radionuclides that have a potential of reaching the groundwater and Columbia River. The near-term strategy also focuses on the performance of key waste retrieval technology demonstrations in a variety of waste forms and tank farm locations to establish a technical base for future work. The near-term work scope focuses on the performance of risk assessments, incorporating vadose zone characterization data on a tank-by-tank basis, updating tank farm closure/post-closure work plans, and maximizing waste storage space in DSTs for waste retrieved from SSTs.

Appendix H of the HFFACO provides the SST waste retrieval criteria procedure formally agreed upon by DOE, Ecology, and EPA. Modifications to this appendix occurred during negotiations for Change Package M-45-00-01A. The modifications included defining the reference baseline waste retrieval technology as past-practice sluicing that has been conducted on tanks AX-104 and C-106, and earlier past-practice sluicing efforts. The new technology design and deployments are to measure their performance against this reference baseline technology. Appendix H provides for SST demonstration of achievability of the waste retrieval goal during

tank S-102 initial retrieval. The second phase evaluates regulatory requirements of HLW disposal from applicable rules, regulations, and DOE orders. In addition, establishment of an interface with the NRC to reach formal agreement on the retrieval and closure actions for SSTs with respect to allowable waste residuals in the tanks and soil column is to be accomplished. Collected data from the demonstration of the waste retrieval technology will assist in the preparation of input in defining the retrieval goal evaluation to accommodate the agreements on allowable residuals.

B.3.8.2 Regulatory Compliance of Waste Retrieval Approach

HFFACO Milestone M-45-05A calls for the completion of initial waste retrieval from tank S-102 using a technology (or technologies) selected based on the principal criteria of maximizing the retrieval of mobile, long-lived radioisotopes and nonradiological hazardous constituents. The goals of the initial waste retrieval project include the retrieval to safe storage of approximately 490 curies of mobile, long-lived radioisotopes and 99% of tank contents by volume per the BBI of August 1, 2000 (BBI 2000).

The HFFACO does not specify which radionuclides are considered mobile and long-lived. For purposes of this evaluation, the following CoCs are considered mobile and long-lived: technetium-99; iodine-129; selenium-79; carbon-14; and uranium-233, -234, -235, -236, and -238.

HFFACO Milestone M-45-05A calls for retrieval of 99% of tank contents by volume. Because the amount of waste in each tank varies, 99% of the contents of tank S-102 may or may not equal the major HFFACO Milestone M-45-00 requirements, which call for the removal of 360 ft^3 of waste from each 100-series tank. Milestones M-45-00 and M-45-05A are considered in this evaluation.

For tank S-102, the HFFACO goal is assessed against two major areas. The first is the achievability of the goal during the tank S-102 initial waste retrieval. In tank S-102 this will demonstrate retrieval of salt cake and sludge wastes in tanks in the 200 West Area. The effectiveness of the waste retrieval operation will be determined with a topographical measurement of remaining waste in the tank and a calculation of waste inventory. The inventory calculation will be based on calculated volume of the tank, waste topography measurements with appropriate surveying techniques, and adjustments for any detectable deformities in the tank structure (e.g., liner bulges). The second area of assessment will be against the evaluation of the regulatory requirements of HLW disposal from applicable rules, regulations, and DOE orders. An interface with the NRC will be established, and formal agreement on the retrieval and closure actions for SSTs with respect to allowable waste residuals in the tank and soil column will be reached.

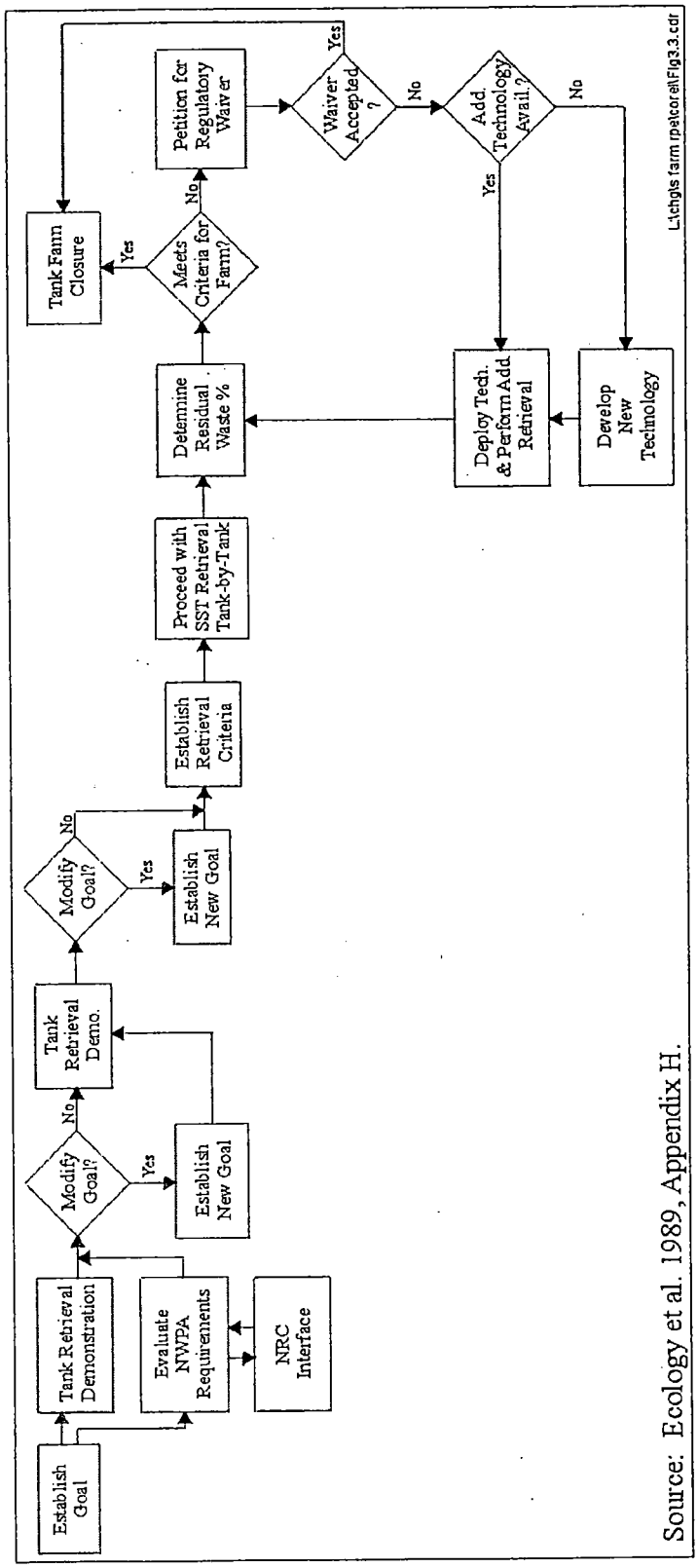
DOE and Ecology will assess the waste retrieval goal and modify that goal to match the most restrictive case (i.e., the highest retrieval percentage requirement). Tank S-102 waste retrieval efforts will be performed, and the residual waste inventory will be calculated for each tank. DOE and Ecology will then perform an assessment of the waste retrieval goal. Based on the retrieval results the goal may be modified to match capabilities of the best available technology. The

agencies will notify NRC as required for compliance with the *Nuclear Waste Policy Act of 1982*. Formal criteria for retrieval of waste from the remaining SSTs will be established, and closure plans for the S tank farm will be finalized with concurrence from regulatory agencies. Waste will be retrieved from the remaining S farm tanks. Retrieval activities may occur on a tank-by-tank basis to allow flexibility to retrieve waste from tanks in various tank farms if desired to support safety issue resolution, pretreatment or disposal feed requirements, or other priorities. Completion of waste retrieval will be in accordance with approved closure plans.

As per Appendix H of the HFFACO, residual waste will be calculated for each tank following retrieval. Notification to appropriate regulatory authorities will document compliance with criteria. If residual waste volumes comply with criteria final closure operations will proceed. If residual waste volumes do not comply, a request for waiver will be prepared. If the waiver is accepted, closure operations for the tank farm will begin; if the waiver is not accepted, additional retrieval operations are required. A review of alternate technologies will be performed relative to the need for additional waste removal. If additional technologies are available they will be used to retrieve additional waste. If additional technologies are not available, new technologies will be developed and deployed. A tank farm will be held in interim status pending completion of the additional tank waste retrieval operations.

When additional waste is retrieved, the residual waste volume will again be calculated and assessed against the criteria. An iterative process will occur. If the goal is met, final tank farm closure will proceed. If the goal is not met, a waiver will be petitioned or additional waste retrieval activities will occur until the appropriate regulatory authorities are satisfied. Figure B.3.3 provides a generic logic diagram of this process.

Figure B.3.3. Process for Assessing Percentage of Waste Retrieved from Waste Retrieval Operations



Source: Ecology et al. 1989, Appendix H.

B.4.0 DESCRIPTION OF WASTE RETRIEVAL CASES

This section summarizes the intent of the 10 waste retrieval cases defined to determine the effects of different volumes of retrieval leak loss and residual waste. These cases are used to determine how sensitive short-term human health risk, impacts to groundwater, long-term human health risk, inadvertent human intrusion, and regulatory impacts are to varying leak loss and residual waste volumes. Section B.4.1 outlines the major enabling assumptions associated with creating and evaluating the cases. Section B.4.2 contains a summary of the case descriptions.

It is important to note that the waste retrieval cases are defined to investigate tradeoffs between risk and volume (both residual waste and retrieval leak loss). As such, evaluation of these cases is not intended to provide a means to relax retrieval requirements, but to provide adequate risk-based analysis to support the HFFACO requirements for waste retrieval.

B.4.1 MAJOR ENABLING ASSUMPTIONS

This section summarizes the major enabling assumptions made to support development of the waste retrieval cases. Assumptions were made when available data were insufficient to support this RPE analysis. It is assumed that because a decision has been made to retrieve waste from tank S-102, this evaluation need not include a no-action case where the current waste inventories would be left in place. A baseline level of waste retrieval is assumed for all remaining tanks in the S tank farm. This assumption supports an evaluation of the long-term performance of tank S-102 cases combined with the long-term performance of the S-101 cross-section (i.e., of tanks S-101, S-102, S-103).

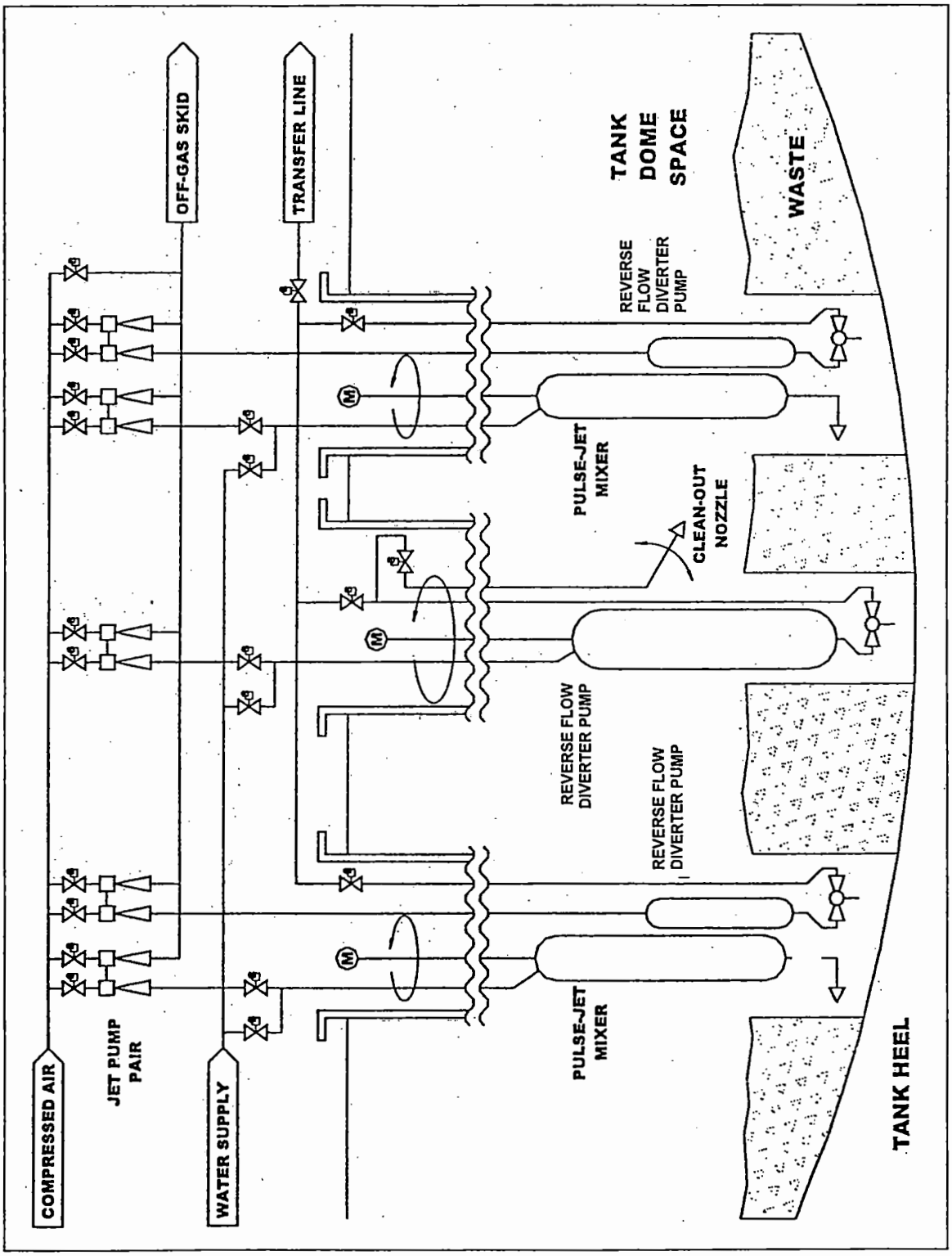
B.4.1.1 Waste Retrieval Technology Assumptions

Current plans for retrieving waste from tank S-102 include design and deployment of a pulsed jet fluidic mixing technology system (Figure B.4.1). Tank S-102 contains both salt cake and sludge waste and is not a candidate for retrieval using the salt cake dissolution technology. The pulse jet fluidic mixing technology involves using a charge vessel or vessels within the tank and repeatedly filling and discharging the vessels to mobilize and slurry the waste so it can be pumped out of the tanks. Preliminary engineering studies are currently being developed to address application of the pulsed jet fluidic mixing technology for retrieval of waste from tank S-102. An evaluation of this technology for use in retrieving SST waste was completed in fiscal year 2000 and concluded that there were no fatal flaws to deploying this technology in a Hanford Site SST (RPP-7819).

B.4.1.2 Leak Detection, Monitoring, and Mitigation System Assumptions

The assumed LDMM strategy for this evaluation is similar to the EPA approach of setting target leak detection rates and leak detection criteria. LDMM information in the following discussion is taken from *LDMM Design Concepts Evaluation Report for Saltcake-Dissolution-Based Retrieval Technologies* (RPP-7627).

Figure B.4.1. Pulsed Jet Fluidic Mixing Schematic



Adapted from RPP-7819.

Each stage in the LDMM process is governed by specific objectives and requirements as follows.

- Leak detection requirements:
  - Target leak detection rate LDMM requirement will be less than or equal to the risk-based release criterion established by the RPE process divided by the expected duration of the retrieval campaign
  - Performance of the leak detection method or combination of methods will have a probability of detection of 95% against the target leak detection rate and a probability of false alarm less than or equal to 5%
  - Leak detection method or combination of methods shall be functional during all retrieval operations.
- Leak monitoring requirements (assuming a leak occurs):
  - Provide an estimate of the leak volume
  - Provide an accuracy assessment of the leak volume estimate (needed to establish probability that the target leak detection rate has or has not been exceeded).
- Leak mitigation requirements:
  - Tank-specific leak response and mitigation plan shall be developed that minimizes the leak risk potential and reduces the environmental and human health impact of a leak if one occurs during waste retrieval operations.

There have been several leak detection technologies and methods considered for tank S-112 and tank S-102 LDMM systems including the following.

- Leak detection in-tank methods:
  - Mass balance
  - Volumetric inventory balance (catastrophic leak detection)
  - Volumetric precision (precision leak detection).
- Leak detection ex-tank methods:
  - Tracers (inoculation, partitioning tracer)
  - Leak detection caissons and borehole technologies (where existing)
  - Electrode development technologies (electrical resistance tomography, high resolution resistivity, and time domain reflectrometry).

In recent years the ex-tank methods identified have improved and could be used to detect a leak and to quantify the volume of liquid released from a tank. Preliminary testing indicates that

those methods are promising; however, none of these technologies are sufficiently mature to deploy in support of tank S-102 waste retrieval on the schedule outlined in the HFFACO. The current drywell leak detection systems for tank S-102 should be used throughout the tank waste retrieval processes as secondary indication capability to the system chosen for LDMM.

The same technologies used to perform leak detection may also be used to monitor a leak. Leak monitoring involves quantifying the liquid waste release volume from an SST if a release is detected during waste retrieval operations.

Leak mitigation technologies include, but are not limited to, auxiliary pumps, inherent liquid minimization, and limited liquid retrieval. The criteria used to evaluate which LDMM technology would best work for tank S-102 included the following:

- Total life cycle cost
- How the technology was applied in the past
- How long the technology has been available and its history
- Potential performance
- Ease of use or how complicated use may or may not be
- Ability to integrate into the waste retrieval operations
- Characteristics of the waste and available data.

According to RPP-7627 the LDMM concept recommended for tank S-102 includes the following:

- **Leak detection**: In-tank volumetric system and preferred ex-tank method
- **Leak monitoring**: In-tank volumetric system and preferred ex-tank method
- **Leak mitigation**: Primary waste mining strategy.

B.4.1.3 Tank Stabilization Assumptions

Following waste retrieval, tank S-102 is assumed to be stabilized to prevent subsidence and provide a structurally sound base for the surface barrier. Closure designs for the SSTs have not been developed in detail; however, most concepts identified to date involve placement of gravel or grout in the tanks. It is likely that grout would be used in the initial step to stabilize the tanks in an attempt to encapsulate the residual waste. DOE/RL-98-72 includes a conceptual description of the activities necessary to stabilize an SST with grout.

Stabilization of tank residual waste with grout is an element of the tank closure process developed at the Savannah River Site (DOE/EIS-0303D). The grout is utilized in the tank closure to facilitate NRC classification of the tank residual waste as incidental waste by doing the following:

- Incorporating the residual waste into a stabilized waste form designed to reduce the release of contaminants to the environment

- Producing a waste form with radionuclide concentrations that, on average, meet NRC Class C LLW criteria.

B.4.1.4 Ancillary Equipment Assumptions

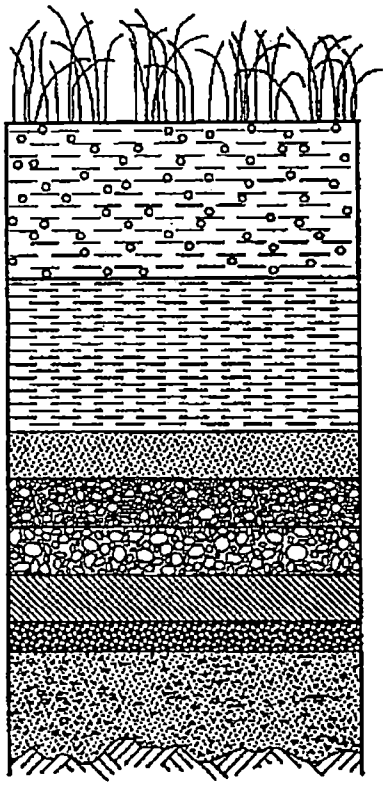
Stabilization of ancillary equipment is assumed to occur during tank farm closure and would include (1) demolishing and removing all surface buildings and equipment that would interfere with constructing the surface barrier and (2) stabilizing the subsurface equipment with grout to prevent long-term subsidence. Concepts for stabilization of ancillary equipment were developed as a part of the AX tank farm RPE (DOE/RL-98-72). These same types of concepts could be used to stabilize the ancillary equipment in the S tank farm. One of the issues identified in developing and evaluating concepts for ancillary equipment stabilization was the worker health and safety issues associated with injecting grout into the abandoned waste transfer lines (HNF-3441). The concept developed for grouting the abandoned waste transfer lines required direct worker contact with equipment to establish grout injection points. If the length of a transfer line was greater than the distance that grout could be pumped, then it was assumed that supplemental pipe penetrations would have to be made along the length of the pipe. One of the conclusions drawn from the AX tank farm RPE was that additional evaluation was required to determine the need for stabilizing the smaller diameter transfer lines.

B.4.1.5 Surface Barrier Assumptions

An enhanced RCRA Subtitle C barrier is assumed to be constructed over the S tank farm. The barrier would be larger than required to cover the tanks and is intended to provide a barrier over the ancillary equipment within the tank farm. The enhanced RCRA Subtitle C barrier design is described in greater detail in *Focused Feasibility Study of Engineered Barriers for Waste Management Units in 200 Areas* (DOE/RL-93-33). This surface barrier is an 8-layer barrier with a combined minimum thickness of 1.7 m (5.6 ft). The barrier is designed to provide long-term contaminant and hydrologic protection for a performance period of 500 years.

An enhanced RCRA Subtitle C barrier is similar in structure to a Hanford barrier, but layer thicknesses are reduced and there is no fractured basalt layer. The design incorporates provisions for biointrusion and human intrusion control. However, the provisions are modest relative to control features incorporated into the Hanford barrier design. The enhanced RCRA Subtitle C barrier is the baseline design for sites containing dangerous waste, Category 3 LLW or Category 3 low-level mixed waste, and Category 1 low-level mixed waste (DOE/RL-93-33). A cross-section of an enhanced RCRA Subtitle C barrier is provided in Figure B.4.2.

Figure B.4.2. Enhanced RCRA Subtitle C Barrier Cross-Section



Cover Vegetation: Mixed perennial grasses

Layer 1: Silt loam topsoil with pea gravel admixture (50 cm [20 in.])

Layer 2: Compacted silt loam topsoil (50 cm [20 in.])

Layer 3: Sand filter layer (15 cm [6 in.])
Layer 4: Gravel filter layer (15 cm [6 in.])
Layer 5: Lateral drainage layer (drainage gravel) (15 cm [6 in.])
Layer 6: Low-permeability asphalt layer (15 cm [6 in.])
Layer 7: Asphalt base course (10 cm [4 in.])

Layer 8: Grading fill (variable thickness)

Adapted from DOE/RL-93-33.

L:\chgis farm rpelcore\Fig4.2.cdr

B.4.1.6 Cost Assumptions

Cost is a performance measure that can be coupled with other measures for use in evaluating different remediation alternatives. For example, when coupled together with risk, cost-versus-risk reduction assessments can be derived and graphed. A total cost estimate, or life cycle cost, for each of the 10 waste retrieval cases has not been developed because (1) the analysis is focused on retrieval decisions for tank S-102 and (2) the variations between the cases are not driven by cost. For example, a number of the cases consider variations in waste retrieval leakage volume for tank S-102. The presence or absence of a retrieval leak does not affect the project cost. However, a leak may result in a stop-work order for waste retrieval operations, therefore resulting in greater residual waste volumes. There also may be added cost for soil characterization and remediation associated with tank farm closure.

B.4.2 SUMMARY OF WASTE RETRIEVAL CASE DESCRIPTIONS

Long-term risk will depend on tank farm closure and endstate decisions that have not yet been made. In the absence of such decisions, long-term risk is evaluated based on assumptions for tank farm closure and endstate. All 10 waste retrieval cases assume a common endpoint that includes the following parameters.

- Vadose zone contamination from past leaks is not remediated.
- Tanks and belowgrade ancillary equipment are stabilized with grout and/or a combination of grout and gravel.
- Aboveground ancillary equipment is removed.
- An enhanced RCRA Subtitle C barrier (Figure B.4.2) is constructed over the tank farm.

The waste retrieval cases are designed to illustrate the effects of different waste retrieval performance levels in tanks S-112 and S-102 as well as for the three-tank cross-section. The following summarize the intent of the different cases.

- Case 1 is designed to illustrate the risks from waste retrieval to the HFFACO interim goal of 360 ft^3 with no leak loss from any tank.
- Case 2 is designed to illustrate the risks associated with retrieving waste to the HFFACO interim retrieval goal but with a 30,000 L (8,000 gal) retrieval leak loss from each tank.
- Cases 3, 8, 9, and 10 are designed to evaluate the effects of varying amounts of retrieval leak loss from tank S-102. Although the evaluation of the temporary barrier in Case 10 specifically evaluated tank S-112 and not tank S-102, the conclusions reached for tank S-112 would apply equally to tank S-102.
- Case 5 is designed to evaluate the effects of retrieving all S farm tanks to the HFFACO interim retrieval goal with a 30,000 L (8,000 gal) retrieval leak loss, but with less

effective retrieval performance for tank S-102 (estimated residual heel of 23,000 L [6,000 gal]).

- Cases 4, 6, and 7 are designed to evaluate the effects of varying the volume of the residual waste left in tank S-102.

Table B.3.1 provides a summary of the principal variables associated with each case. Specifics of the variables associated with each case are delineated in *Enabling Assumptions and Calculations to Support the Tanks S-112 and S-102 Retrieval Performance Evaluation* (HNF-7990).

B.5.0 ANALYSIS RESULTS

This section describes the results of the impact assessment for the 10 waste retrieval cases evaluated for this report. Two significant figures are used for presentation of numerical results to show relative differences between the waste retrieval cases. This is not intended to imply a level of confidence in the results, which are generally order-of-magnitude projections.

B.5.1 TANK S-102 ASSESSMENT RESULTS

Impact assessment results specific to the areas of short-term human health risk, groundwater impacts, long-term human health risk, intruder risk, and regulatory compliance specific to tank S-102 are provided in the following sections.

B.5.1.1 Tank S-102 Short-Term Human Health Risk Assessment Results

The short-term human health risk analysis supports a comparison of the short-term human health risks associated with variations in waste retrieval as defined by the waste retrieval cases. Because of the limited amount of data and because only the differences between the waste retrieval cases are of interest, activities that are common among the cases are not included in the short-term human health risk calculations. For example, activities associated with retrieval of waste from tank S-102 using the fluidic mixing system (e.g., installation of the fluidic mixing system and the support systems) is the same for all the tank S-102 waste retrieval cases with the exception of retrieval operations and construction of an interim barrier. Therefore, only the short-term human health risk associated with retrieval operations and construction of an interim barrier are calculated for comparison in this analysis. However, it should be noted that adding the risk from activities that are common to all cases would reduce the differences (by percent) between the waste retrieval cases. Therefore, the differences between the waste retrieval cases presented in this document are bounding. Retrieval leak losses are also excluded from this short-term human health risk analysis because they do not result in an appreciable short-term human health risk (the leaks are assumed to occur at the base of the tanks and are assumed to have no associated atmospheric release). Retrieval leak losses do, however, contribute to the long-term human health risk (i.e., post-remediation health impacts) and are evaluated in Section B.5.1.3.

Short-term human health risk is calculated for both normal (i.e., nonaccident or routine) and accident conditions. Routine conditions include anticipated exposure to radiation fields and radiological and chemical releases to the atmosphere during normal retrieval operation conditions. Accidents are unplanned events or a sequence of events that result in undesirable consequences. The accidents evaluated in this analysis include potential occupational accidents resulting in physical trauma, radiological exposure resulting in LCFs, and toxic or corrosive toxicological exposure resulting in adverse health effects. Initiating events that could result in adverse health effects include natural phenomena, human error, and component failure. The methodology used for the short-term human health risk analysis is discussed in Section B.3.4.

B.5.1.1.1 Occupational Accident. The occupational accidents in this analysis are evaluated in terms of the number of total recordable cases (TRCs) and lost workday cases (LWCs) resulting from accidental injuries. The analysis also includes the number of fatalities resulting from accidents. Injuries (i.e., TRCs and LWCs) and fatalities are calculated by multiplying the labor requirements to support the activities of interest by Hanford Site-specific incidence rates.

The parameters of the calculation and the number of incidents to the involved workers for each case are presented in Table B.5.1. Details of the enabling assumptions, data for analysis, and the analysis calculations are provided in HNF-7990.

Table B.5.1. Occupational Accidents

Incident	Labor Requirements (labor-hr)	Incident rate (incident/labor-hr)	Number of Incidents
Cases 1, 2, 4, 6, 7, 8, and 9			
TRC	3.3E+04	1.9E-05	6.3E-01
LWC	3.3E+04	8.0E-06	2.6E-01
Fatality	3.3E+04	1.4E-08	4.4E-04
Case 3			
TRC	3.3E+04	1.9E-05	6.4E-01
LWC	3.3E+04	8.0E-06	2.7E-01
Fatality	3.3E+04	1.4E-08	4.5E-04
Case 5			
TRC	3.1E+04	1.9E-05	5.9E-01
LWC	3.1E+04	8.0E-06	2.5E-01
Fatality	3.1E+04	1.4E-08	4.2E-04
Case 10			
TRC	4.0E+04	1.93E-05	7.7E-01
LWC	4.0E+04	8.04E-06	3.2E-01
Fatality	4.0E+04	1.35E-08	5.4E-04

Note: U.S. Department of Energy regulations limit exposures to an inadvertent human intruder to no greater than 100 mrem/yr for chronic exposure (post-driller resident) and 500 mrem for an acute or single event (well driller) at a point in time 100 years after closure (DOE O 435.1).

LWC = lost workday case.
TRC = total recordable case.

B.5.1.1.2 Routine Radiological Risk. The unit of measure for routine radiological risk in this analysis is the number of LCFs resulting from radiological exposures from routine (nonaccident) conditions for the population receptors. For the MEI receptors it is the probability of an LCF. Exposure to an involved worker would be from ionizing radiation fields in radiation zones.

Exposure to an noninvolved worker and the general public would be from abated air emissions. Exposure rates are measured in a dose unit of rem and multiplied by a dose-to-risk conversion factor to calculate the LCF risk.

The parameters of the calculation and the routine radiological risk to the involved workers, noninvolved workers, and general public for each waste retrieval case are presented in Table B.5.2. Details of the enabling assumptions, data for analysis, and analysis calculations are provided in HNF-7990. The dose to the MEI involved worker is assumed to be the Administrative Control Level of 500 mrem/yr for all waste retrieval cases. To exceed this dose would require approval from Level 3 line management and the Radiological Control Manager (HSRCM-1).

Table B.5.2. Routine Radiological Risk

Receptor	Dose (rem)*	Dose-to-Risk Conversion Factor (LCF/rem)*	Risk (LCF)
Cases 1, 2, 4, 6, 7, 8, 9, and 10			
Involved worker MEI	5.0E-01	4.0E-04	2.0E-04
Involved worker population	5.7E+01	4.0E-04	2.3E-02
Noninvolved worker MEI	3.8E-08	4.0E-04	1.5E-11
Noninvolved worker population	2.9E-05	4.0E-04	1.2E-08
General public MEI	3.8E-07	5.0E-04	1.9E-10
General public population	1.4E-02	5.0E-04	7.0E-06
Case 3			
Involved worker MEI	5.0E-01	4.0E-04	2.0E-04
Involved worker population	5.1E+01	4.0E-04	2.3E-02
Noninvolved worker MEI	4.0E-08	4.0E-04	1.6E-11
Noninvolved worker population	2.9E-05	4.0E-04	1.2E-08
General public MEI	3.8E-07	5.0E-04	1.9E-10
General public population	1.4E-02	5.0E-04	7.0E-06
Case 5			
Involved worker MEI	5.0E-01	4.0E-04	2.0E-04
Involved worker population	5.4E+01	4.0E-04	2.2E-02
Noninvolved worker MEI	3.7E-08	4.0E-04	1.4E-11
Noninvolved worker population	2.8E-05	4.0E-04	1.1E-08
General public MEI	3.8E-07	5.0E-04	1.9E-10
General public population	1.4E-02	5.0E-04	7.0E-06

*Person-rem for population receptors.

LCF = latent cancer fatality.
MEI = maximally exposed individual.

B.5.1.1.3 Routine Chemical Risk. The routine chemical risk from waste retrieval operations includes toxic health effects measured in exceedance of the hazard index for each toxic chemical and carcinogenic health effects measured in ILCR. The chemical health risk was evaluated for the involved worker MEI, noninvolved worker MEI, and the general public MEI.

The ILCR and the hazard index to the involved worker MEI, noninvolved worker MEI, and general public MEI for each case are presented in Table B.5.3. The enabling assumptions, data for analysis, and analysis calculations are provided in HNF-7990.

Table B.5.3. Routine Chemical Risk to Maximally Exposed Individuals

Receptor	ILCR	Hazard Index
Cases 1, 2, 4, 6, 7, 8, 9, and 10		
Involved worker MEI	2.8E-08	<2.3E-01
Noninvolved worker MEI	1.2E-08	<1.0E-07
General public MEI	3.7E-12	<5.3E-05
Case 3		
Involved worker MEI	2.9E-08	<2.3E-01
Noninvolved worker MEI	1.3E-08	<1.0E-07
General public MEI	3.7E-12	<5.3E-05
Case 5		
Involved worker MEI	2.7E-08	<2.3E-01
Noninvolved worker MEI	1.2E-08	<1.0E-07
General public MEI	3.5E-12	<5.3E-05

Note: Ammonia is the major chemical contributor for the hazard index. 1,3-Butadiene is the major chemical contributor for the ILCR.

ILCR = incremental lifetime cancer risk.
MEI = maximally exposed individual.

B.5.1.1.4 Radiological Accident Risk. Only operational accidents are evaluated in this RPE. Additional accidents will be evaluated as part of conceptual design. All waste retrieval cases assume the same fluidic mixing technology for retrieval; therefore, each case is subject to the same type of accidents. Fluidic mixing-based retrieval accidents would be similar to those evaluated in *Preliminary Engineering Report for the 241-C-104 Retrieval System* (RPP-6843); that analysis was performed to determine if any accidents could be identified at the early preconceptual stage that would exceed the safety envelope of the tank farms authorization basis (HNF-SD-WM-SAR-067). The annual frequency and level of severity of the potential accidents evaluated in the assessment were shown to be bound by that authorization basis. The severity of a given accident and the frequency of the accident is common to all waste retrieval cases; however, the probability of the accident occurring varies slightly because of the slight variation in duration of operations between the cases. The variation is so slight that there is no change in

frequency categories. A table of potential accidents, consequences, and likelihood is provided in HNF-7990.

B.5.1.1.5 Chemical Accident Risk. The same conclusions reached in Section B.5.1.1.4 for radiological accidents also apply to potential chemical accidents. Because all waste retrieval cases assume the same fluidic mixing technology for waste retrieval, each case is subject to the same type of chemical accident. The severity of a given accident and the frequency of the accident is common to all waste retrieval cases; however, the probability of the accident occurring varies slightly because of the slight variation in duration of operations between the cases. The variation is so slight that there is no change in frequency category.

B.5.1.2 Tank S-102 Groundwater Impact Assessment Results

The near-field groundwater impacts at the tank farm boundary associated with tank S-102 are presented in this section based on simulations of cross-section S-101 which includes tanks S-101, S-102, and S-103. The groundwater impacts are reported as tank S-102 would perform in the following manner.

- Individually with no other releases assumed from other tanks in the tank farm where the metric is the near-field contaminant concentration at the S tank farm fence line along the centerline of the S-101 cross-section.
- In the context of the two other tanks in the S-101 cross-section. Tank S-102 is between tanks S-101 and S-103. The metric is the near-field contaminant concentration at the S tank farm fence line along the centerline of the S-101 cross-section.
- In the context of all the tanks within the S tank farm where the metric is far-field contaminant concentrations at the 200 West Area fence line and the 200 Area exclusion zone boundary.

The near-field groundwater impact results associated with tank S-102 are presented in this section based on simulations of cross-section S-101. Section B.5.2.1 presents the far-field groundwater impact results associated the whole tank farm (i.e., releases from 12 tanks in S tank farm).

Ten groundwater impact simulations were performed to determine the reasonable range of impacts expected from tank S-102. As discussed in Section B.3.5, the groundwater impact assessment approach for tank S-102 is more focused on the isolated impacts associated with potential releases from this tank. Thus, the source terms incorporated into the groundwater impact simulations were limited to those for tank S-102 only (i.e., four simulations address retrieval losses from tank S-102 only and four simulations address residual releases from tank S-102 only). The exception was for the two base case simulations where for the retrieval and residual loss source terms, a 30,000 L (8,000 gal) retrieval loss and a 10,200 L (2,700 gal) residual waste were assumed for each of the three tanks in the S-101 cross-section.
The 10 simulations were also combined to allow for assessment of the potential composite impacts associated with all three tanks in the S-101 cross-section, in addition to just those

impacts from tank S-101. The potential groundwater impacts associated with retrieval loss, residual waste, and the composite of retrieval loss and residual waste releases are discussed in the following sections.

B.5.1.2.1 Tank-Specific Results for Tank S-102. Tank-specific results for tank S-102 are provided individually for the retrieval leakage, residual waste, and composite source terms.

B.5.1.2.1.1 Tank S-102 Groundwater Impacts Associated with Retrieval. Five simulations of the potential groundwater impacts from the retrieval source term were performed for the S-101 cross-section. Four of these simulations had assumed releases from tank S-102 ranging from 7,600 L (2,000 gal) to 150,000 L (40,000 gal) with no losses from the other two tanks in the cross-section. The remaining simulation assumed 30,000 L (8,000 gal) retrieval losses from each of the three tanks in the cross-section. A comparison of the potential groundwater impacts for the range of retrieval losses is illustrated in Figures B.5.1 through B.5.3 for the technetium-99, nitrate, and uranium-238, the three contaminants for which transport was simulated. Two contaminants, technetium-99 and nitrate, are both mobile in the Hanford subsurface and have similar trending groundwater concentration versus time plots (see Figures B.5.1. and B.5.2). The simulation of these contaminants indicate there would be two concentration peaks. The traces in these two plots are similar as described in the following.

- Both plots exhibit an early peak at about the year 2075 and a late peak between the years 3100 and 3160. The early peak is comparatively sharp. It is in response to the relatively larger recharge and shedding of recharge water over the tank domes that would occur until the surface barrier is installed in the year 2040. The later peak is broader and occurs after the tanks and the surface barrier are assumed to have degraded and after an extended period of relatively low recharge.

- Contaminant concentration in the groundwater would have dissipated to near zero by about the year 6000 for both contaminants.

- The peak technetium-99 concentrations for the 7,600 L (2,000 gal) retrieval loss scenario are 540 and 290 pCi/L for the early and late concentration peaks, respectively. The early and late peak technetium-99 concentrations for the other scenarios range from about 1,100 pCi/L to 16,800 pCi/L for the early peaks and 575 pCi/L to 5,400 pCi/L for the late peaks (see Figure B.5.1).

- The peak nitrate concentrations for the 7,600 L (2,000 gal) retrieval loss scenario are about 3.5 mg/L and 2 mg/L for the early and late concentration peaks, respectively (Figure B.5.2). The early and late peak nitrate concentrations for the other scenarios range from about 4 mg/L to 110 mg/L for the early peaks and 7 mg/L to 36 mg/L for the late peaks.

Figure B.5.1. Technetium-99 Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Cross-Section S-101 Retrieval Source Term

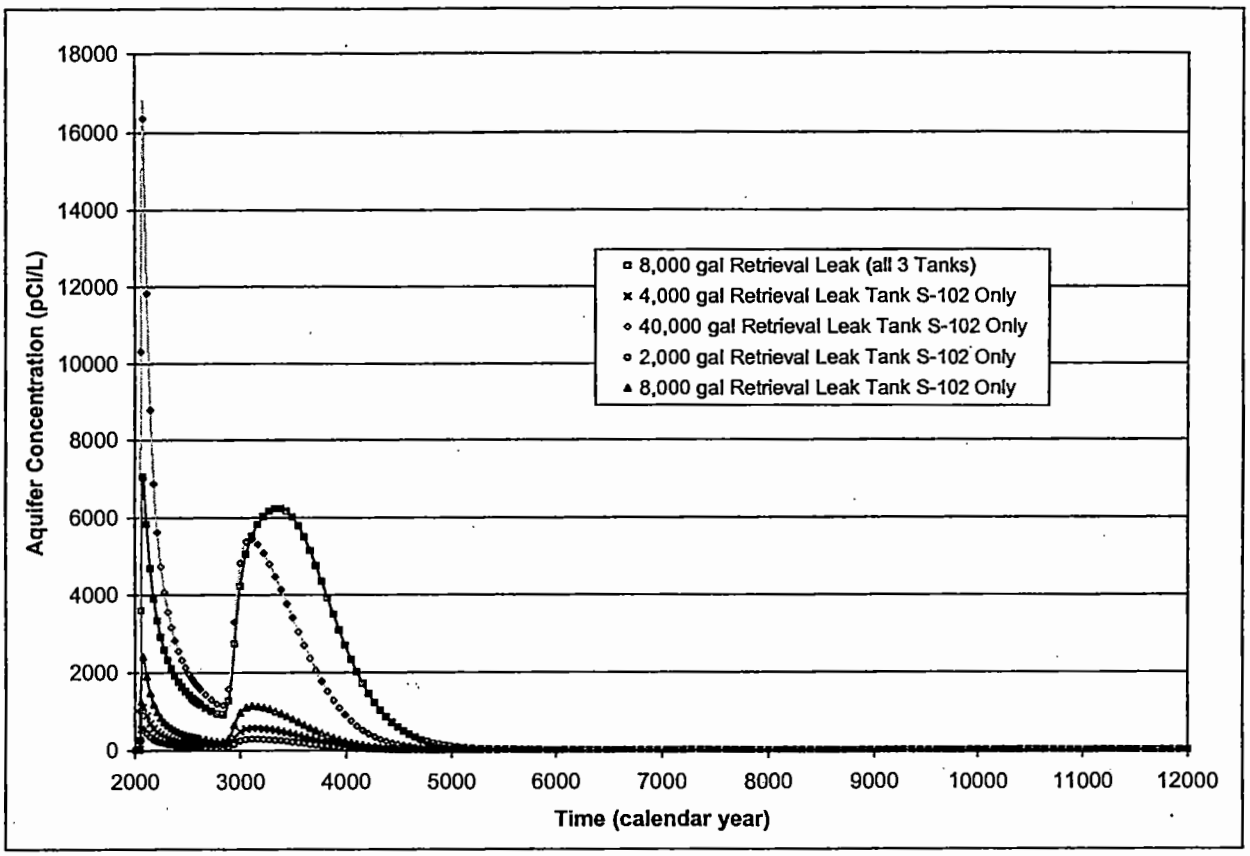
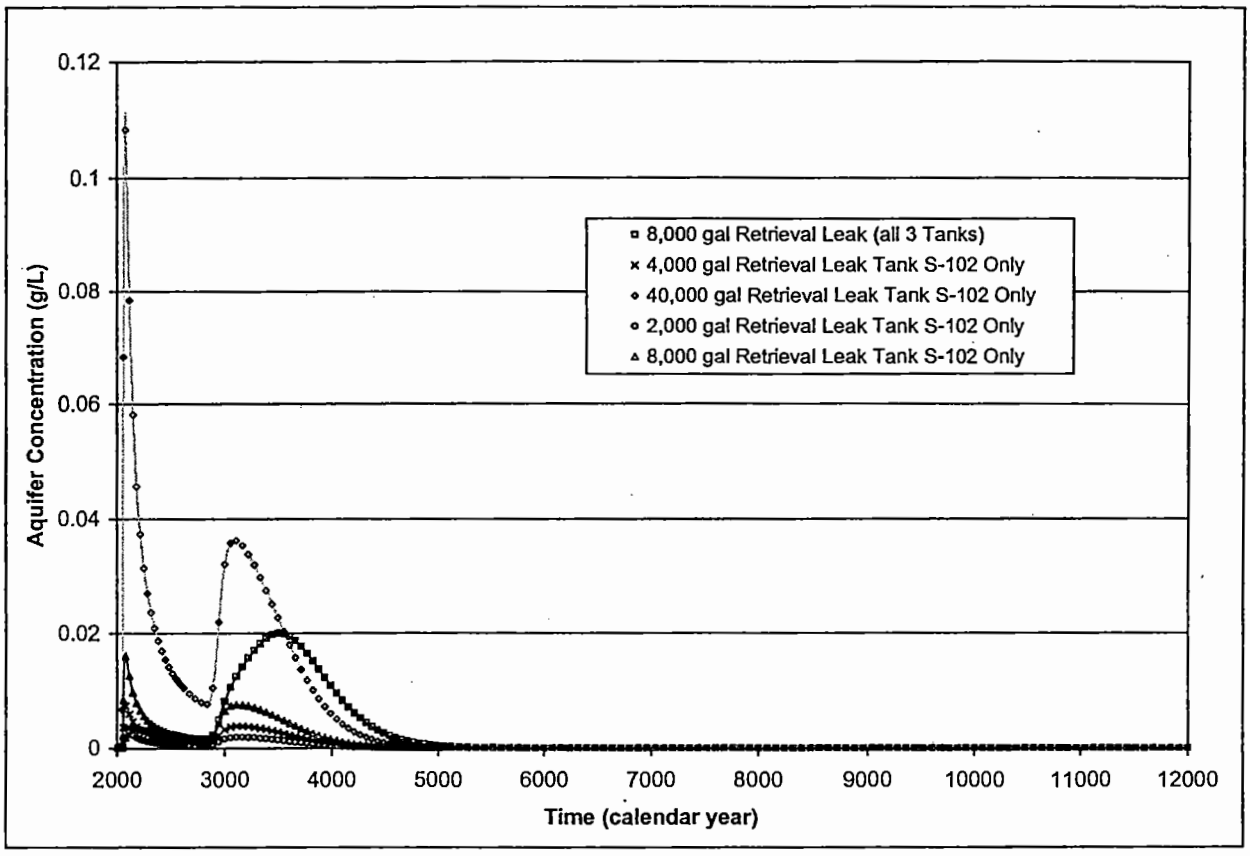
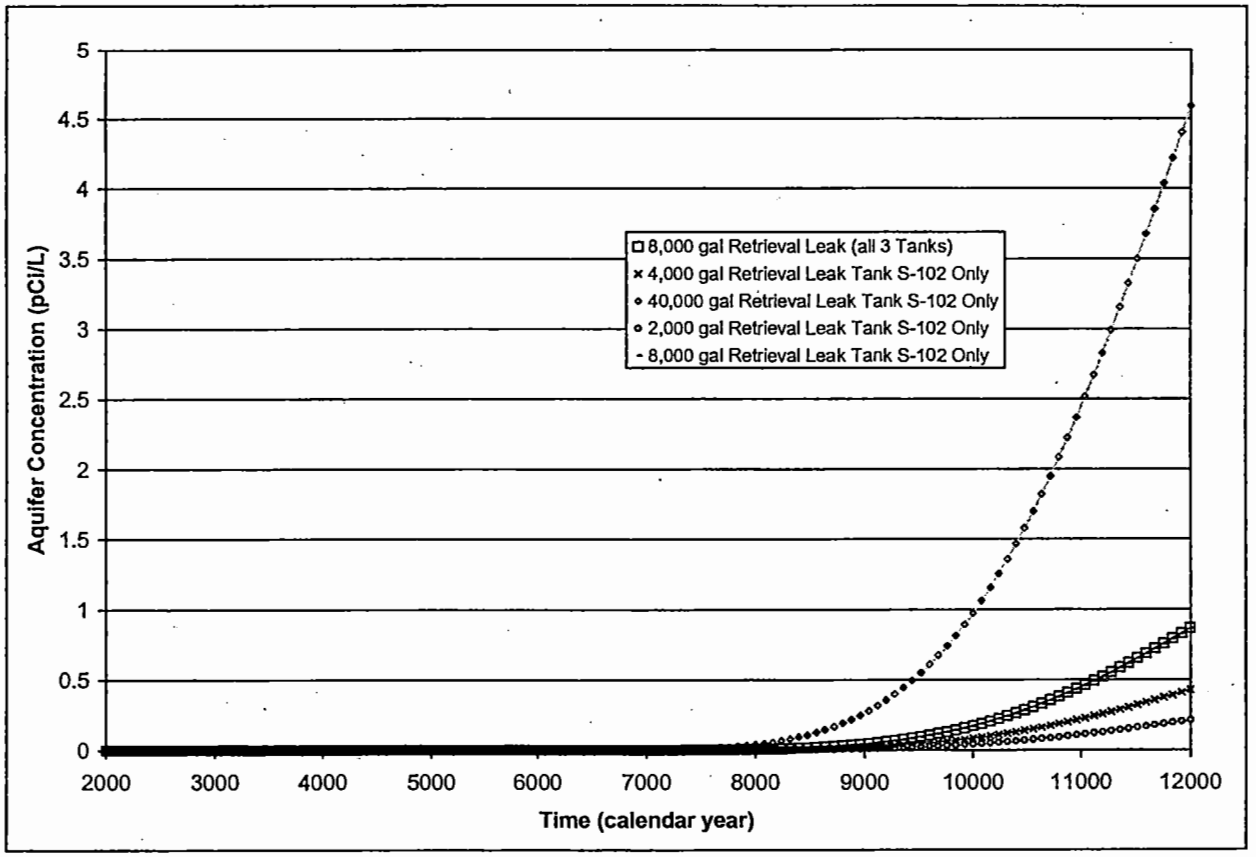


Figure B.5.2. Nitrate Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Cross-Section S-101 Retrieval Source Term



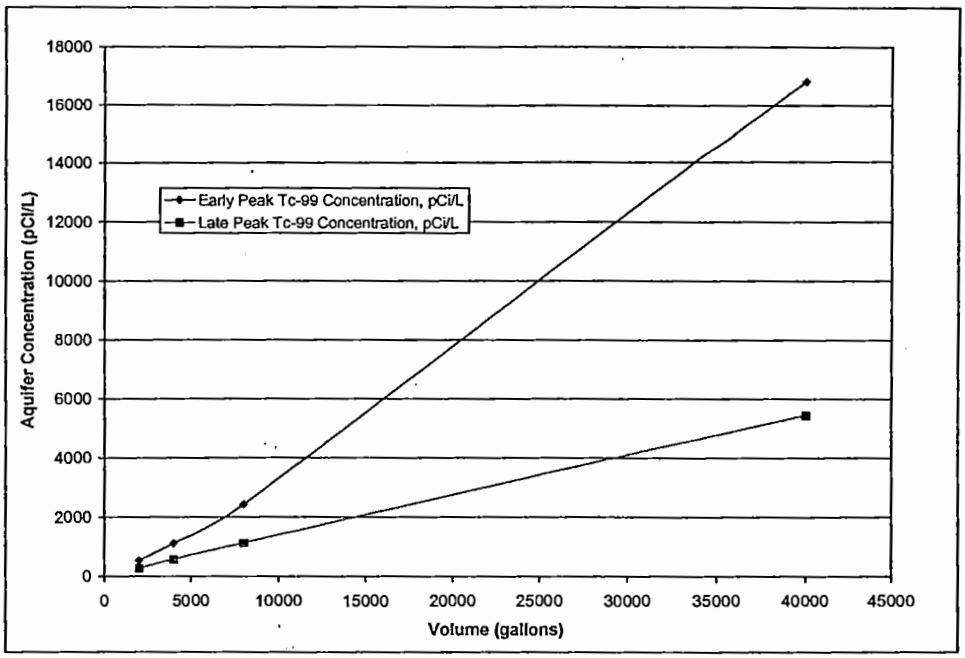
The transport of uranium-238 was also simulated from the retrieval releases. Due to the lower mobility of uranium-238 compared to technetium-99 or nitrate, the potential groundwater impacts of uranium-238 remain at a low level, on the order of 4.5×10^{-7} pCi/L through the year 7000. By the year 8000, the uranium-238 concentrations would be on the order of 6.0×10^{-3} pCi/L and continually increasing until the end of the period of interest at the year 12000. Uranium-238 would not have peaked during the 10,000-year period of interest (Figure B.5.3).

Figure B.5.3. Uranium Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Cross-Section S-101 Retrieval Source Term



There is a relationship between volume of retrieval loss and peak contaminant concentration. This relationship is illustrated in Figure B.5.4 for both the early and late peak techetium-99 concentrations for tank S-102. The late peak technetium-99 concentration versus volume relationship is nearly linear and could be approximated as such. The early peak technetium-99 concentration versus volume relationship is not linear but could be still be approximated.

Figure B.5.4. Technetium-99 Groundwater Concentration at the S Tank Farm Fence Line Versus Retrieval Volume from Tank S-102



B.5.1.2.1.2 Tanks S-102 Groundwater Impacts Associated with Residual Waste. Five simulations of the potential groundwater impacts from the residual waste source term were performed for the S-101 cross-section. These simulations had assumed remaining residual waste volumes in tank S-102 of 5,000 L (1,300 gal), 10,200 L (2,700 gal), 102,000 L (27,000 gal) and 190,000 L (50,000 gal) with no residual waste in the other two tanks in the cross-section. The fifth simulation assumed 10,200 L (2,700 gal) residual waste volume in each of the three tanks in the cross-section. A comparison of the potential groundwater impacts for the range of assumed residual waste volumes is illustrated in Figures B.5.5 through B.5.7 for technetium-99, nitrate, and uranium-238.

Technetium-99 and nitrate are both mobile in the Hanford subsurface and have similar trending groundwater concentration versus time plots (see Figures B.5.5. and B.5.6). The transport simulations of these contaminants in the residual waste source term results in only one concentration peak for all combinations of residual waste that were considered. The concentration peak would be at about the year 3900 when residual waste is left in tank S-102 only. Otherwise, when residual waste is assumed to remain in all three tanks in the cross-section (see Figures B.5.5 and B.5.6), the concentration peak would be slightly later at about the year 4000.

Figure B.5.5. Technetium-99 Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Cross-Section S-101 Residual Source Term

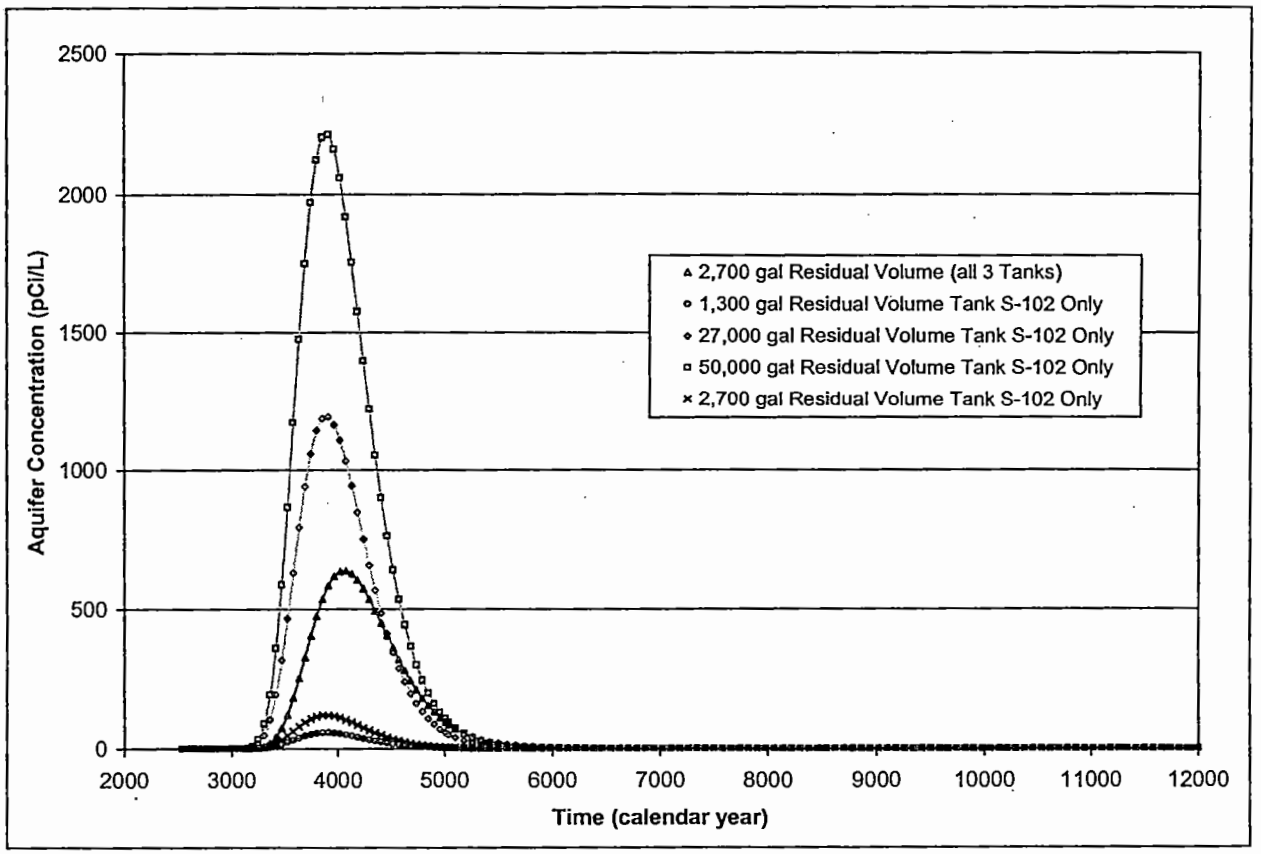
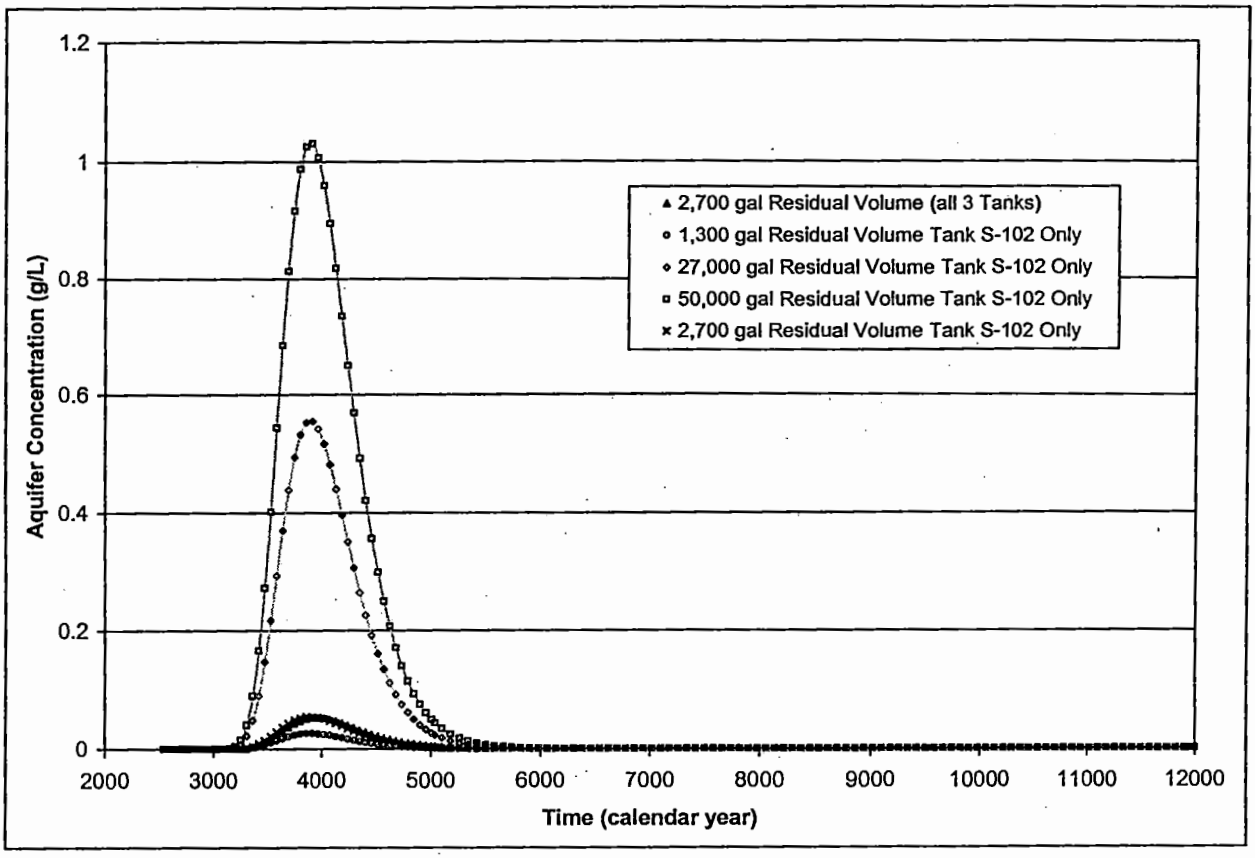


Figure B.5.6. Nitrate Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Cross-Section S-101 Residual Source Term



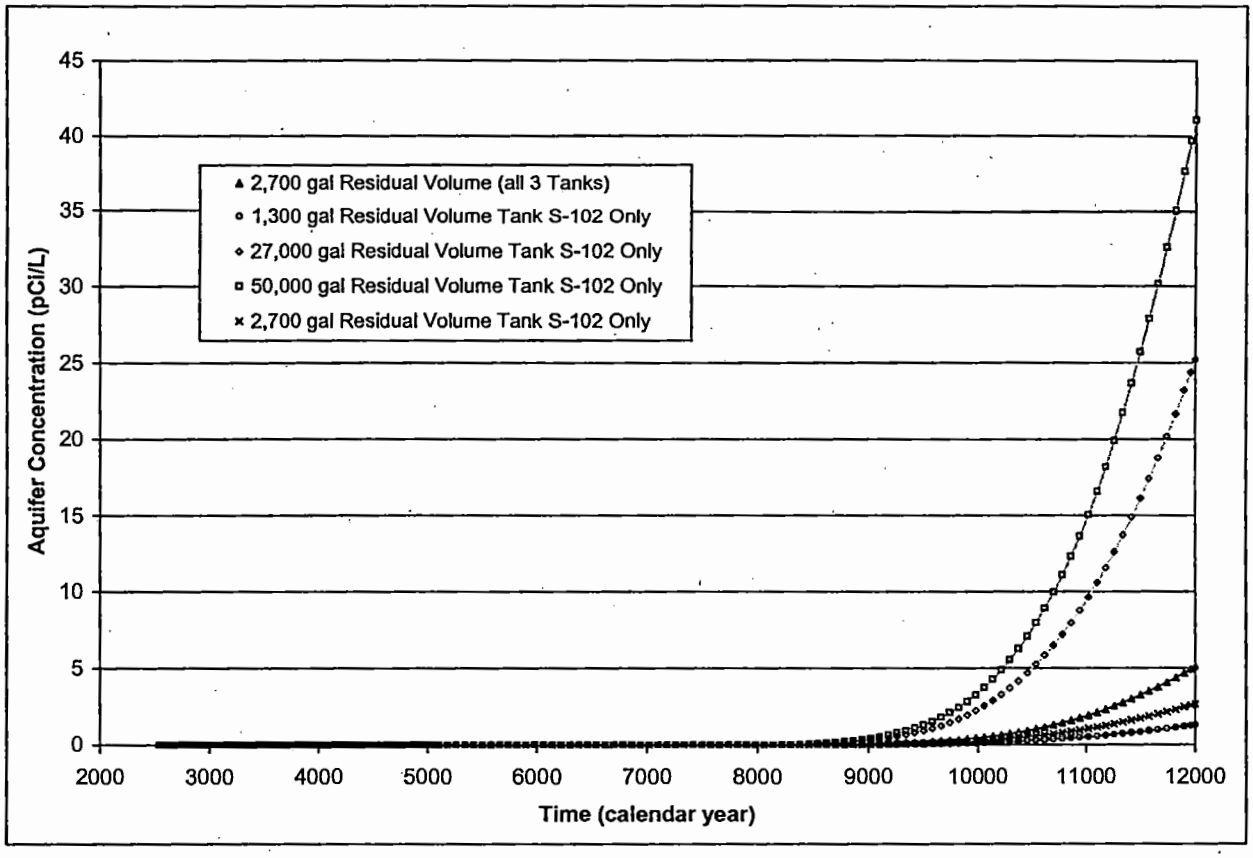
The groundwater concentration versus time traces for technetium-99 and nitrate (Figures B.5.5 and B.5.6) are similar as described in the following.

- Initial contaminant concentrations become evident in the near-field at about the year 3200 and peak at about the year 4000.
- There is only one peak contaminant concentration over the 10,000-year period of interest.
- The peak technetium-99 concentrations range from about 60 pCi/L for the 5,000 L (1,300 gal) residual waste scenario to 2,220 pCi/L both at about the year 3900 (see Figure B.5.5).
- The peak nitrate concentrations range from about 25 mg/L for the 5,000 L (1,300 gal) residual waste release from tank S-102 only to 1,050 mg/L for the 190,000 L (50,000 gal) residual waste scenario in tank S-102 only (see Figure B.5.6).

The transport of uranium-238 was also simulated for the assumed residual volumes. Due to the lower mobility of uranium-238 compared to technetium-99 or nitrate, the potential groundwater impacts of uranium-238 remain at a low level, on the order of 10^{-7} pCi/L through the year 7000 to 10^{-5} pCi/L in the year 8000. By the year 8500, the uranium-238 concentrations

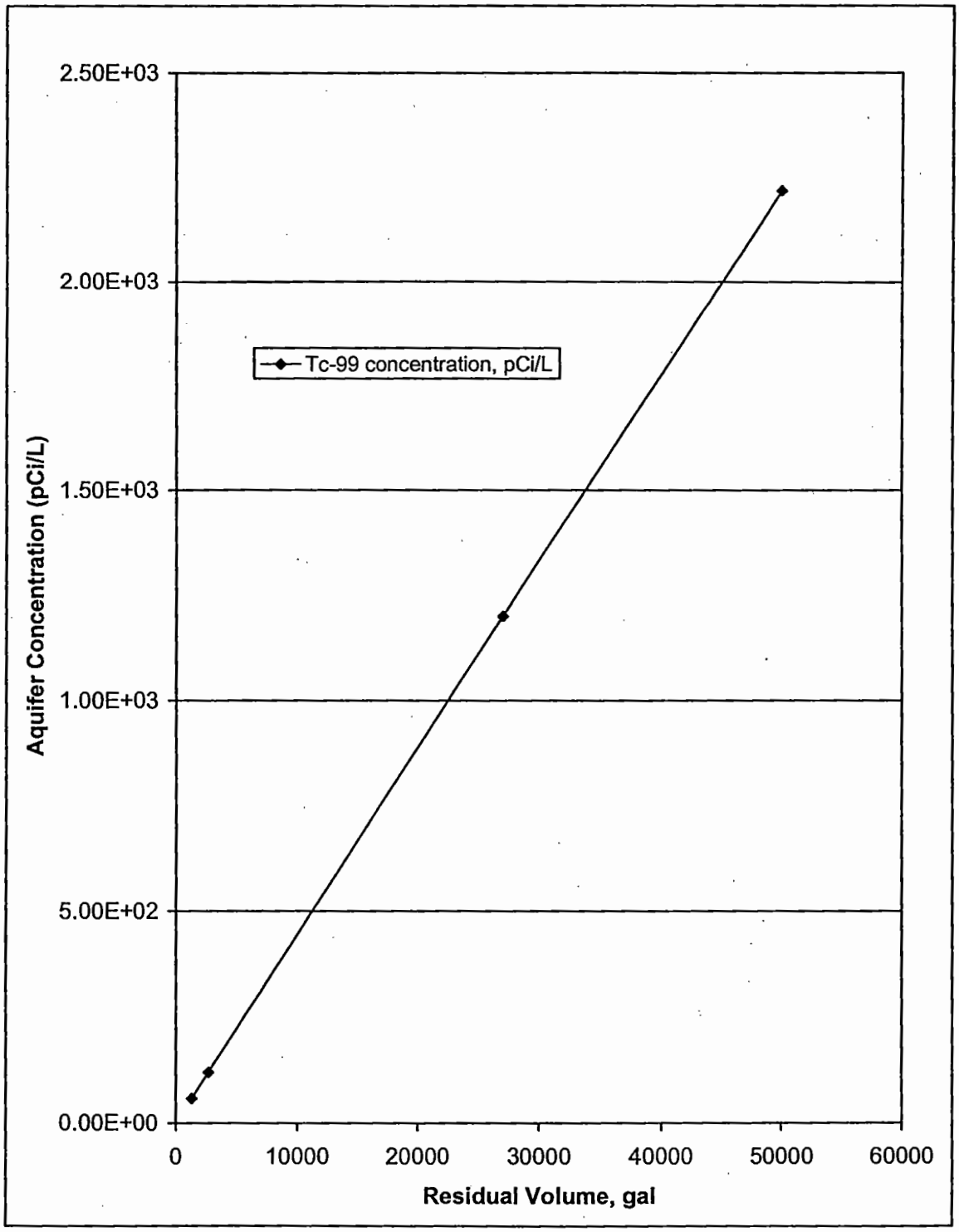
would be on the order of 10^{-2} pCi/L and continually increasing until the end of the period of interest at the year 12000. Uranium-238 would not have peaked during the 10,000-year period of interest (Figure B.5.7).

Figure B.5.7. Uranium-238 Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Cross-Section S-101 Residual Source Term



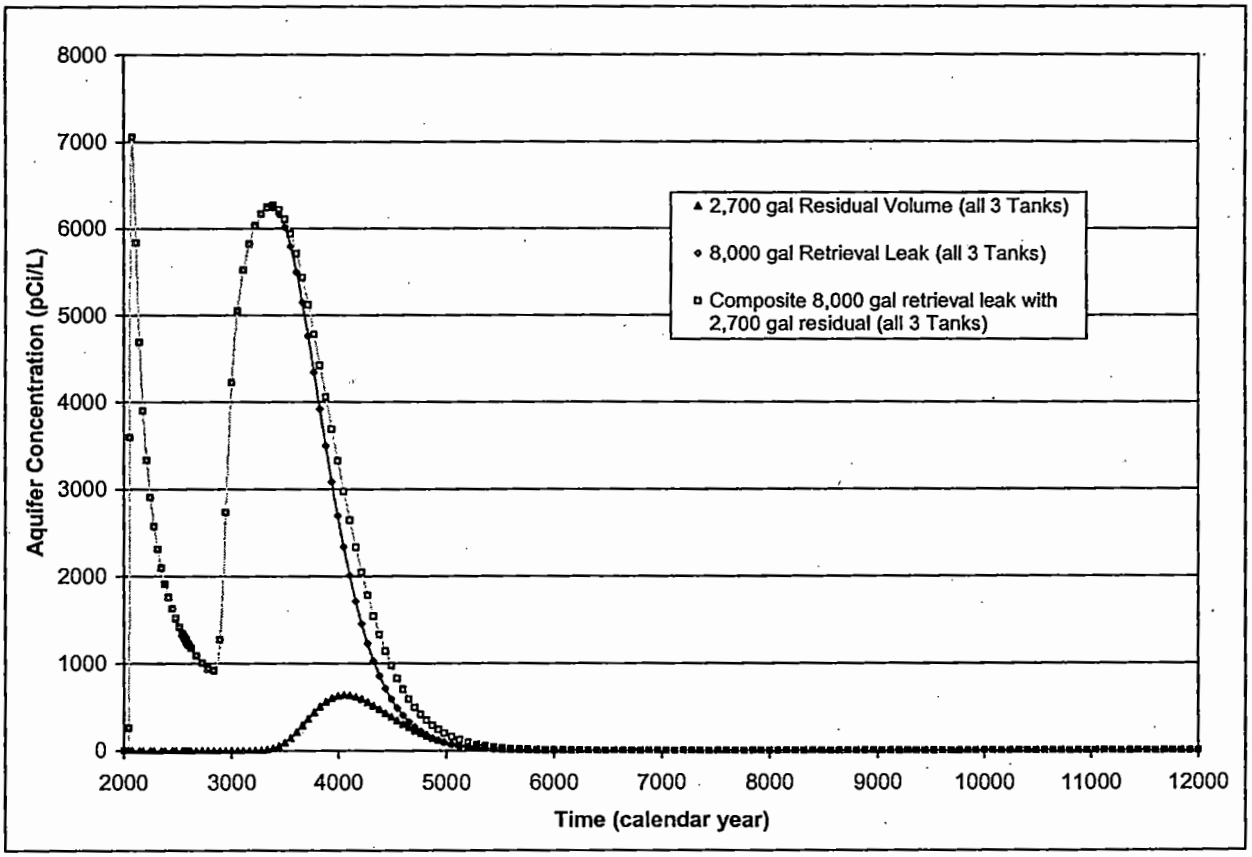
The relationship between volume of residual waste released and peak contaminant concentration for tank S-102 is illustrated in Figure B.5.8 for the near-field peak techetium-99 concentrations in groundwater. The overall relationship is not linear but could be approximated as two separate linear segments.

Figure B.5.8. Technetium-99 Peak Groundwater Concentration at the S Tank Farm Fence Line Versus Residual Volume in Tank S-102



B.5.1.2.2 Cross-Section Composite Retrieval Loss and Residual Waste Groundwater Impacts. The previous sections provided details on the potential impacts of the two individual source terms. In this section, the composite groundwater impacts that would occur are provided for selected combinations of the two source terms. The three traces in Figure B.5.9 illustrate near-field concentration of technetium-99 in groundwater versus time for (1) a 30,000 L (8,000 gal) retrieval loss from all three tanks; (2) a 10,200 L (2,700 gal) residual waste volume in all three tanks; and (3) the composite of these two source terms that would result from the comingling of the two technetium-99 contaminant plumes.

Figure B.5.9. Technetium-99 Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Composite 8,000 Gallon Retrieval Loss (All Tanks) and 2,700 Gallon Residual (All Tanks) for Cross-Section S-101



Using the waste retrieval cases defined in Section B.3.2, five variations of the potential composite groundwater impacts of the two source terms have been constructed, including the example illustrated in Figure B.5.9. These selected composite scenarios have assumed retrieval losses that range from 15,000 L (4,000 gal) to 150,000 L (40,000 gal) from tank S-102 and residual waste volumes that range from 5,000 L (1,300 gal) to 102,000 L (27,000 gal) from tank S-102. Figures B.5.10 through B.5.12 provide a graphical comparison of the selected composite results of the near-field contaminant concentrations. The mobile contaminants, techetium-99 and nitrate, exhibit a bimodal peak response. Groundwater impacts from the residual source term do not begin to occur until about the year 3200 which is well after the early peak, thus the early peak

for the composite impacts is the same as shown for the retrieval loss impacts in the previous section. The late-time peaks are affected by the residual and retrieval waste source terms. The year of peak contaminant concentration and the contaminant concentration at the peak for technetium-99, uranium-238, and nitrate are summarized in Table B.5.4 for each of the seven potential cross-section S-101 composite cases. Cross-references to the waste retrieval cases defined in Section B.3.2 are also provided in this table.

Figure B.5.10. Comparison Groundwater Concentrations of Technetium-99 Versus Time at the S Tank Farm Fence Line for Composite Retrieval and Residual Source Terms for Cross-Section S-101

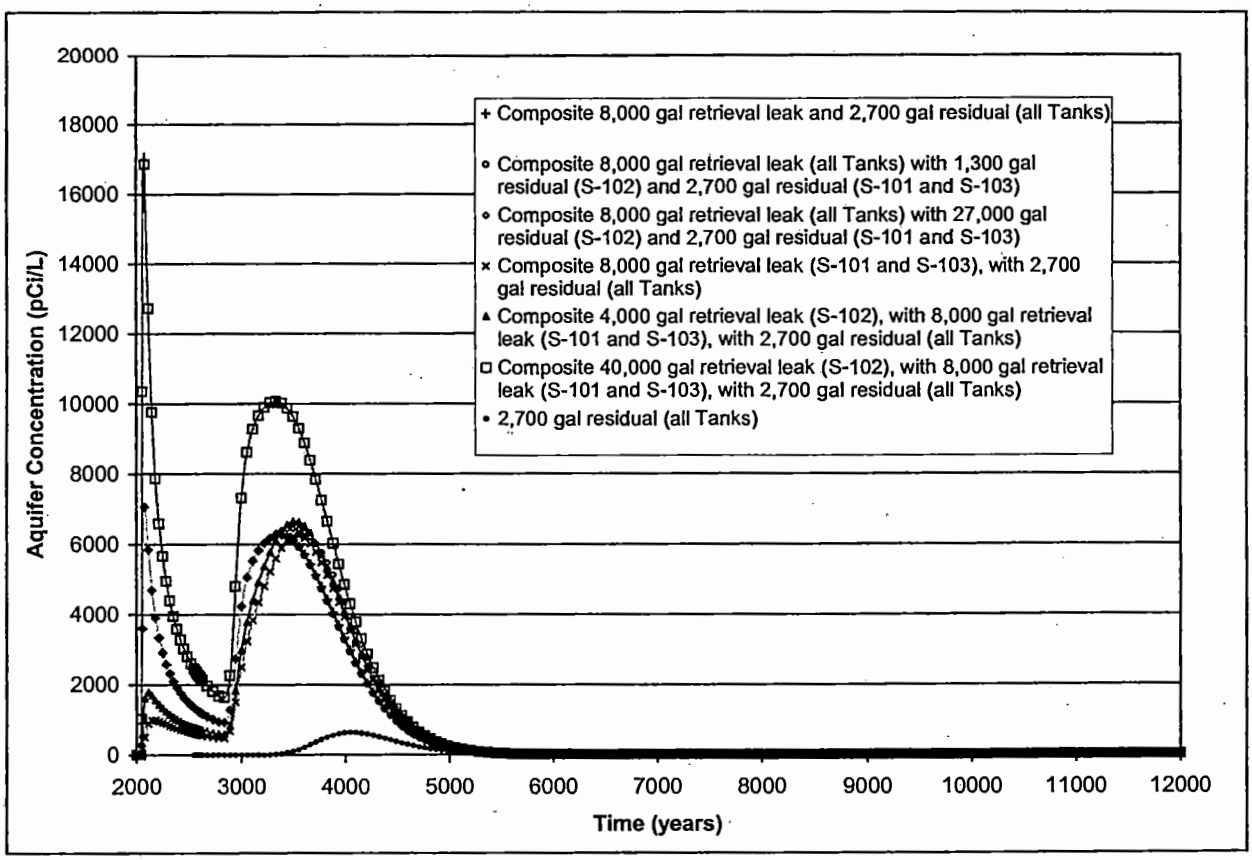


Figure B.5.11. Comparison Groundwater Concentrations of Nitrate Versus Time at the S Tank Farm Fence Line for Composite Retrieval and Residual Source Terms for Cross-Section S-101

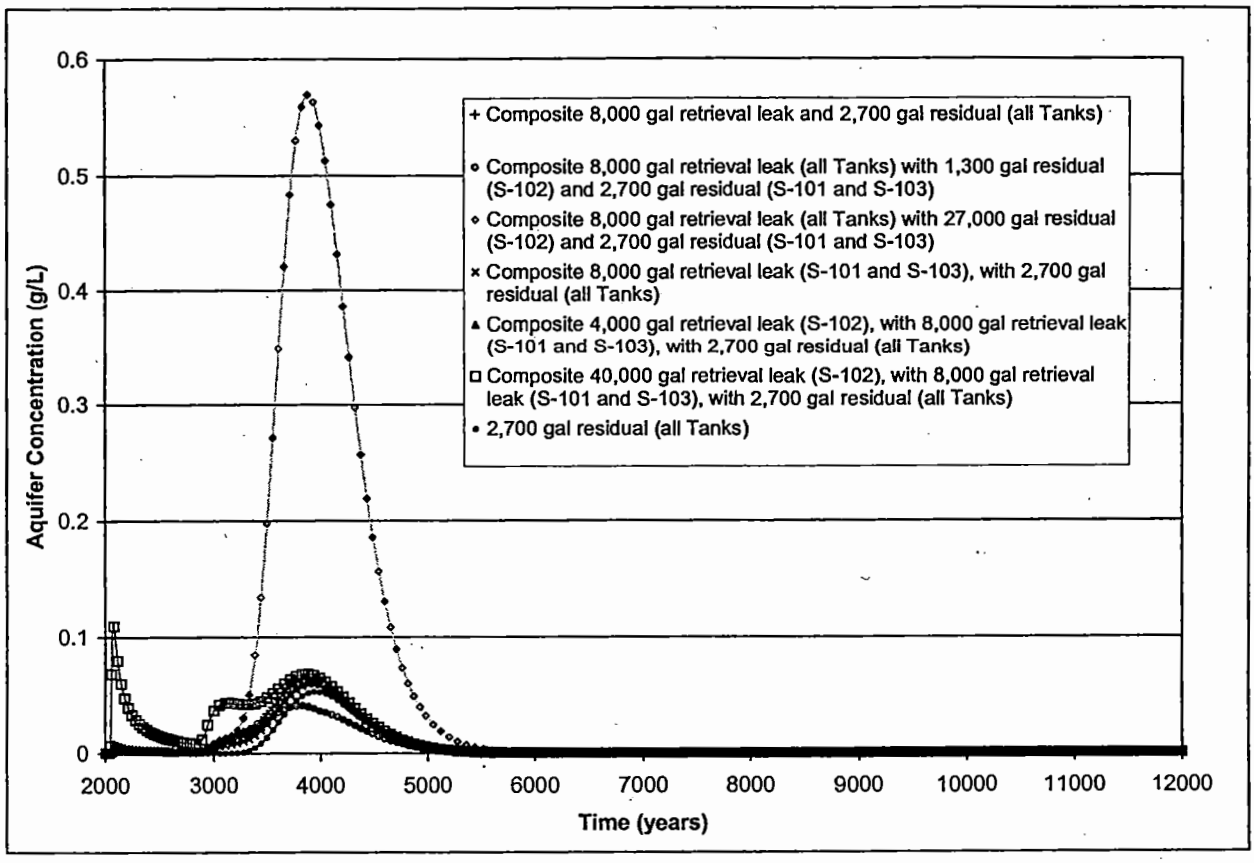


Figure B.5.12. Comparison Groundwater Concentrations of Uranium-238 Versus Time at the S Tank Farm Fence Line for Composite Retrieval and Residual Source Terms for Cross-Section S-101

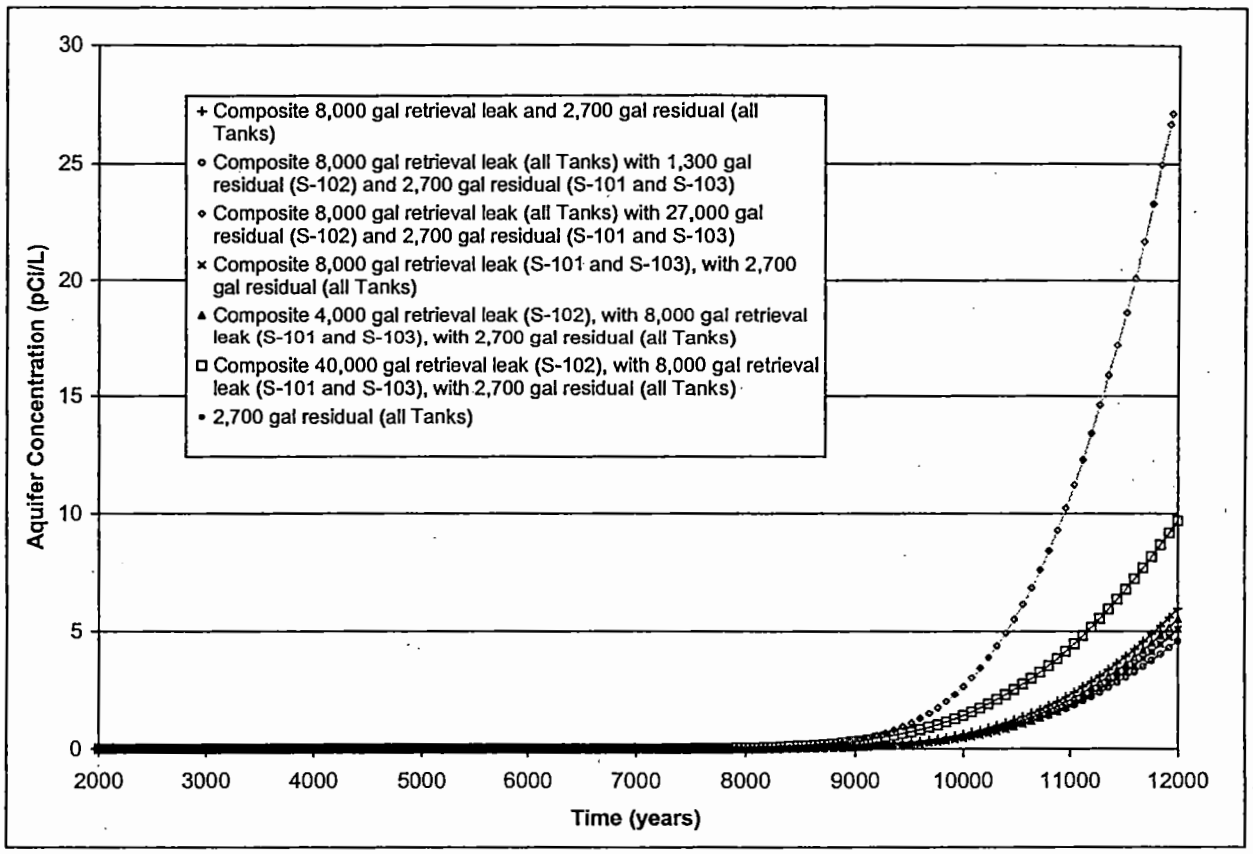


Table B.5.4. Summary of Peak Contaminant Concentrations and the Calendar Year in which they occur for Selected Composite Terms for Cross-Section S-101

Case Number and Description of Composite Retrieval and Residual Simulation		U-238, pCi/L	Tc-99, pCi/L	Nitrate, g/L
Case 1: 2,700 gal residual waste volume in all three tanks, no retrieval losses	Peak Conc.	5.10E+00	6.39E+02	5.31E-02
	Year Peak Occurs	12000	4050	3950
Case 2: Composite 8,000 gal retrieval leak (all tanks) and 2,700 gal residual waste (all tanks)	Peak Conc.	5.97E+00	7.06E+03	6.57E-02
	Year Peak Occurs	12000	2075	3895
Case 3: Composite 8,000 gal retrieval leak (all tanks), with 1,300 gal residual (S-102), with 2,700 gal residual (S-101 and S-103)	Peak Conc.	4.60E+00	7.06E+03	4.11E-02
	Year Peak Occurs	12000	2075	3805
Case 5: Composite 8,000 gal retrieval (all tanks), with 27,000 gal residual waste (S-102), with 2,700 gal residual waste (S-101 and S-103)	Peak Conc.	2.72E+01	7.06E+03	5.70E-01
	Year Peak Occurs	12000	2075	3885
Case 6: Composite 8,000 gal retrieval leak (S-101 and S-103) and 2,700 gal residual waste (all tanks)	Peak Conc.	5.10E+00	6.26E+03	6.00E-02
	Year Peak Occurs	12000	3535	3905
Case 7: Composite 4,000 gal retrieval leak (S-102), with 8,000 gal retrieval leak (S-101 and S-103), with 2,700 gal residual waste (all tanks)	Peak Conc.	5.53E+00	6.65E+03	6.10E-02
	Year Peak Occurs	12000	3515	3910
Case 8: Composite 40,000 gal retrieval leak (S-102), with 8,000 gal retrieval leak (S-101 and S-103), with 2,700 gal residual waste (all tanks)	Peak Conc.	9.69E+00	1.72E+04	1.12E-01
	Year Peak Occurs	12000	2070	2070

Notes: (1) Peak concentration values for technetium-99 and uranium-238 are decayed from the year 2000. (2) All tanks refer to all tanks in the S-101 cross-section (S-101, S-102, S-103). (3) Case 4 is not shown because for the S-101 cross-section it is the same as Case 2.

B.5.1.2.3 Tank S-102 Composite Results. To investigate the groundwater impacts associated with the tank S-102, the composite source term (retrieval leakage and residual waste) was analyzed for the waste retrieval cases identified in Section B.3.2. Results are summarized in Table B.5.5. The highest concentrations are associated with the largest retrieval losses.

Table B.5.5. Summary of Peak Contaminant Concentrations and the Calendar Year in Which They Occur for Releases from Tank S-102 Only

Case Number and Description of Release Associated with Tank S-102		U-238, pCi/L	Tc-99, pCi/L	Nitrate, g/L
2,000 gal retrieval leak with 2,700 gal residual from S-102 only*	Peak Conc.	2.86E+00	5.36E+02	5.55E-02
	Year Peak Occurs	12000	2075	3890
Cases 1 and 6: 2,700 gal residual waste volume in S-102 only	Peak Conc.	2.65E+00	1.19E+02	5.49E-02
	Year Peak Occurs	12000	3890	3890
Cases 2 and 4: 8,000 gal retrieval leak with 2,700 gal residual only from S-102 only	Peak Conc.	3.51E+00	2.42E+03	5.70E-02
	Year Peak Occurs	12000	2075	3880
Case 3: 8,000 gal retrieval leak with 1,300 gal residual only from S-102 only	Peak Conc.	2.14E+00	2.42E+03	2.86E-02
	Year Peak Occurs	12000	2075	3865
Case 5: 8,000 gal retrieval leak with 27,000 gal residual from S-102 only	Peak Conc.	2.61E+01	2.42E+03	5.59E-01
	Year Peak Occurs	12000	2075	3890
8,000 gal retrieval leak with 50,000 gal residual from S-102 only*	Peak Conc.	4.20E+01	2.56E+03	1.04E+00
	Year Peak Occurs	12000	3845	3890
Case 7: 4,000 gal retrieval leak with 2,700 gal residual only from S-102 only	Peak Conc.	3.07E+00	1.12E+03	5.60E-02
	Year Peak Occurs	12000	2075	3885
Case 8: 40,000 gal retrieval leak with 2,700 gal residual only from S-102 only	Peak Conc.	7.24E+00	1.68E+04	1.12E-01
	Year Peak Occurs	12000	2070	2070

*Sensitivity cases.

B.5.1.3 Tank S-102 Long-Term Human Health Risk Assessment Results

Results of the tank S-102 long-term human health risk assessment are provided in this section based on predicted contaminant concentrations in groundwater at the east fence line of the S tank farm (Section B.5.1.2). Results are provided on both a tank-specific (Section B.5.1.3.1) and cross-section (Section B.5.1.3.2) basis. A comparison of the results for the different receptor scenarios evaluated is also provided (Section B.5.1.3.3). Assessment results for the S tank farm as a whole, including changes in S tank farm impacts resulting from changes in tank S-102 retrieval leakage, are provided in Section B.5.3.3.

The Washington State Department of Health has issued guidance that the dose limit for release of a site is 15 mrem/yr total effective dose equivalent (WDOH/320-015). The DOE dose limit defined in DOE O 435.1 for LLW facility closure is 25 mrem/yr total effective dose equivalent from all exposure pathways. To provide a comparison of these dose rates with the long-term risks presented, the 25 mrem/yr dose limit can be converted to long-term human health risk by using a conversion factor of 6×10^{-4} cancer incidences per rem. This dose can be converted to an annual dose by taking the scenario-specific exposure durations into account. Using the conversion an annual dose of 15 mrem/yr converts to a risk of 9×10^{-6} on an annual basis. When the exposure durations for the industrial worker (20 years) and residential farmer (30 years) are taken into account the 15 mrem/yr dose corresponds to an ILCR of 1.8×10^{-4} and 2.7×10^{-4} for the industrial worker and residential farmer scenarios, respectively.

B.5.1.3.1 Tank-Specific Results for Tank S-102. Tank-specific results for tank S-102 are provided individually by source term for the retrieval leakage, residual waste, and composite source terms.

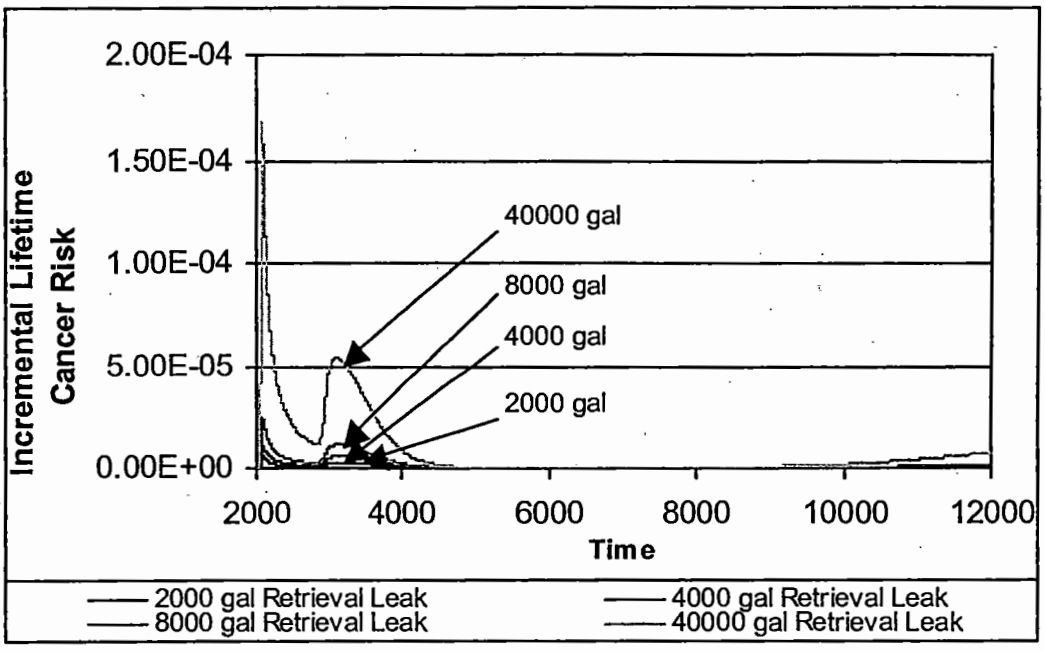
B.5.1.3.1.1 Retrieval Leakage. To develop a risk-to-volume relationship for retrieval leakage from tank S-102, retrieval leaks of 7,500, 15,000, 30,000, and 150,000 L (2,000, 4,000, 8,000, and 40,000 gal) are analyzed. Results are summarized in Table B.5.6 and Figure B.5.13. Table B.5.6 shows the peak ILCR and hazard index at the tank farm fence line for each leak volume; Figure B.5.13 illustrates variations in ILCR from retrieval leakage over time for each leak volume. The peak industrial worker ILCR ranges between 5.4×10^{-6} and 1.7×10^{-4} and the peak hazard index ranges between 9.1×10^{-2} and 2.9×10^{0}. The peak residential farmer ILCR ranges between 2.1×10^{-4} and 6.6×10^{-3} and the peak hazard index ranges between 2.7×10^{1} and 8.6×10^{2}.

Table B.5.6. Tank S-102 Peak ILCR and Hazard Index at the S Tank Farm Boundary from Retrieval Leakage

Volume (gal)	ILCR		Hazard Index	
	Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
2,000	2.1E-04	5.4E-06	2.7E+01	9.1E-02
4,000	4.4E-04	1.1E-05	5.7E+01	1.9E-01
8,000	9.4E-04	2.4E-05	1.2E+02	4.1E-01
40,000	6.6E-03	1.7E-04	8.6E+02	2.9E+00

ILCR = incremental lifetime cancer risk.

Figure B.5.13. Tank S-102 Industrial Worker ILCR Versus Time at the S Tank Farm Boundary from Retrieval Leakage



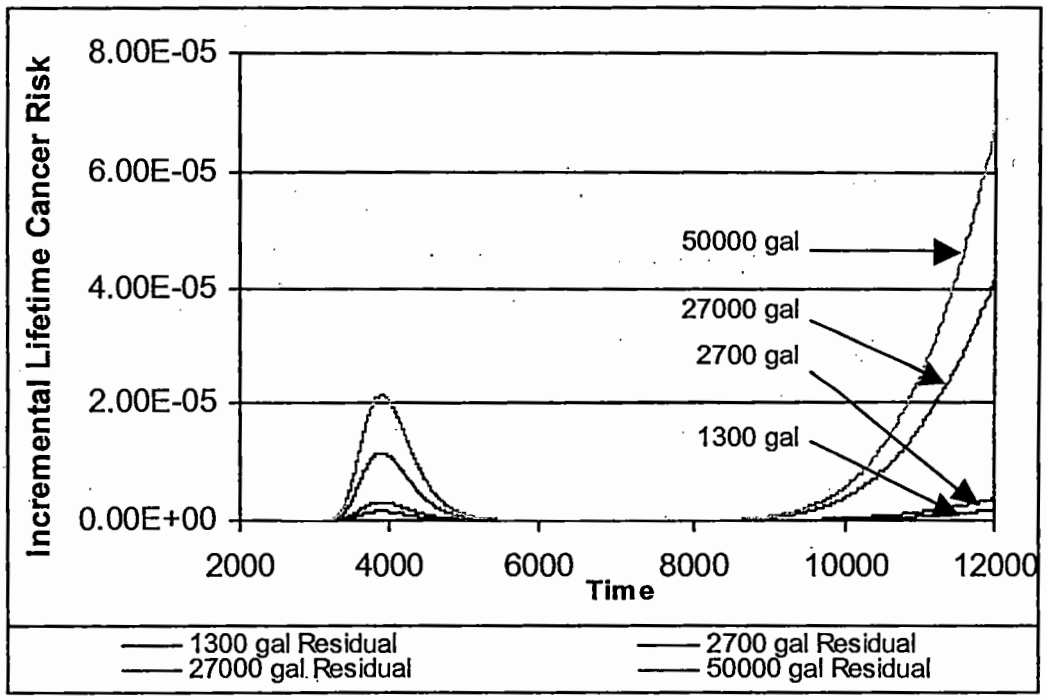
B.5.1.3.1.2 Residual Waste. To develop a risk-to-volume relationship for residual waste in tank S-102, residual waste volumes of 5,000, 10,200, 102,000, and 190,000 L (1,300, 2,700, 27,000, and 50,000 gal) are analyzed. Results are summarized in Table B.5.7 and Figure B.5.14. Table B.5.7 shows the peak ILCR and hazard index at the tank farm fence line for each residual waste volume; Figure B.5.14 illustrates variations in ILCR from residual waste over time for each residual waste volume. The peak industrial worker ILCR ranges between 1.8×10^{-6} and 6.8×10^{-5} and the peak hazard index ranges between 2.8×10^{-1} and 6.5×10^{0}. The peak residential farmer ILCR ranges between 3.2×10^{-5} and 7.9×10^{-4} and the peak hazard index ranges between 2.0×10^{2} and 7.8×10^{3}.

Table B.5.7. Tank S-102 Peak ILCR and Hazard Index at the S Tank Farm Boundary from Residual Waste

Volume (gal)	ILCR		Hazard Index	
	Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
1,300	3.2E-05	1.8E-06	2.0E+02	2.8E-01
2,700	6.6E-05	3.6E-06	4.2E+02	5.8E-01
27,000	4.3E-04	4.2E-05	4.2E+03	3.5E+00
50,000	7.9E-04	6.8E-05	7.8E+03	6.5E+00

ILCR = incremental lifetime cancer risk.

Figure B.5.14. Tank S-102 Industrial Worker ILCR Versus Time at the S Tank Farm Boundary from Residual Waste



B.5.1.3.1.3 Composite Source Term. To illustrate the effects of variation in the two primary system components for tank S-102 (i.e., retrieval leakage and residual waste volume), analysis results are provided for two sets of composite source term combinations. The first set illustrates the effects of retrieval leakage variation by combining each of the four retrieval leak volumes analyzed with a residual waste volume of 10,000 L (2,700 gal). The second set illustrates the effects of residual waste variation by combining each of the four residual waste volumes analyzed with a 30,000 L (8,000 gal) retrieval leak. Results for the retrieval leakage set are shown in Table B.5.8 and Figure B.5.14. Results in Table B.5.8 closely track the results for the retrieval leakage source term cases (Table B.5.6), indicating retrieval leakage dominates a residual waste volume of 10,000 L (2,700 gal) even at small leak volumes. Results for the residual waste set are shown in Table B.5.8 and Figure B.5.15. Results in Table B.5.9 diverge at low volumes from the results shown in Table B.5.7, indicating residual waste dominates a 30,000 L (8,000 gal) retrieval leak at moderate to high residual waste volumes but not at low residual waste volumes. Table B.5.10 summarizes the tank S-102 composite source term results for the 10 waste retrieval cases identified in Section B.3.2.

Table B.5.8. Tank S-102 Peak ILCR and Hazard Index at the S Tank Farm Boundary from Composite of Varying Retrieval Leakage Volumes and 2,700 Gallons of Residual Waste

Retrieval Leakage Volume (gal)	ILCR		Hazard Index	
	Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
0	6.64E-05	3.64E-06	4.18E+02	5.81E-01
2,000	2.09E-04	5.38E-06	4.22E+02	5.96E-01
4,000	4.37E-04	1.12E-05	4.26E+02	6.10E-01
8,000	9.44E-04	2.43E-05	4.34E+02	6.37E-01
40,000	6.55E-03	1.69E-04	8.58E+02	2.87E+00

ILCR = incremental lifetime cancer risk.

Figure B.5.15. Tank S-102 Industrial Worker ILCR Versus Time at the S Tank Farm Boundary from Varying Retrieval Leakage and 2,700 Gallons of Residual Waste

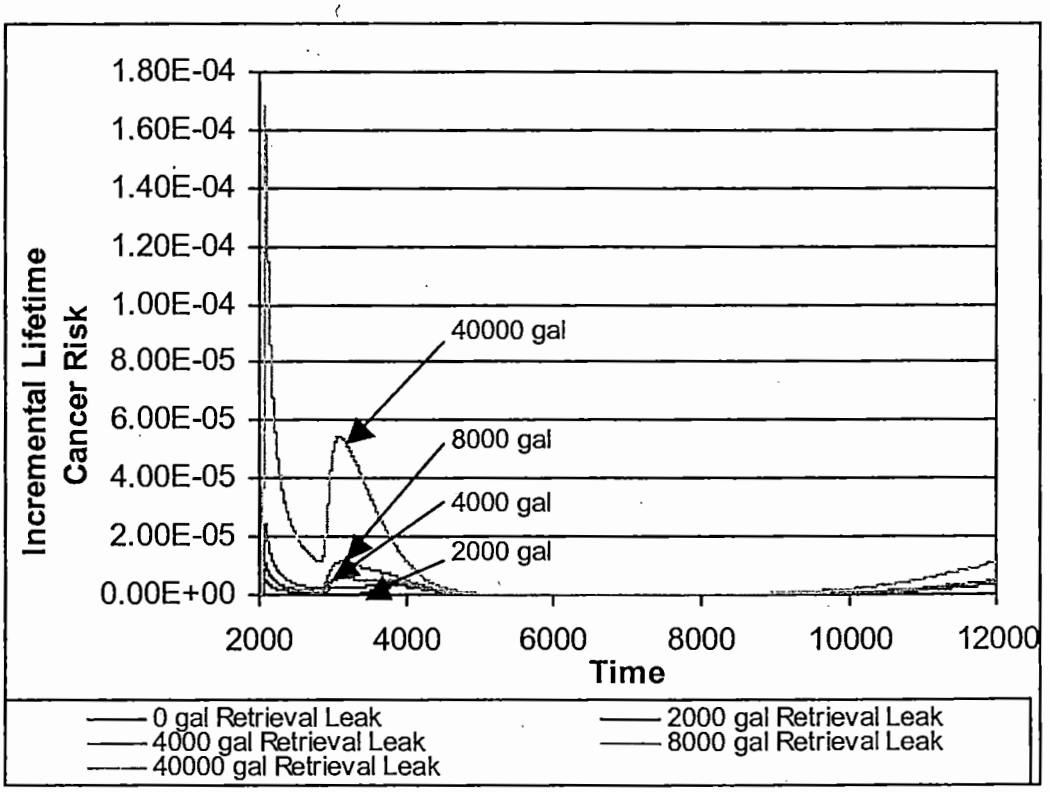


Table B.5.9. Tank S-102 Peak ILCR and Hazard Index at the S Tank Farm Boundary from Composite of Varying Residual Waste Volumes and 8,000 Gallons of Retrieval Leakage

Residual Waste Volume (gal)	ILCR		Hazard Index	
	Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
0	9.44E-04	2.43E-05	1.23E+02	4.13E-01
1,300	9.44E-04	2.43E-05	2.18E+02	4.13E-01
2,700	9.44E-04	2.43E-05	4.34E+02	6.37E-01
27,000	9.44E-04	4.30E-05	4.24E+03	3.55E+00
50,000	9.44E-04	6.93E-05	7.84E+03	6.53E+00

ILCR = incremental lifetime cancer risk.

Figure B.5.16. Tank S-102 Industrial Worker ILCR Versus Time at the S Tank Farm Boundary from Varying Residual Waste Volumes and 8,000 Gallons of Retrieval Leakage

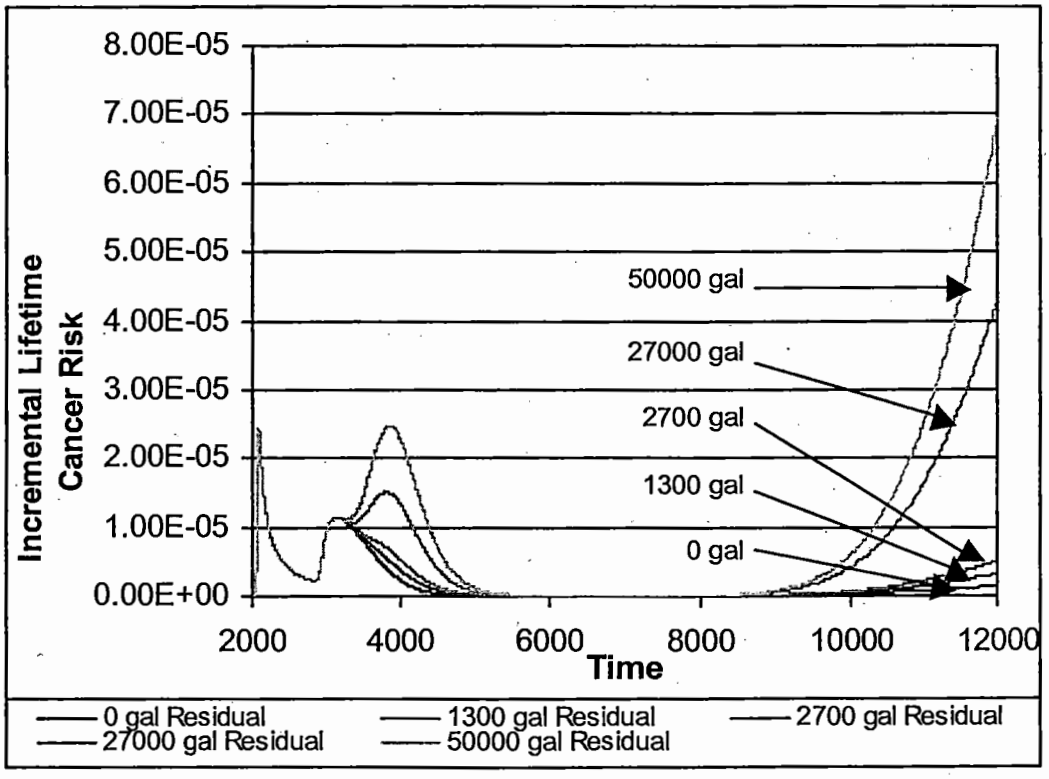


Table B.5.10. Tank S-102 Peak ILCR and Hazard Index at the S Tank Farm Boundary from Composite Source Term

Case (Table B.3.1)	Retrieval Leakage Volume (gal)	Residual Waste Volume (gal)	ILCR		Hazard Index	
			Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
1	0	2,700	6.64E-05	3.64E-06	4.18E+02	5.81E-01
2	8,000	2,700	9.44E-04	2.43E-05	4.34E+02	6.37E-01
3	8,000	1,300	9.44E-04	2.43E-05	2.18E+02	4.13E-01
4	8,000	2,700	9.44E-04	2.43E-05	4.34E+02	6.37E-01
5	8,000	27,000	9.44E-04	4.30E-05	4.24E+03	3.55E+00
6	0	2,700	6.64E-05	3.64E-06	4.18E+02	5.81E-01
7	4,000	2,700	4.37E-04	1.12E-05	4.26E+02	6.10E-01
8	40,000	2,700	6.55E-03	1.69E-04	8.58E+02	2.87E+00
9	8,000	2,700	9.44E-04	2.43E-05	1.23E+02	4.13E-01
10	NA	NA	NA	NA	NA	NA

ILCR = incremental lifetime cancer risk.
NA = not applicable.

B.5.1.3.2 S-101 Cross-Section Results. To investigate the human health impacts associated with the S-101 cross-section, the composite source term for the three tanks in combination is analyzed for the 10 waste retrieval cases identified in Section B.3.2. Results are summarized in Table B.5.11. The highest impacts are associated with Case 8, which represents a scenario with a large retrieval leak from tank S-102, small retrieval leaks from the other two cross-section tanks, and small residual waste volumes in each of the three cross-section tanks. The lowest impacts are associated with Case 1, which represents a scenario with no retrieval leaks from any of the three cross-section tanks and small residual waste volumes in each of the three tanks.

Table B.5.11. Cross-Section S-101 Peak ILCR and Hazard Index at the S Tank Farm Boundary from Composite Source Term

Case (Table B.3.1)	Retrieval Leakage Volume (gal)		Residual Waste Volume (gal)		ILCR		Hazard Index	
	Tank S-102	Tanks S-101, S-103	Tank S-102	Tanks S-101, S-103	Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
1	0	0	2,700	2,700	3.56E-04	1.68E-05	4.18E+02	5.81E-01
2, 4, 9	8,000	8,000	2,700	2,700	2.65E-03	7.16E-05	4.94E+02	8.53E-01
3	8,000	8,000	1,300	2,700	2.64E-03	7.08E-05	2.82E+02	5.77E-01
5	8,000	8,000	27,000	2,700	2.81E-03	7.61E-05	4.30E+03	3.75E+00
6	0	8,000	2,700	2,700	2.37E-03	6.47E-05	4.77E+02	7.87E-01
7	4,000	8,000	2,700	2,700	2.51E-03	6.82E-05	4.86E+02	8.21E-01
8	40,000	8,000	2,700	2,700	6.71E-03	1.73E-04	8.63E+02	2.89E+00
10	NA	NA	NA	NA	NA	NA	NA	NA

ILCR = incremental lifetime cancer risk.
NA = not applicable.

B.5.1.3.3 Receptor Scenario Comparison. Table B.5.12 provides a comparison of the composite source term results for the receptor scenarios based on DOE/RL-91-45 (industrial worker and residential farmer) with the results for the MTCA scenarios (Method B and Method C). Because the MTCA risk criteria (WAC 173-340) are applicable only to nonradioactive contaminants, Table B.5.12 compares only hazard index values. Table B.5.12 indicates that the residential farmer scenario is consistently the most conservative (i.e., produces the highest hazard index values), followed by MTCA Method B and MTCA Method C. The industrial worker scenario is the least conservative (i.e., produces the lowest hazard index values) of the four exposure scenarios.

Table B.5.12. Comparison of Peak Hazard Index at the S Tank Farm Boundary from Composite Source Term for Different Receptor Scenarios

Case	Tank S-102				S-101 Cross-Section			
	Residential Farmer	Industrial Worker	MTCA Method B	MTCA Method C	Residential Farmer	Industrial Worker	MTCA Method B	MTCA Method C
1	4.18E+02	5.81E-01	1.34E+01	6.12E+00	4.18E+02	5.81E-01	1.34E+01	6.12E+00
2	4.34E+02	6.37E-01	1.39E+01	6.37E+00	4.94E+02	8.53E-01	1.60E+01	7.31E+00
3	2.18E+02	4.13E-01	7.02E+00	3.21E+00	2.82E+02	5.77E-01	9.19E+00	4.20E+00
4	4.34E+02	6.37E-01	1.39E+01	6.37E+00	4.94E+02	8.53E-01	1.60E+01	7.31E+00
5	4.24E+03	3.55E+00	2.51E+01	1.15E+01	4.30E+03	3.75E+00	2.72E+01	1.24E+01
6	4.18E+02	5.81E-01	1.34E+01	6.12E+00	4.77E+02	7.87E-01	1.54E+01	7.04E+00
7	4.26E+02	6.10E-01	1.37E+01	6.25E+00	4.86E+02	8.21E-01	1.57E+01	7.18E+00
8	8.58E+02	2.87E+00	2.91E+01	1.33E+01	8.63E+02	2.89E+00	2.93E+01	1.34E+01
9	4.34E+02	6.37E-01	1.39E+01	6.37E+00	4.94E+02	8.53E-01	1.60E+01	7.31E+00
10	NA	NA	NA	NA	NA	NA	NA	NA

MTCA = Model Toxics Control Act.
NA = not applicable.

B.5.1.4 Tank S-102 Intruder Risk Assessment Results

This section presents the results of the risk analyses for an inadvertent human intruder based on the DOE and NRC methodologies described in Section B.3.7. The DOE inadvertent human intruder analysis involves a well driller scenario and post-driller resident scenario, whereas the NRC inadvertent human intruder analysis is based on a scenario of the tank waste meeting the concentration limits established for Class C for an inadvertent human intruder at 500 years.

B.5.1.4.1 U.S. Department of Energy Intruder Scenario. The doses to the well driller and post-driller resident for each of the waste retrieval cases are presented in Table B.5.13. The source or the total activity in curies of each constituent exhumed and made available at the surface for all the cases includes a fraction of waste from the residual waste in tank S-102 and soil contaminated by tank S-102 retrieval leak losses. The radiological activity in the residual waste and retrieval leak losses is obtained from calculations presented in the Attachment to this appendix.

Table B.5.13. Well Driller and Post-Driller Resident Dose in the Year 2100 for Tank S-102

Case (Table B.3.1)	Well Driller (mrem/incident)	Post-Driller Resident (mrem/yr)
1	6.9E-01	7.9E+00
2	3.1E+00	1.8E+01
3	2.8E+00	1.4E+01
4	3.1E+00	1.8E+01
5	9.2E+00	8.9E+01
6	6.8E-01	7.9E+00
7	1.9E+00	1.3E+01
8	1.3E+01	5.7E+01
9	3.1E+00	1.8E+01
10	6.8E-01	7.9E+00

Note: U.S. Department of Energy regulations limit exposures to an inadvertent human intruder to no greater than 100 mrem/yr for chronic exposure (post-driller resident) and 500 mrem for an acute or single event (well driller) at a point in time 100 years after closure (DOE O 435.1).

B.5.1.4.2 U.S. Nuclear Regulatory Commission Requirements. A comparison of the radionuclide concentrations in the residual waste in tank S-102 to the Class C upper limit concentration values is presented in Table B.5.14. The tank S-102 residual concentrations are discussed in more detail in the Attachment to this appendix. The comparison shows that all isotopes are less than the Class C upper limits. Table B.5.14 also shows the long-lived and short-lived radionuclide sums-of-fractions are less than 1.

Table B.5.14. Tank S-102 Residual Waste Concentrations Compared to the Class C Upper Limits

Radionuclides	Class C Upper Limits	All Cases
Long-Lived Radionuclides		
Carbon-14	8 Ci/m^3	0.0003 Ci/m^3
Carbon-14 in activated metal	80 Ci/m^3	0 Ci/m^3
Nickel-59 in activated metal	220 Ci/m^3	0 Ci/m^3
Niobium-94 in activated metal	0.2 Ci/m^3	0 Ci/m^3
Technetium-99	3 Ci/m^3	0.02 Ci/m^3
Iodine-129	0.08 Ci/m^3	0 Ci/m^3
Alpha emitting transuranic with $t_{1/2} > 5$ yr		
Neptunium-237	100 nCi/g	0.005 nCi/g
Plutonium-238, 239, 240	100 nCi/g	2.5 nCi/g
Americium-241, 243	100 nCi/g	2.2 nCi/g
Curium-243 to 247	100 nCi/g	0.004 nCi/g
Berkelium-247	100 nCi/g	0 nCi/g
Californium-249 to 251	100 nCi/g	0 nCi/g
Plutonium-241	3,500 nCi/g	7.8 nCi/g
Curium-242	20,000 nCi/g	0.01 nCi/g
Short-Lived Radionuclides		
Nickel-63	700 Ci/m^3	2.6 Ci/m^3
Nickel-63 in activated metal	7,000 Ci/m^3	0 Ci/m^3
Strontium-90	7,000 Ci/m^3	372 Ci/m^3
Cesium-137	4,600 Ci/m^3	54 Ci/m^3
Sum-of-fractions for long-lived radionuclides	1.0	0.1
Sum-of-fractions for short-lived radionuclides	1.0	0.07

B.5.1.5 Tank S-102 Regulatory Compliance Assessment Results

This section describes the regulatory compliance for the results presented in Sections B.5.1.1 to B.5.1.4 for Cases 1 through 9 as defined in Section B.3.2. Each of the following items is evaluated against the regulatory standards:

- Short-term human health risk to the worker MEI and the general public MEI from radiological and hazardous constituents
- Groundwater protection

- Long-term human health risk to the residential farmer and industrial worker from radiological and hazardous constituents for the peak time periods over a 10,000-year period
- Risk to DOE and NRC inadvertent human intruder
- HFFACO milestones.

B.5.1.5.1 Tank S-102 Short-Term Human Health Risk Compliance. Short-term human health risk is evaluated based on operating the waste retrieval system to different endpoints in terms of residual waste volumes. Short-term human health risk is affected by variance in the duration of the waste retrieval operations; that is, the more waste retrieved, the longer the duration for waste retrieval and more exposure to workers and the public.

B.5.1.5.1.1 Routine Radiological Exposure During Retrieval Operations. The regulatory requirement for worker exposure based on annual whole body dose is 5.0 rem/yr (10 CFR 20; DOE Order 5480.11). Hanford Site Administrative Controls limit a worker's annual whole body dose to 0.5 rem/yr (HSRCM-1). Worker radiological dose during routine waste retrieval operations will be carefully monitored to ensure levels do not exceed recommended standards. The functional requirement or standard of practicality in this instance is to demonstrate with worker dose estimates that waste from tank S-102 can be retrieved with appropriate time, distance, and shielding provisions in a manner that maintains worker doses within acceptable limits. The general public radiological dose from normal operations does not exceed the regulatory requirement standard of 100 mrem/yr for all waste retrieval cases based on the assumptions and data in this report. Based on the results, no LCFs are reported for the general public or offsite receptor.

B.5.1.5.1.2 Routine Chemical Exposure During Retrieval Operations. Short-term chemical health impacts from normal operations would be below the regulatory standard for noncarcinogenics for all waste retrieval cases based on available data and assumptions documented in this report. For carcinogenic risks from exposure, the ILCR for the noninvolved worker and public would be below the regulatory standard of 1.0×10^{-6}. The involved worker ILCR would be below the Washington State standard of 1.0×10^{-5} for multiple constituents (WAC 173-340) and below the federal standard of 1.0×10^{-4} (55 FR 8666).

B.5.1.5.2 Tank S-102 Groundwater Protection Compliance. Groundwater quality requirements include compliance with EPA maximum contaminant levels (MCLs) (40 CFR 141), the DOE derived concentration guide (DOE Order 5400.5), and concentration limits under WAC 173-303-645. The most restrictive of these groundwater quality requirements is the EPA MCLs.

Three CoCs were evaluated for compliance with regulatory requirements. The CoC with the highest predicted concentration level for the radionuclides in the groundwater is technetium-99. Technetium-99 is used as an indicator contaminant because of its mobility in the environment (distribution coefficient of 0) and its long half-life. Uranium-238 is also of interest because of its moderate mobility in the environment (distribution coefficient of 0.6) and its long half-life.

The third contaminant evaluated is nitrate, a chemical of concern for potential groundwater impact.

Results of groundwater protection compliance evaluation are presented first for groundwater impacts associated with retrieval, then for impacts associated with residual waste, third for impacts for tank S-102 composite source term, and finally for the S-101 cross-section.

B.5.1.5.2.1 Retrieval. As discussed in Section B.5.1.2.1.1, technetium-99 exceeds the EPA regulatory MCL (900 pCi/L) for all retrieval loss volumes considered except 7,600 L (2,000 gal). Uranium-238 does not exceed the EPA regulatory MCL (6.7 pCi/L) for any volume. Nitrate exceeds drinking water standards (DWSs) (45 mg/L) only for the 150,000 L (40,000 gal) retrieval loss.

B.5.1.5.2.2 Residual. As discussed in Section B.5.1.2.1.2, technetium-99 exceeds the EPA regulatory MCL (900 pCi/L) for residual waste volumes of 102,000 L (27,000 gal) and 190,000 L (50,000 gal). Uranium-238 exceeds the EPA regulatory MCL (6.7 pCi/L) for 102,000 L (27,000 gal) and 190,000 L (50,000 gal) of residual waste. Nitrate exceeds DWSs (45 mg/L) for all volumes except 5,000 L (1,300 gal) of residual waste.

B.5.1.5.2.3 Tank S-102 Composite Retrieval Loss and Residual Waste. As shown in Table B.5.4 of Section B.5.1.2.1.3, technetium-99 exceeds the EPA regulatory MCL (900 pCi/L) in all cases except Cases 1 and 6. Uranium-238 exceeds the EPA regulatory MCL (6.7 pCi/L) only in Cases 5 and 8. Nitrate exceeds DWSs (45 mg/L) in all cases except Case 3.

B.5.1.5.2.4 Cross-Section. As shown in Table B.5.4 of Section B.5.1.2.2, in the cross-section for tank S-112 technetium-99 exceeds the EPA regulatory MCL (900 pCi/L) in all cases except Case 1. Uranium-238 exceeds the EPA regulatory MCL (6.7 pCi/L) only in Cases 5 and 8. Nitrate exceeds DWSs (45 mg/L) in all cases except Case 3.

B.5.1.5.3 Tank S-102 Long-Term Human Health Risk Compliance. Long-term human health risk is evaluated based on maximum groundwater concentration and exposure scenarios as expressed in human health risk resulting from exposure to nine radiological contaminants (technetium-99; selenium-79; iodine-129; carbon-14; and uranium-233, -234, -235, -236, and -238) and four chemical contaminants (total uranium, chromate, nitrate, and nitrite). These contaminants were chosen to evaluate long-term human health risk.

For carcinogenic risk the level of protection required under the regulations ranges from 1 in 10,000 (1.0×10^{-4}) to 1 in 1,000,000 (1.0×10^{-6}). Washington State requires the ILCR be no higher than 1.0×10^{-6} for individual contaminants and 1.0×10^{-5} for multiple contaminants (WAC 173-340), while the EPA requires the ILCR be no higher than 1.0×10^{-4} (55 FR 8666). For noncarcinogenic risk a hazard index equal to or greater than 1.0 exceeds state and federal standards.

Regulatory standards may be exceeded for long-term human health risk and not for DWSs (40 CFR 141; EPA/822-B-96-002) as a result of water being used for bathing, washing food, irrigation, as well as drinking for the residential farmer exposure scenario; the DWS only

assumes consumption. For example, the DWS for technetium-99 is 900 pCi/L; exposure to groundwater concentrations at this level would result in an ILCR of 2.3×10^{-4} for a residential farmer.

Results of the long-term human health risk protection compliance (ILCR and hazard index) evaluation are presented in both industrial worker and residential farmer scenarios first for long-term impacts associated with retrieval, then for impacts associated with residual waste, third for impacts for the tank S-102 composite source term, and finally for the S-101 cross-section.

B.5.1.5.3.1 Retrieval. As shown in Table B.5.5 of Section B.5.1.3.1.1, the ILCR risk exceeds the Washington State long-term human health cancer risk standard (1.0×10^{-5}) for all retrieval loss volumes considered except 7,500 L (2,000 gal) of retrieval loss for the industrial worker; it is exceeded for all volumes for the residential farmer. The hazard index standard of 1.0 is only exceeded for the industrial worker for 150,000 L (40,000 gal) of retrieval loss; it is exceeded for all volumes for the residential farmer.

B.5.1.5.3.2 Residual. As shown in Table B.5.6 of Section B.5.1.3.1.2, the ILCR risk exceeds the Washington State long-term human health cancer risk standard (1.0×10^{-5}) for 102,000 L (27,000 gal) and 190,000 L (50,000 gal) of residual waste for the industrial worker; it is exceeded for all volumes for the residential farmer. The hazard index standard of 1.0 is also exceeded for the industrial worker for 102,000 L (27,000 gal) and 190,000 L (50,000 gal) of residual waste; it is exceeded for all volumes for the residential farmer.

B.5.1.5.3.3 Tank S-102 Composite Retrieval Loss and Residual Waste. As shown in Table B.5.9 of Section B.5.1.3.1.3, the ILCR risk exceeds the Washington State long-term human health cancer risk standard (1.0×10^{-5}) for the composite source term for tank S-102 for the industrial worker in all cases except Cases 1 and 6; exceedance occurs in all cases for the residential farmer. The hazard index standard of 1.0 is exceeded for the industrial worker only in Cases 5 and 8; it is exceeded in all cases for the residential farmer.

B.5.1.5.3.4 Cross-Section. As shown in Table B.5.10 of Section B.5.1.3.2, the ILCR risk exceeds the Washington State long-term human health cancer risk standard (1.0×10^{-5}) for the S-101 cross-section in all cases for both the industrial worker and the residential farmer. The hazard index standard of 1.0 is exceeded for the industrial worker only in Cases 5 and 8; it is exceeded in all cases for the residential farmer.

B.5.1.5.4 Tank S-102 Inadvertent Human Intrusion Compliance. DOE regulations limit exposures to an inadvertent human intruder to no greater than 100 mrem/yr for chronic exposure and 500 mrem for an acute or single event at a point in time 100 years after closure (DOE O 435.1). A post-driller resident scenario is used to provide the bounding analysis for chronic exposure; a well-driller scenario is used to provide the bounding analysis for acute exposure. Results of the analysis (Table B.5.14) indicate that tank S-102 would meet the 500 mrem acute dose limit in all waste retrieval cases and would meet the 100 mrem/yr chronic dose limit in all cases. According to the results presented in Section B.5.2.4.2, the NRC standard for upper concentration limits for Class C LLW disposal is not exceeded in any of the waste retrieval cases.

B.5.1.5.5 Tank S-102 HFFACO Milestone Compliance. HFFACO Milestone M-45-05A states:

> Goals of this demonstration shall include the retrieval to safe storage of approximately 490 Curies of mobile long-lived radioisotopes and 99% of tank contents by volume (per DOE Best-Basis Inventory data, 8/01/2000).

The contaminants considered mobile and long-lived in this evaluation are technetium-99; iodine-129; selenium-79; carbon-14; and uranium-233, -234, -235, -236, and -238. Per the August 2000 BBI these radioisotopes in tank S-102 contained a total of 487 curies; therefore, none of the waste retrieval cases can meet the Milestone M-45-05A demonstration goal of retrieving approximately 490 curies of mobile, long-lived radioisotopes. However, leaving a residual of 10,200 L (2,700 gal) or less, all cases evaluated except Case 5, will retrieve approximately 487 curies of mobile, long-lived radioisotopes from tank S-102.

Based on the current inventory (Hale 2001) used in risk analyses of this RPE (see the Attachment to this Appendix), the contaminants of interest contain a total of 275 curies so it is impossible to meet the HFFACO milestone of removing approximately 490 curies. Leaving a residual of 10,200 L (2,700 gal) or less, all cases except Case 5, will retrieve approximately 275 of the curies.

The second part of Milestone M-45-05A has the goal of retrieving 99% of tank contents by volume. Given the volume of waste in tank S-102, the retrieval of 99% of tank content is achieved by leaving a residual of 18,600 L (4,920 gal). The HFFACO Milestone M-45-00 interim retrieval goal of 360 ft^3 is 10,200 L (2,700 gal). The 8,400 L (2,200 gal) difference between 99% of volume and 360 ft^3 is minor in comparison to the uncertainty associated with measuring residual waste volumes.

B.5.2 S TANK FARM ASSESSMENT RESULTS

Impact assessment results for the S tank farm are provided in the following sections. Impacts evaluated for the S tank farm include impacts to groundwater, long-term human health risk, and regulatory compliance.

B.5.2.1 S Tank Farm Groundwater Impact Assessment Results

The previous sections provided the results that are specific to tank S-102 or the S-101 cross-section. It is also necessary to discuss the potential impacts from tank S-102 in the context of the potential release from all the tanks in the S tank farm. This is accomplished by considering base case retrieval loss and residual waste releases from the remaining tanks in combination with the past leak associated with tank S-104. These releases were simulated with three cross-sections: cross-section S-104 with three tanks and three source terms (i.e. past leak from tank S-104, retrieval losses from all tanks, and residual losses from all tanks) and cross-sections S-107 and S-110 with three tanks each and retrieval and residual losses from all tanks in each cross-section.

Selected retrieval loss and residual waste scenarios were then identified for the entire tank farm and the composite releases were developed with the principle of superposition as described in Section B.3.5. Then, using a simple stream tube analytical solution consistent with the approach used for the WMA S-SX field investigation report (RPP-7884) contaminant concentrations were calculated at two potential far-field compliance points:

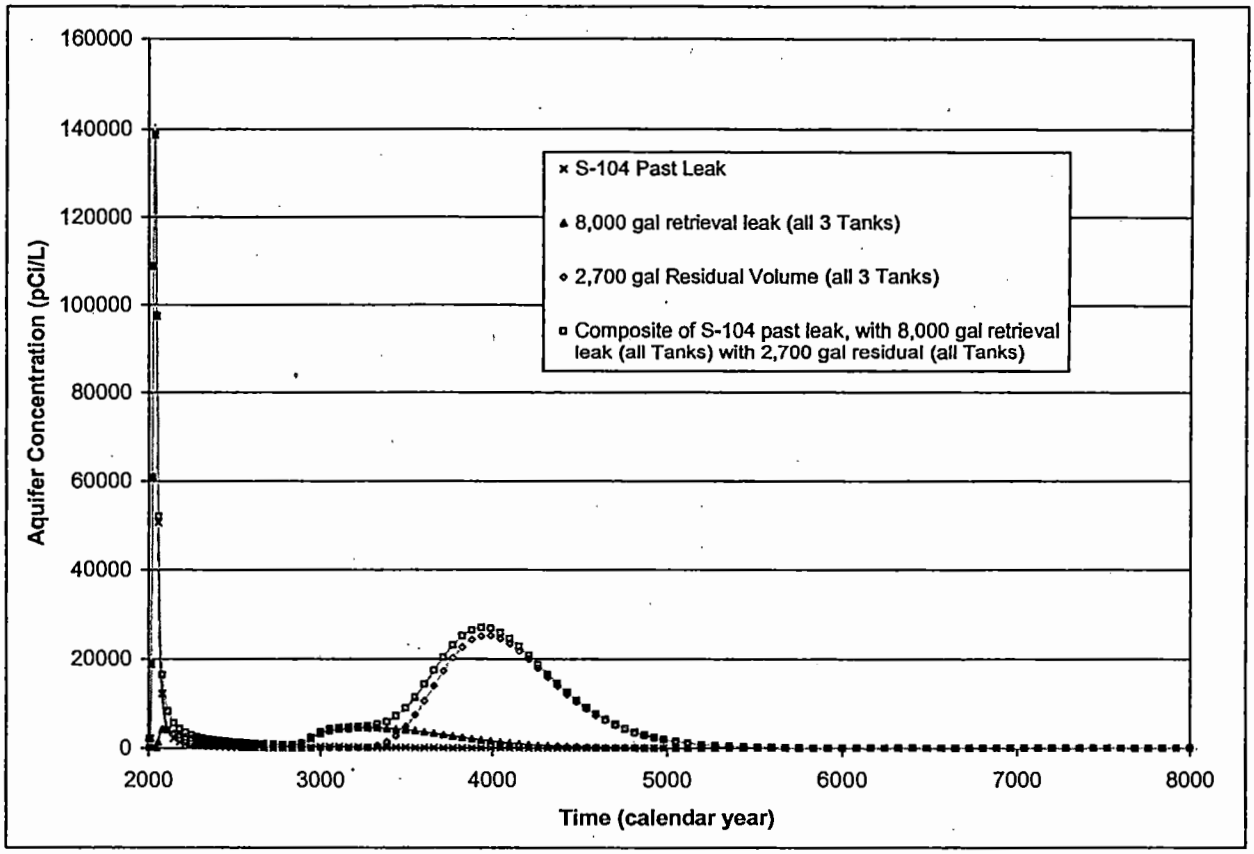
- The 200 West Area fence line located about 1.8 km (1.12 mi) east of the S tank farm
- The 200 Area exclusion zone boundary located about 10.5 km (6.52 mi) east of the S tank farm.

The potential near-field groundwater impacts at the S tank farm boundary associated with releases from cross-sections S-104 and S-107 are presented in the following sections followed by a discussion of potential groundwater impacts associated with the composite releases from all 12 tanks in the S tank farm.

B.5.2.1.1 Groundwater Impacts Associated with Past Leaks, Retrieval Losses, and Residual Waste from Cross-Section S-104. Potential groundwater impact results associated with the past leak from tank S-104, the base case retrieval scenario of 30,000 L (8,000 gal) from each of the three tanks (S-104, S-105, and S-106), and the base case residual volume of 10,200 L (2,700 gal) in each of the three tanks are presented in this section. The potential groundwater impacts resulting from these three source terms are shown as technetium-99 concentration versus time plots in Figure B.5.17. The approximate near-field peak technetium-99 concentrations at the S tank farm boundary for the individual source terms and the year in which the peak would occur are as follows:

- Past leak: year 2032 and 140,000 pCi/L
- Retrieval: year 3300 and peak of 4,600 pCi/L
- Residual: year 4000 and 25,000 pCi/L.

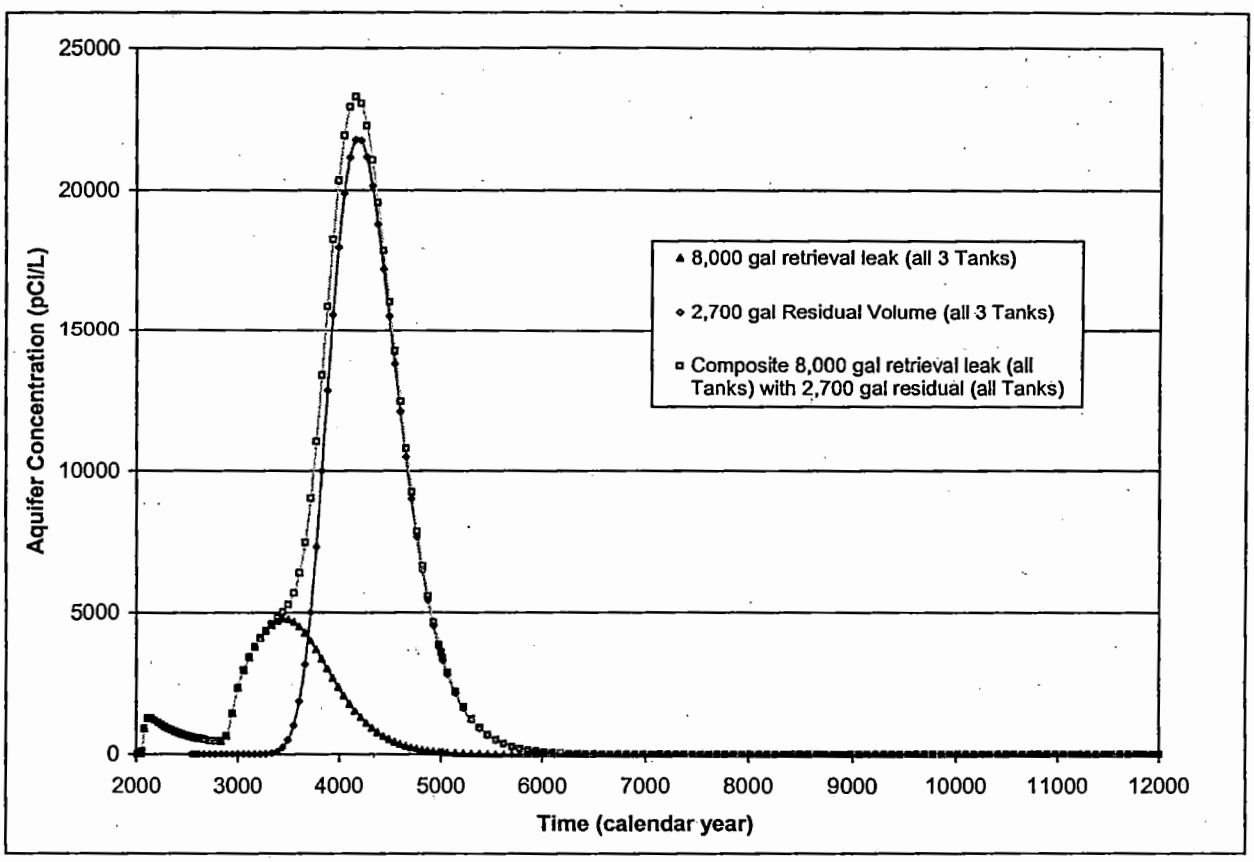
Figure B.5.17. Technetium-99 Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for Past Leak, 8,000 Gallon Retrieval Loss (All Tanks) and 2,700 Gallon Residual (All Tanks) for Cross-Section S-104



B.5.2.1.2 Groundwater Impacts Associated with Retrieval Losses and Residual Waste from Cross-Section S-107. Potential groundwater impact results associated with the base case retrieval scenario of 30,000 L (8,000 gal) from each of the three tanks and the base case residual waste volume of 10,200 L (2,700 gal) in each of the three tanks in cross-section S-107 (S-107, S-108, and S-109) are presented in this section. The potential groundwater impacts resulting from these three source terms are shown as technetium-99 concentration versus time plots in Figure B.5.18. The approximate near-field peak technetium-99 groundwater concentrations for the individual source terms and the year in which the peak would occur are as follows:

- Retrieval: year 3450 and peak of 4,800 pCi/L
- Residual: year 4200 and 21,900 pCi/L.

Figure B.5.18. Technetium-99 Groundwater Concentrations at the S Tank Farm Fence Line Versus Time for 8,000 Gallon Retrieval Loss (All Tanks) and 2,700 Gallon Residual (All Tanks) for Cross-Section S-107



B.5.2.1.3 Composite Tank Farm Groundwater Impacts. The far-field composite groundwater impact results associated the entire tank farm (i.e., releases from 12 tanks in the S tank farm) are provided in this section. Three combinations of source terms have been assumed from which the potential far-field groundwater impacts for techetium-99 and uranium-238 are described. These two contaminants were selected based on their range of mobility in the subsurface at Hanford. Technetium-99 is mobile and would move with groundwater. The mobility of uranium-238 is somewhat less than that of technetium-99 but much more mobile than contaminants such as cesium-137. The impacts of the past leak from tank S-104 are included in each of the three combinations. Two potential far-field compliance points are considered:

- The eastern fence line of the 200 West Area
- The eastern side of the 200 Area exclusion zone boundary.

The three source term combinations that are considered are described in Table B.5.15.

Table B.5.15. Source Terms Assumed for the Far-Field Composite S Tank Farm Groundwater Impact Calculations

Composite Tank Farm Case	Description of Assumed Source Terms
1	Past leak from tank S-104 with 2,700 gal residual volume in all 12 tanks and 8,000 gal retrieval leak from all 12 tanks
2	Past leak from tank S-104 with 2,700 gal residual volume in all 12 tanks plus a 40,000 gal retrieval leak from tank S-102; there would be no other retrieval leaks from the other 11 tanks
3	Past leak from tank S-104 with 2,700 gal residual volume in all 12 tanks; there would be no retrieval leaks from any of the 12 tanks

Figures B.5.19 and B.5.20 illustrate the groundwater concentration versus time for technetium-99 and uranium-238, respectively, at the two potential compliance points for Case 1, which involves the past leak from tank S-104, plus a 30,000 L (8,000 gal) retrieval loss from all 12 tanks, and a 10,200 L (2,700 gal) residual waste volume in all 12 tanks. The peak technetium-99 groundwater concentrations and associated time at the peak would be about 7,950 pCi/L in the year 2200 and 1,720 pCi/L in the year 2350 at the 200 West Area fence line and the 200 Area exclusion zone boundary, respectively. Uranium-238 would still be increasing in the year 12000. The uranium-238 groundwater concentration at the 200 West Area fence line would be about 1.6 pCi/L. At the 200 Area exclusion zone boundary, uranium-238 groundwater concentrations would have dropped to about 0.36 pCi/L, approximately a 4.4 fold reduction.

Figure B.5.19. Technetium-99 Concentrations at Selected Compliance Points for S Tank Farm Past Leak from Tank S-104 with 2,700 Gallon Residual Volume in All 12 Tanks and 8,000 Gallon Retrieval Leak from All 12 Tanks

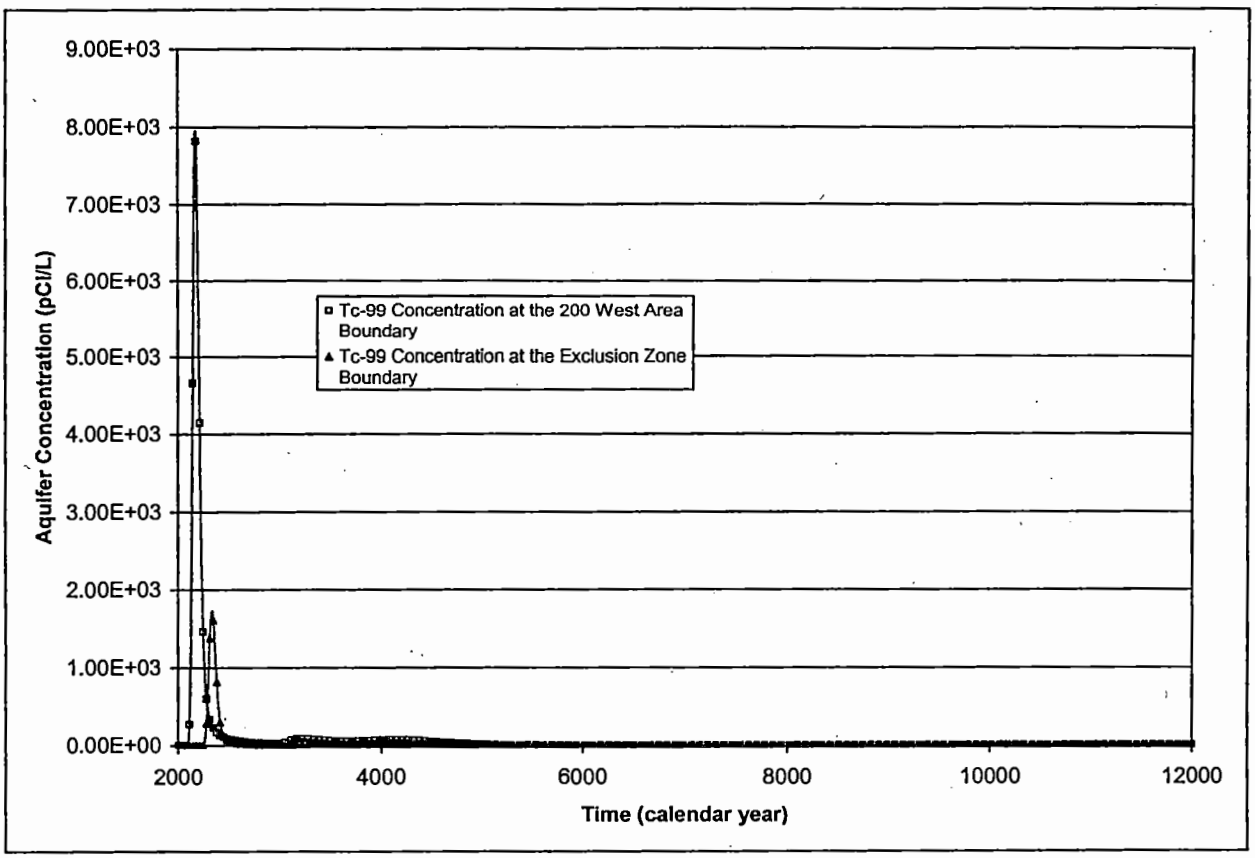


Figure B.5.20. Uranium-238 Concentrations at Selected Compliance Points for S Tank Farm Past Leak from Tank S-104 with 2,700 Gallon Residual Volume in All 12 Tanks and 8,000 Gallon Retrieval Leak from All 12 Tanks

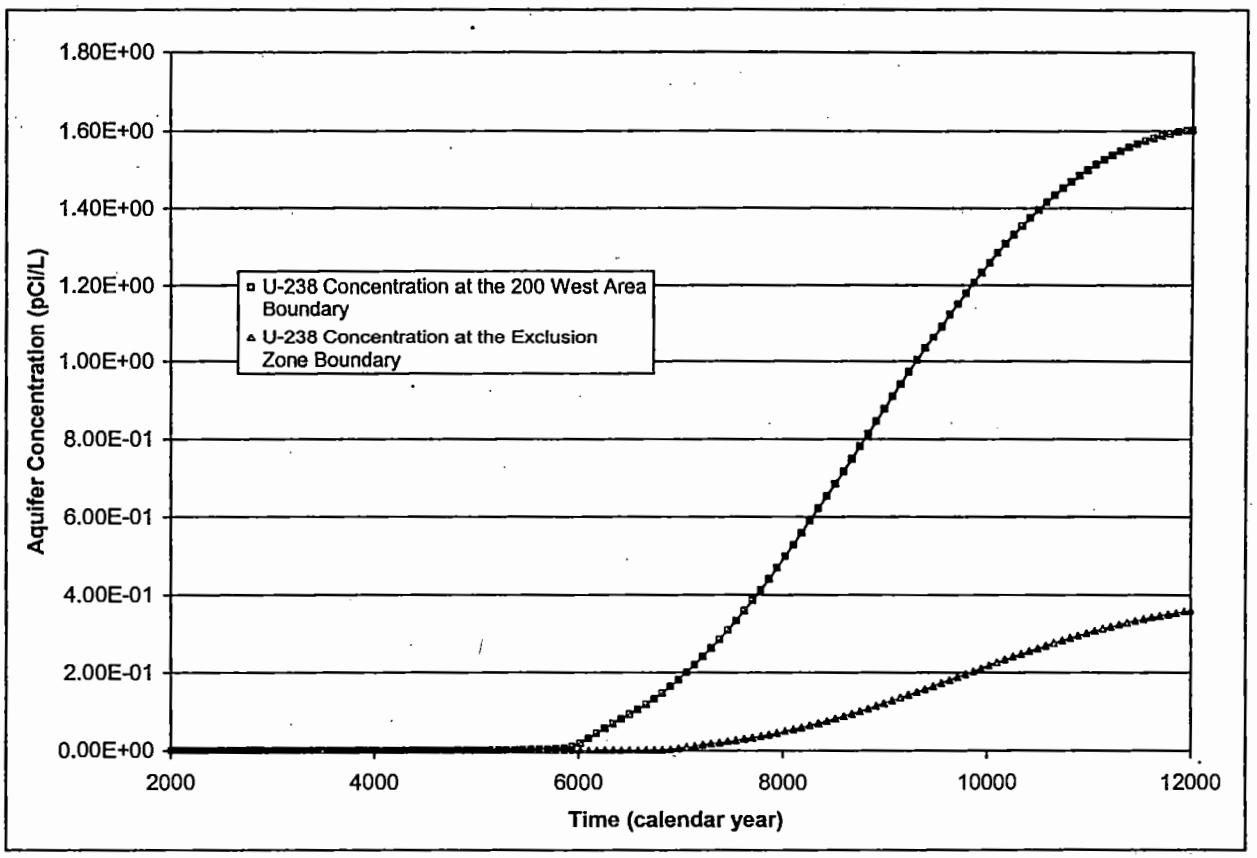


Figure B.5.21 and B.5.22 illustrate the groundwater concentration versus time for technetium-99 and uranium-238, respectively, at the two potential compliance points for Case 2 (i.e., consists of past leak from tank S-104; 10,200 L [2,700 gal] residual in all 12 tanks; plus a single 150,000 L [40,000 gal] retrieval loss from tank S-102 and no other losses). The peak technetium-99 groundwater concentrations and associated time at the peak would be the same as described for Case 1, which is about 7,950 pCi/L in the year 2200 and 1,720 pCi/L in the year 2350 at the 200 West Area fence line and the 200 Area exclusion zone boundary, respectively. The values are the same because of the overwhelming impacts associated the past leak source term. Likewise, the uranium-238 concentrations at the year 12000 remain as they were calculated for Case 1.

Figure B.5.21. Technetium-99 Concentrations at Selected Compliance Points for S Tank Farm Past Leak from Tank S-104 with 2,700 Gallon Residual Volume in All 12 Tanks Plus a 40,000 Gallon Retrieval Leak from Tank S-102

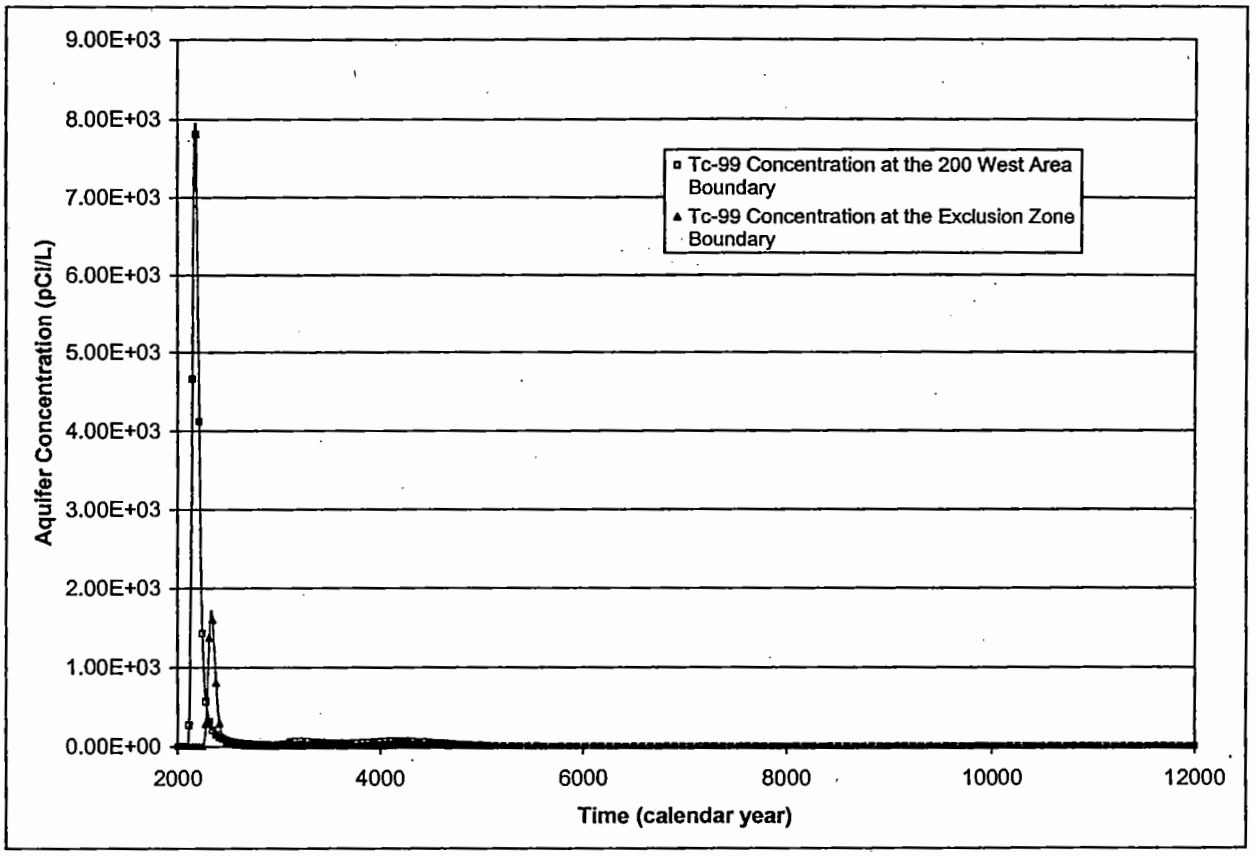
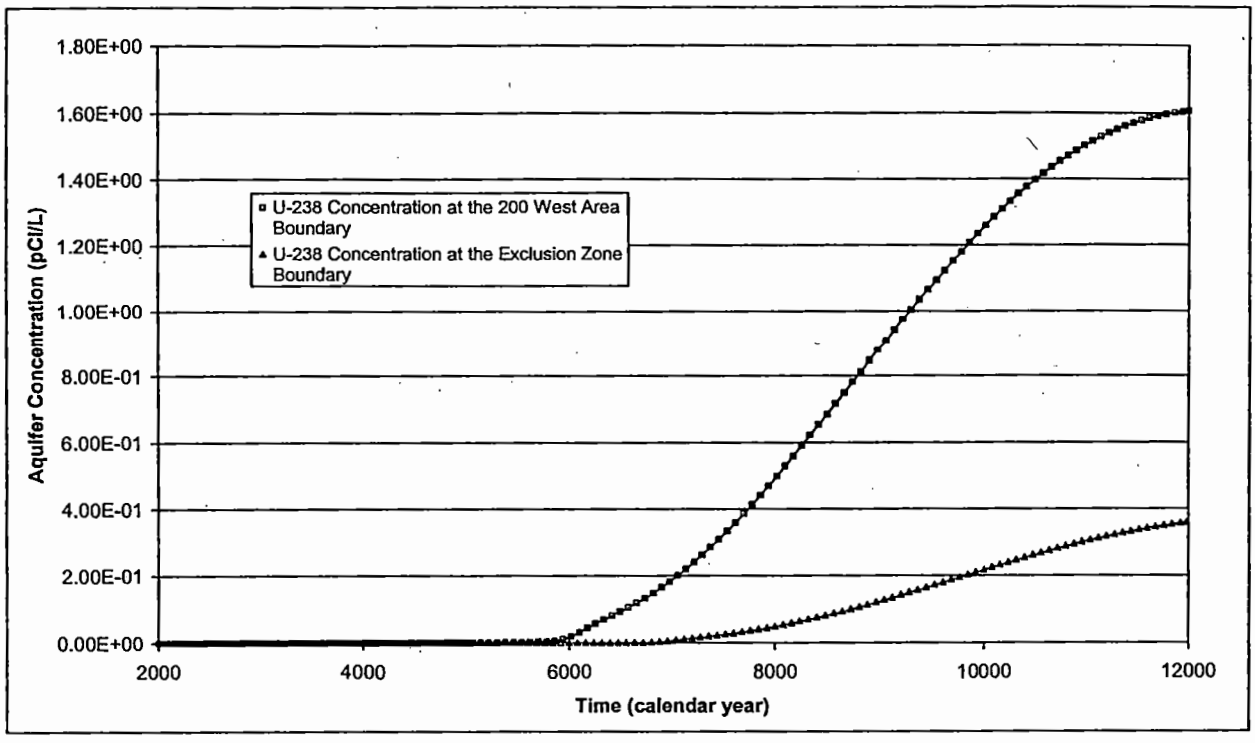


Figure B.5.22. Uranium-238 Concentrations at Selected Compliance Points for S Tank Farm Past Leak from Tank S-104 with 2,700 Gallon Residual Volume in All 12 Tanks Plus a 40,000 Gallon Retrieval Leak from Tank S-102



The results of the third case are illustrated in Figures B.5.23 and B.5.24. This case includes the past leak from tank S-104 and a 10,200 L (2,700 gal) residual volume in each of the 12 tanks. There would be no other losses. The time of peak concentration and concentration at the peak would be as with the other two cases, except at the 200 Area exclusion zone boundary where the peak technetium-99 concentration would be about 1,600 pCi/L in the year 2350.
The uranium-238 concentrations at the year 12000 remain as they were calculated for Cases 1 and 2.

Figure B.5.23. Technetium-99 Concentrations at Selected Compliance Points for S Tank Farm Past Leak from Tank S-104 with 2,700 Gallon Residual Volume in All 12 Tanks

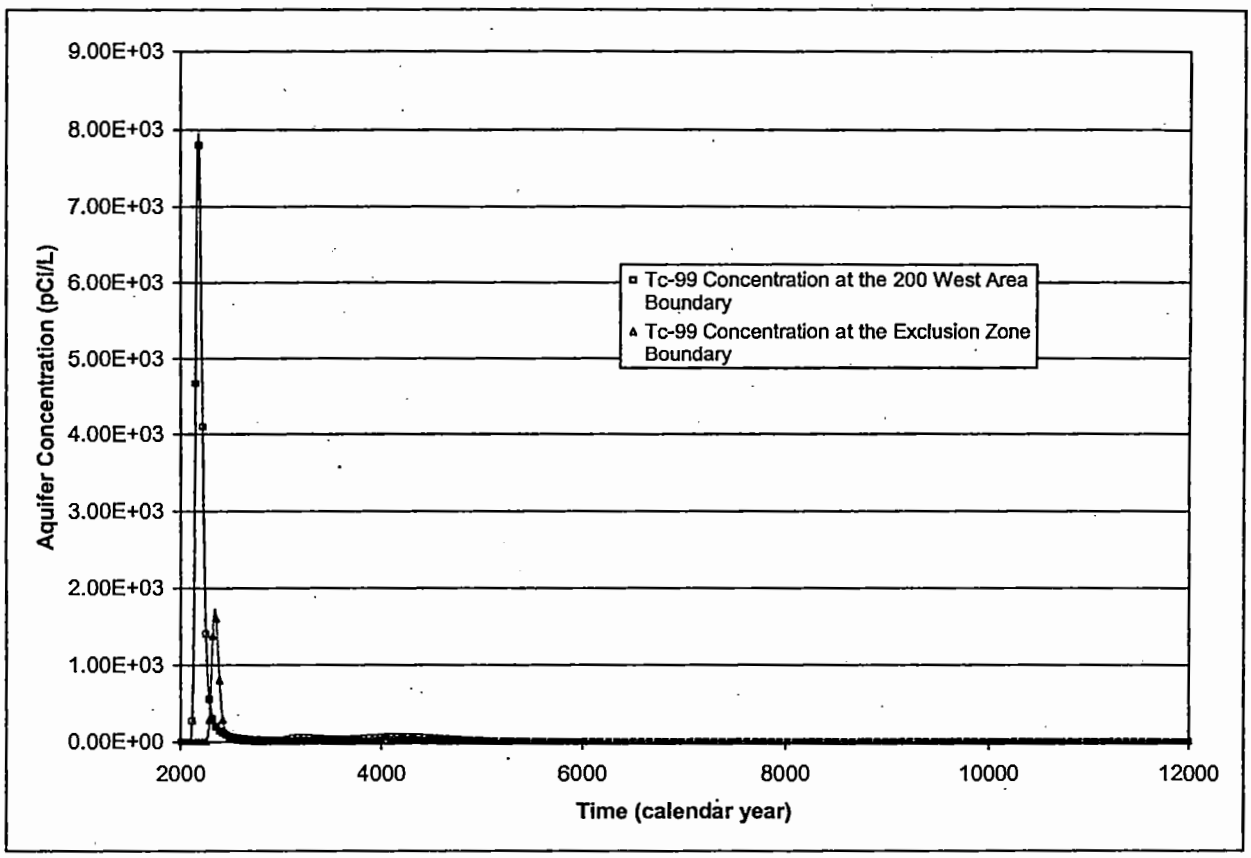
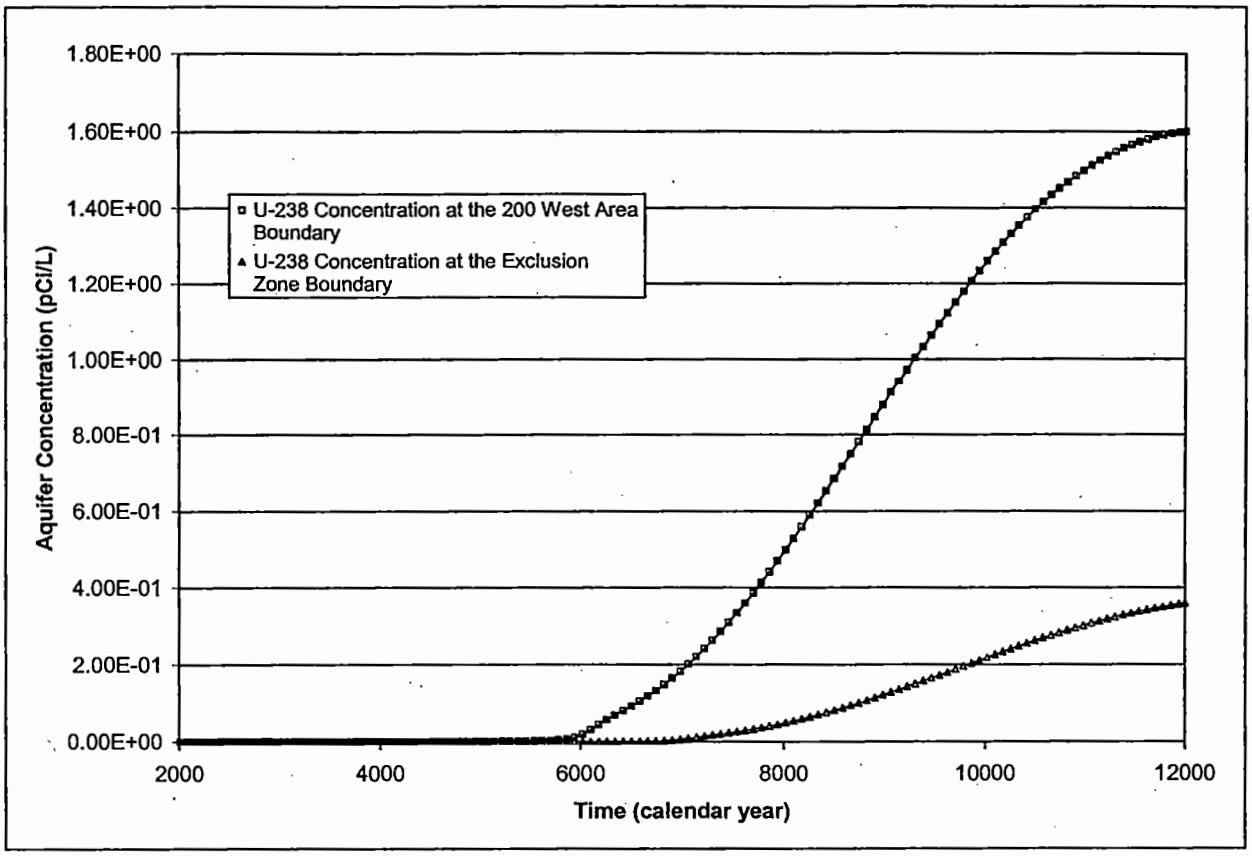


Figure B.5.24. Uranium-238 Concentrations at Selected Compliance Points for S Tank Farm Past Leak from Tank S-104 with 2,700 Gallon Residual Volume in All 12 Tanks



The results of the far-field composite groundwater impacts discussed previously indicate that the past leak component dominates all other impacts and makes it difficult to assess impact changes associated with the other source terms (i.e., the retrieval loss and residual waste). The same cases as described in Table B.5.15 were recompiled without the past leak source term component to observe the effects of variations in retrieval loss and residual waste in the far field.

Figures B.5.25 and B.5.26 illustrate the groundwater concentration versus time for technetium-99 and uranium-238, respectively, at the two potential compliance points for Case 1, without the past leak source term. There is still a bimodal response for technetium-99 but the early peak now occurs at a lower concentration than the late peak without the past leak source term.

The contaminant concentration in groundwater is reduced as a function of distance. The peak technetium-99 concentrations are reduced between the 200 West Area fence line and the 200 Area exclusion zone boundary by about a factor of 4.5 and 4.2 for the early and late peaks, respectively. The peak technetium-99 groundwater concentrations and time when they would occur for the three cases without the past leak source term are summarized in Table B.5.16.

Without the past leak contribution, the uranium-238 groundwater concentration at the year 12000 would be about 7.7×10^{-3} pCi/L at the 200 West Area fence line and 5.7×10^{-4} at the 200 Area exclusion zone boundary (see Figure B.5.26).

Figure B.5.25. Technetium-99 Concentrations at Selected Compliance Points for S Tank Farm 2,700 Gallon Residual Volume in All 12 Tanks and 8,000 Gallon Retrieval Leak from All 12 Tanks (without Past Leak)

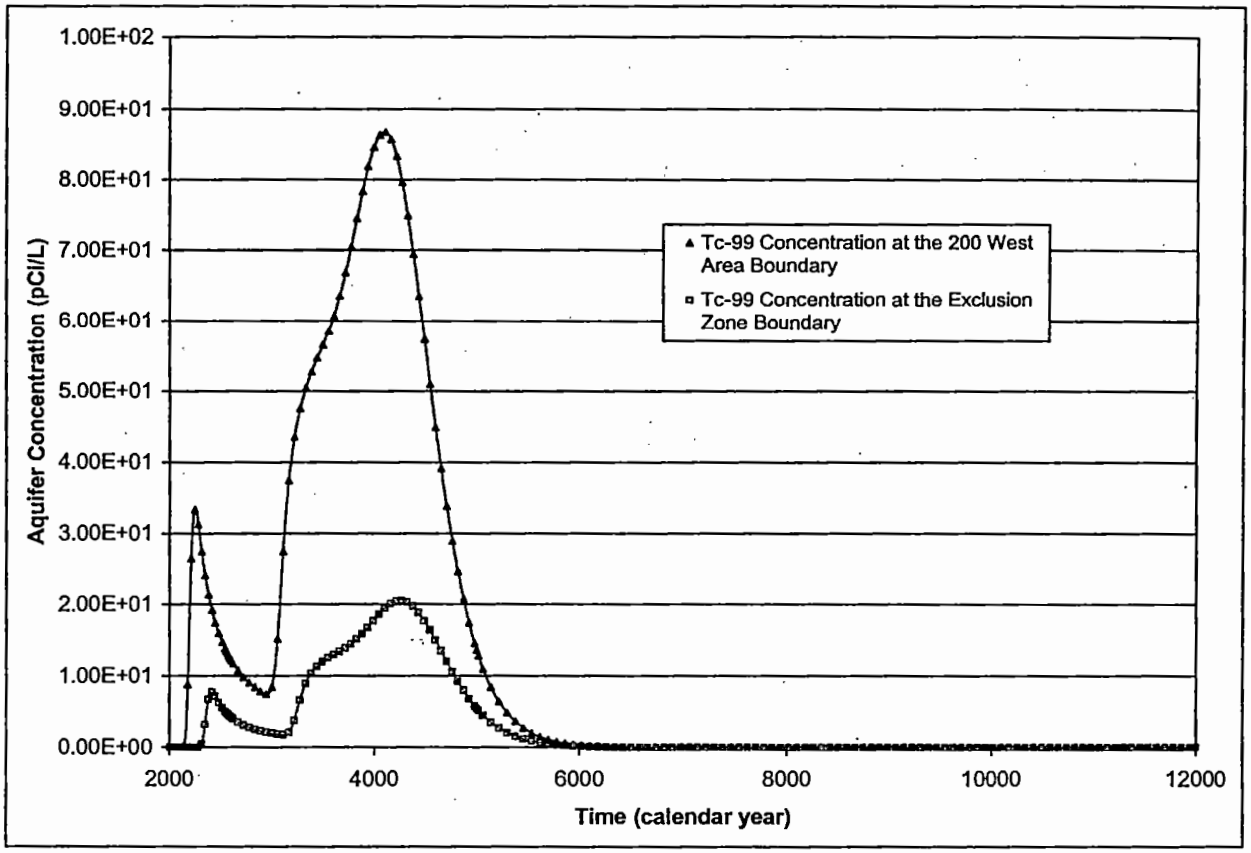


Figure B.5.26. Uranium-238 Concentrations at Selected Compliance Points for S Tank Farm 2,700 Gallon Residual Volume in All 12 Tanks and 8,000 Gallon Retrieval Leak from All 12 Tanks (without Past Leak)

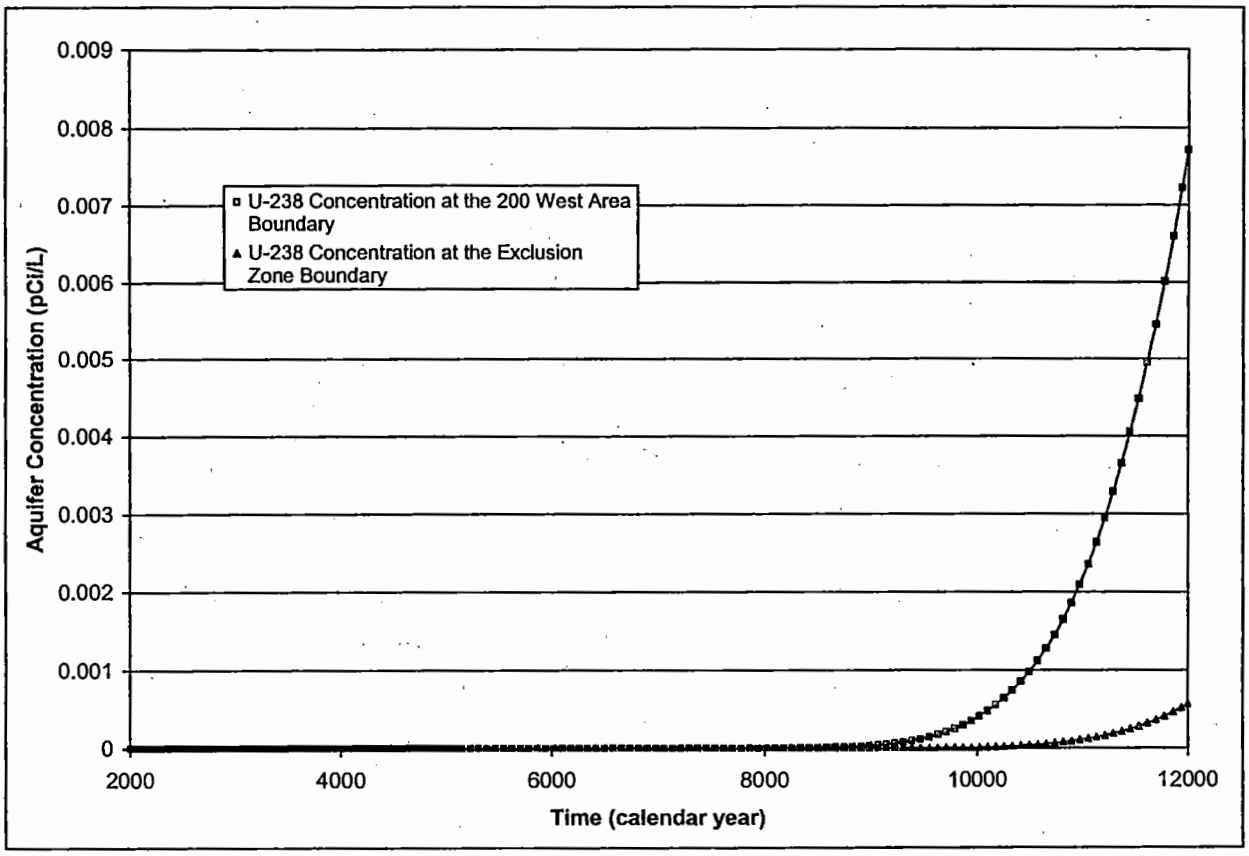


Table B.5.16. Summary of Peak Technetium-99 Concentrations and Time when Peak Would Occur for the Potential Compliance Points for the S Tank Farm Composite Cases without the Past Leak Source Term

Composite Tank Farm Case	200 West Area Fence Line		200 Area Exclusion Zone Boundary	
	Year in which Peak Concentration Occurs	Tc-99 Concentration at Peak (pCi/L)	Time to Peak (Year)	Tc-99 Concentration at Peak (pCi/L)
1	4100	87	4275	21
2	4200	64	4375	15
3	4210	63	4380	15

Figures B.5.27 and B.5.28 illustrate the groundwater concentration versus time for technetium-99 and uranium-238, respectively, at the two potential compliance points for Case 2 without the past leak source term (i.e., consists of 10,200 L [2,700 gal] residual in all 12 tanks, plus a single 150,000 L [40,000 gal] retrieval loss from tank S-102 and no other losses). The time to peak technetium-99 concentration is about the same as for Case 1 but the peak concentrations for

Case 2 are both reduced by about 26 and 28% at the 200 West Area fence line and the 200 Area exclusion zone boundary, respectively (see Table B.5.2). Without the past leak contribution, the uranium-238 groundwater concentration at the year 12000 would be about 1.2×10^{-2} pCi/L at the 200 West Area fence line and 1.1×10^{-3} at the 200 Area exclusion zone boundary (see Figure B.5.28).

Figure B.5.27. Technetium-99 Concentrations at Selected Compliance Points for S Tank Farm 2,700 Gallon Residual Volume in All 12 Tanks Plus a 40,000 Gallon Retrieval Leak from Tank S-102 (without Past Leak)

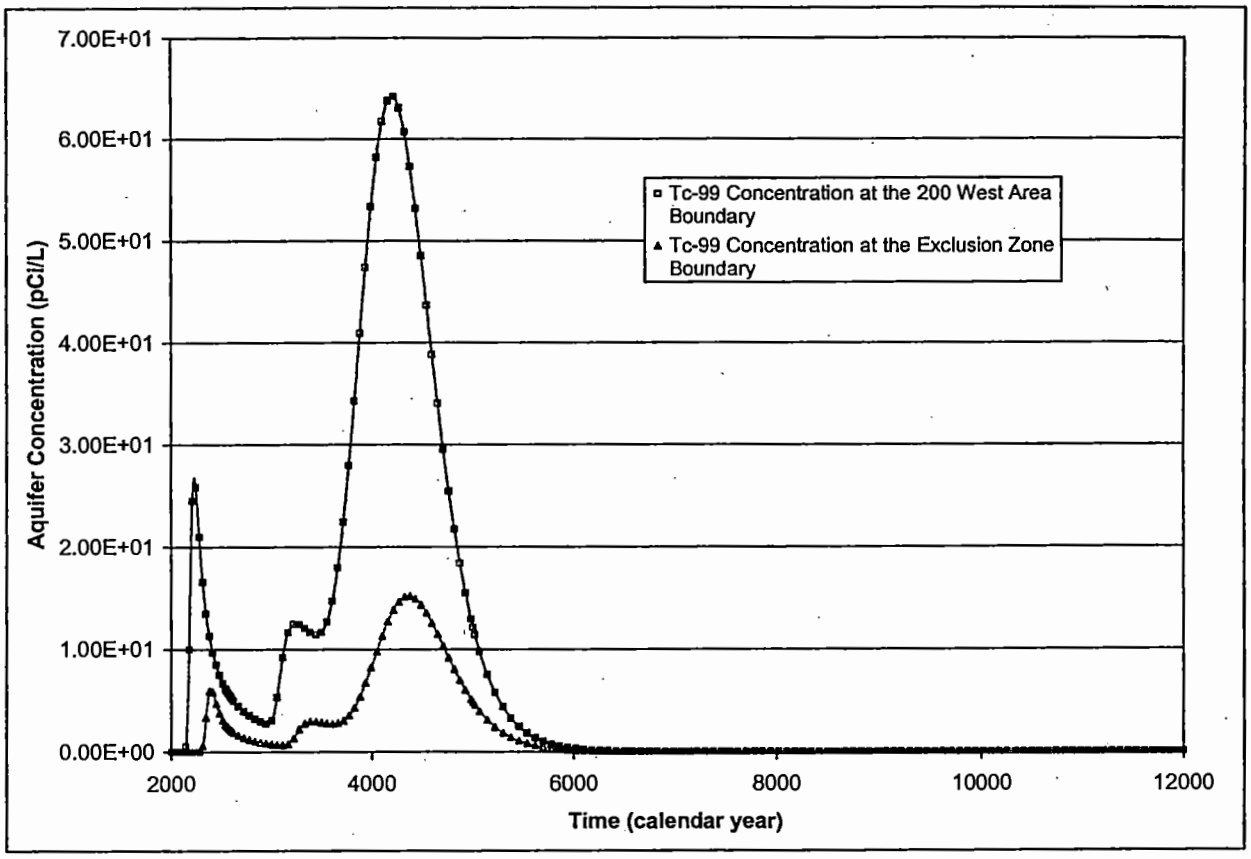
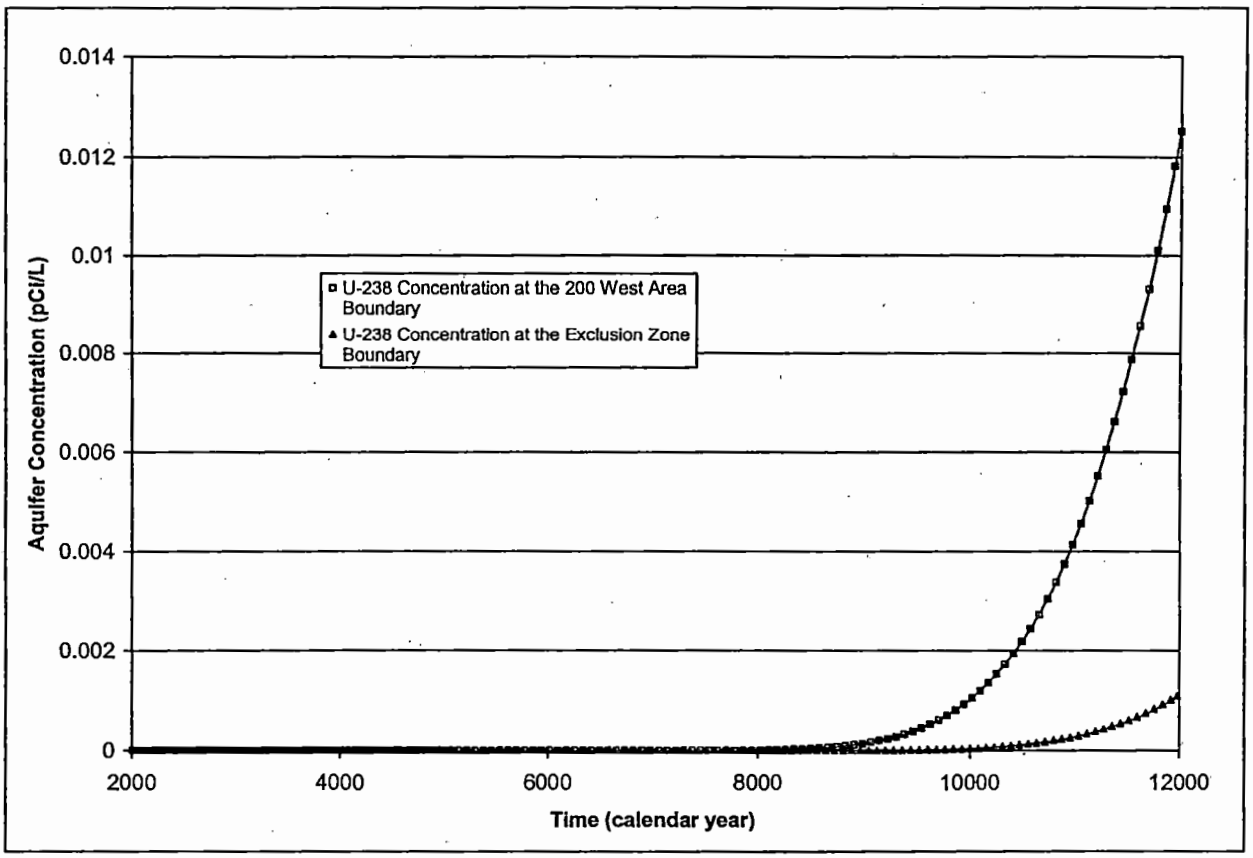


Figure B.5.28. Uranium-238 Concentrations at Selected Compliance Points for S Tank Farm 2,700 Gallon Residual Volume in All 12 Tanks Plus a 40,000 Gallon Retrieval Leak from Tank S-102 (without Past Leak)



The results of the third case without the past leak source term are illustrated in Figures B.5.29 and 5.30. This case includes a 10,200 L (2,700 gal) residual volume in each of the 12 tanks. There would be no other losses. There is only one peak in the traces for this case and it occurs at about the year 4210 at the 200 West Area fence line and the year 4380 at the 200 Area exclusion zone boundary (see Table B.5.2). The peak technetium-99 concentrations for Case 3 are both reduced by about 27 and 29% at the 200 West Area fence line and the 200 Area exclusion zone boundary, respectively (see Table B.5.2) compared to Case 1. The uranium-238 groundwater concentration at the year 12000 would be about 6.0×10^{-3} pCi/L at the 200 West Area fence line and 4.0×10^{-4} at the 200 Area exclusion zone boundary (see Figure B.5.30).

Figure B.5.29. Technetium-99 Concentrations at Selected Compliance Points for S Tank Farm 2,700 Gallon Residual Volume in All 12 Tanks (without Past Leak)

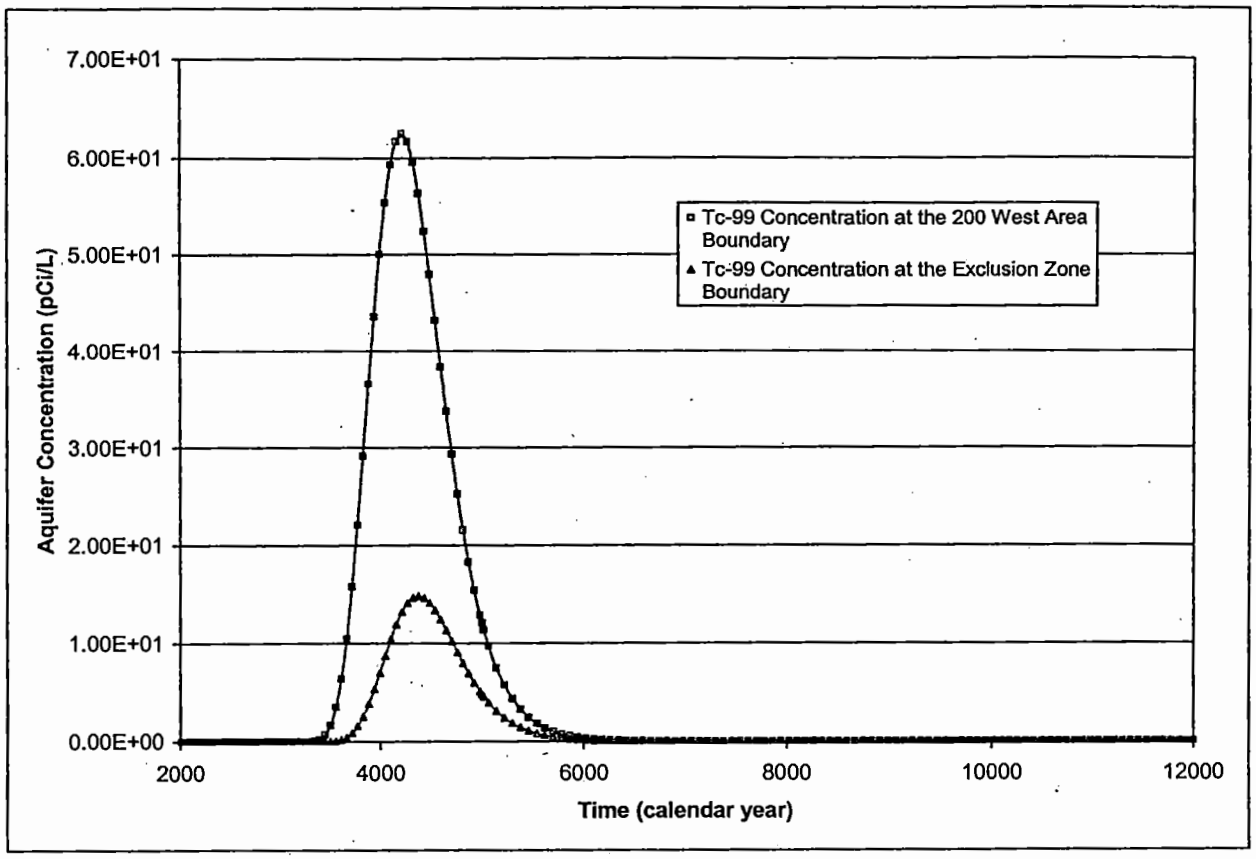
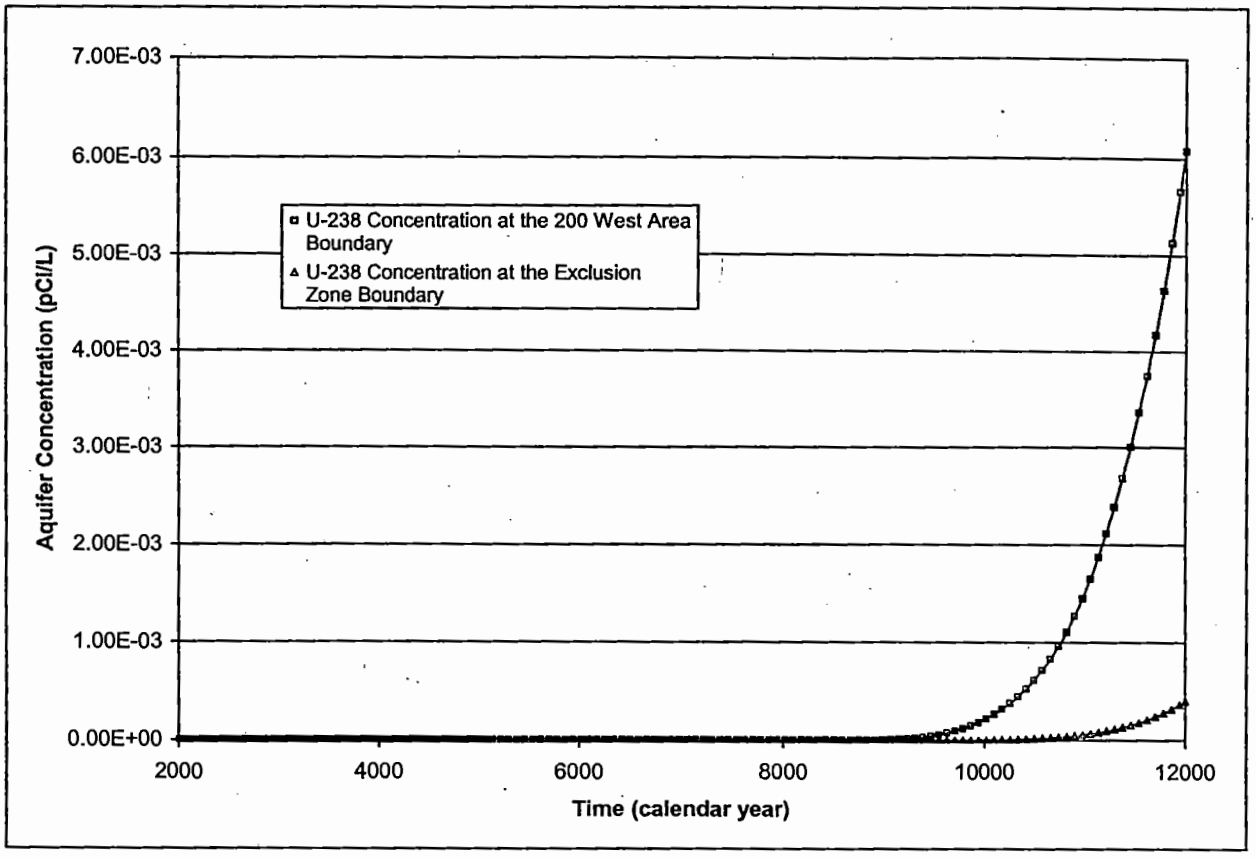


Figure B.5.30. Uranium-238 Concentrations at Selected Compliance Points for S Tank Farm 2,700 Gallon Residual Volume in All 12 Tanks (without Past Leak)



B.5.2.2 S Tank Farm Long-Term Human Health Risk Assessment Results

Results of the long-term human health risk assessment for the S tank farm as a whole are provided in this section based on predicted contaminant concentrations in groundwater at the east fence line of the 200 West Area and the east side of the 200 Area exclusion zone boundary (Section B.5.3.2). Results are summarized in Table B.5.17, which shows the peak composite source term impacts for the three composite tank farm cases evaluated. Note that these three cases involve contributions from retrieval leakage and residual waste only and do not include the contribution from the tank S-104 past leak. The assessment results revealed that the tank S-104 past leak drives the peak impacts for all three cases, rendering them indistinguishable.
To illustrate the effects of variation in the primary system components (i.e., retrieval leakage and residual waste), the tank S-104 past leak contribution has been removed from the results shown in Table B.5.17.

Results for Case 3 illustrate the farm wide impacts of closing the tank farm with all tanks retrieved to the HFFACO interim goal of 10,000 L (2,700 gal) of residual waste and without incurring retrieval leakage from any of the tanks. Comparing results for Case 3 with Case 1 illustrates the incremental increase in farm wide impacts from incurring a retrieval leak of 30,000 L (8,000 gal) from all tanks while retrieving all tanks to the HFFACO interim goal. The increase in impacts would be quite small, a factor of 3 increase at most.

Comparing results for Case 3 with Case 2 illustrates the incremental increase in farm-wide impacts from incurring a large retrieval leak (150,000 L [40,000 gal]) from tank S-102 (Case 2) while retrieving all tanks to the HFFACO interim goal. The increase in impacts would once again be quite small, a factor of 2 increase at most.

Table B.5.17. Peak ILCR and Hazard Index for S Tank Farm as a Whole

Composite Tank Farm Case	S Tank Farm Source Term		200 West Fence		200 Area Exclusion Boundary	
			Residential Farmer	Industrial Worker	Residential Farmer	Industrial Worker
1	2,700 gal residual waste and 8 kgal retrieval leak for all tanks	ILCR	3.17E-05	8.49E-07	7.51E-06	2.01E-07
		HI	1.70E+00	5.70E-03	4.04E-01	1.35E-03
2	2,700 gal residual waste in all tanks and 40 kgal retrieval leak from tank S-102 (no leak from other tanks)	ILCR	2.34E-05	6.27E-07	5.52E-06	1.48E-07
		HI	1.36E+00	4.54E-03	3.12E-01	1.05E-03
3	2,700 gal residual waste in all tanks	ILCR	2.28E-05	6.11E-07	5.38E-06	1.45E-07
		HI	6.85E-01	2.29E-03	1.62E-01	5.44E-04

HI = hazard index.
ILCR = incremental lifetime cancer risk.

B.5.2.3 S Tank Farm Regulatory Compliance Assessment Results

This section describes the regulatory compliance assessment results for the analyses presented in Sections B.5.2.1 and B.5.2.2. Three specific analysis cases, which differ from the cases presented in Section B.3.2, are analyzed for the S tank farm as a whole. The three cases are evaluated with and without the contributions from past leaks associated with tank S-104. Two potential far-field compliance points are considered: the west side of the 200 West Area boundary which is the fence line, and the west side of the 200 Area exclusion boundary.

It is not possible to evaluate short-term human health risk or inadvertent human intrusion risk for the tank farm system, so there are no regulatory compliance assessment results. The HFFACO milestone compliance is tank-specific and therefore not appropriately considered for the entire tank farm system.

B.5.2.3.1 S Tank Farm Short-Term Human Health Risk Compliance. Not applicable.

B.5.2.3.2 S Tank Farm Groundwater Protection Compliance. Groundwater quality requirements include compliance with EPA MCLs (40 CFR 141), the DOE derived concentration guide (DOE Order 5400.5), and concentration limits under WAC 173-303-645. The most restrictive of these groundwater quality requirements are the EPA MCLs.

Three CoCs were evaluated for compliance with regulatory requirements. The CoC with the highest predicted concentration level for the radionuclides in the groundwater is technetium-99. Technetium-99 is used as an indicator because of its mobility in the environment (distribution coefficient of 0) and its long half-life. Uranium-238 is also of interest because of its moderate mobility in the environment (distribution coefficient of 0.6) and its long half-life. The third contaminant evaluated is nitrate, a CoC for groundwater impacts.

The analysis results indicate that technetium-99 exceeds the EPA regulatory MCL (900 pCi/L) in all 3 cases at both points of compliance. Uranium-238 does not exceed the EPA regulatory MCL (6.7 pCi/L) in any case at either point of compliance. Nitrate does not exceed DWSs (45 mg/L) in any case at either point of compliance. When the past leak contributions are removed from the evaluation as shown in Table B.5.16 the technetium-99 concentrations are all well below the MCL (900 pCi/L) for all 3 cases at both points of compliance.

B.5.2.3.3 S Tank Farm Long-Term Human Health Risk Compliance. Long-term human health risk is evaluated based on maximum groundwater concentration and health effects (i.e., ILCR and hazard index) as expressed in human health risk resulting from exposure to 9 radiological contaminants (technetium-99; selenium-79; iodine-129; carbon-14; and uranium-233, -234, -235, -236, and -238) and four chemical contaminants (total uranium, chromate, nitrate, and nitrite). These contaminants were chosen to evaluate long-term human health risk.

As shown in Table B.5.17, the ILCR exceeds the Washington State long-term human health cancer risk standard (1.0×10^{-5}) for the composite source term for the S tank farm for the residential farmer located at the 200 West Area fence in all cases. The ILCR does not exceed 1×10^{-5} for the industrial worker under any case at either point of compliance. The hazard index standard of 1.0 is not exceeded for the industrial worker in any case at either point of compliance. The hazard index standard of 1.0 is exceeded for the residential farmer for Cases 1 and 2 at the 200 West Area fence line.

B.5.2.3.4 S Tank Farm Inadvertent Human Intrusion Compliance. Not Applicable.

B.5.2.3.5 S Tank Farm HFFACO Milestone Compliance. Not Applicable.

B.6.0 CONCLUSIONS

This section provides the conclusions relative to tank waste retrieval for tank S-102 based on the analysis results presented in Section B.5.0. Section B.6.1 provides a summary of the conclusions as they relate to near-term waste retrieval efforts. Sections B.6.2 provides summaries of the conclusions specific to the different areas of analysis for tank S-102. Section B.6.3 provides summaries of the conclusions related to the S tank farm as a whole.

B.6.1 SUMMARY CONCLUSIONS

The summary conclusions in the following sections are RPE findings that would influence waste retrieval and LDMM system criteria for tank S-102.

B.6.1.1 Tank S-102 Summary Conclusions

The goal of the tank S-102 waste retrieval project is to retrieve as much waste from the tank as technically practical. The HFFACO F&R document will identify the proposed methodology for waste retrieval along with the retrieval system requirements. Because of the potential for leakage to occur during tank waste retrieval and the inter-relationship between retrieval leakage and residual waste from a tank farm closure standpoint, it is important to understand how the variations in residual waste and retrieval leakage volumes influence the risk- and regulatory-based performance measures.

The final extent of tank waste retrieval is a tank farm closure issue; however, because one of the goals of the waste retrieval function is to enter a tank one time, the extent of waste retrieval should be considered in the F&R of the initial retrieval system. It is recognized that closure criteria have not been fully defined; however, the criteria as they are currently understood can be used to guide the development of initial waste retrieval criteria. This approach does not preclude the retrieval of additional waste from a tank in the future as additional information is gathered during and after waste retrieval activities in the remaining S farm tanks and as closure criteria are established.

Long-term human health risks from retrieval leak losses are a constraint for defining tank S-102 LDMM system criteria. The performance measures that influence F&R for defining retrieval leak loss limits and the extent of retrieval (i.e., how much waste needs to be retrieved) for tank S-102 are driven by the long-term risk to a future site user. The point-of-compliance assumed for the evaluation of tank-specific impacts is the S tank farm fence line. The long-term human health risk results indicate that impacts from tank S-102 retrieval leakage volumes, when considered by themselves, exceed an ILCR of 10^{-5} for the industrial worker scenario at the tank farm fence line at volumes as low as 14,000 L (3,600 gal). The long-term human health risk results indicate that impacts from tank S-102 residual waste, when considered by themselves, are below an ILCR of 10^{-5} for the industrial worker for residual volumes below approximately 26,000 L (6,800 gal). When the residential farmer scenario is considered the long-term human health risks from a residual volume equal to 10,200 L (2,700 gal) from tank S-102 are above an ILCR of 10^{-5}, which means that under this scenario there would be no retrieval leakage allowance.

The influence of waste retrieval leakage to long-term human health risk is not unexpected at tank S-102. Tank S-102 is specifically targeted in the SST retrieval strategy as a sound mixed salt cake/sludge tank with elevated levels of technetium-99 relative to the other SSTs (RPP-7087).

A number of conservative assumptions are made in this assessment and the uncertainties associated with these assumptions are discussed further in Section B.6.4. This conservatism, in combination with consideration of alternative points of compliance and/or higher acceptable risk levels (e.g., 10^{-4} under EPA guidance), could provide a means for identifying an acceptable leakage envelope for moving forward with waste retrieval from tank S-102. An uncertainty and sensitivity analysis is currently being conducted to evaluate the range and distribution of estimated risks. The uncertainty analysis results will be incorporated into future revisions of this RPE.

For the waste retrieval leakage impacts, the time that the peak impacts are projected to occur for leak volumes greater than 30,000 L (8,000 gal) from tank S-102 is during the time when the tank farm would be under post-closure care and it is unlikely that the groundwater exposure pathway would be accessible for industrial or residential use at the S tank farm fence line. At points of compliance beyond the tank farm fence line those concentrations would be attenuated.

For tank S-102 the inadvertent human intruder analysis results indicate that a residual waste volume of approximately 129,000 L (34,000 gal) or less with no waste retrieval leakage would be required to meet the post-drilling resident DOE inadvertent intruder performance criteria of 100 mrem/yr. Therefore, for defining risk-based residual waste volumes, the inadvertent human intrusion performance measure is not as restrictive as the long-term human health risk industrial worker scenario.

B.6.1.2 S Tank Farm Summary Conclusions

The potential groundwater impacts and long-term human health risks for the S tank farm were evaluated in Section B.5.2 with and without the contribution from past leaks. The results of this analysis indicate that the contribution from past leaks dominate the impacts from the retrieval leak and residual source terms. On a tank farm level the impacts associated with retrieval to the HFFACO interim retrieval goal with no retrieval leakage from any of the S farm tanks results in risk levels that are above 10^{-5} at the 200 West Area fence line for the residential farmer but are below 10^{-5} for the industrial worker. When the long-term human health risks are evaluated at the 200 Area exclusion zone boundary the risks estimated for retrieval to the HFFACO interim retrieval goal with no retrieval leakage are below 10^{-5} for both the residential farmer and the industrial worker.

At the tank farm level, the long-term human health risks are not sensitive to changes in the retrieval leakage volume. A 151,000 L (40,000 gal) leak from tank S-102 only increases the long-term human health risk by approximately 3% above the risk from the tank residuals.

Alternative performance measures could be used in the evaluation of retrieval leak loss criteria. If an approach similar to that taken for the remedial action objectives for the 200-UP-1 operable

unit were used, where 10 times DWSs were established as the performance objective, the corresponding leak loss volume for tank S-102 would be considerably higher than the risk-based number. As shown in Section B.5.2.1.3 the technetium-99 groundwater concentrations for a leak volume of 150,000 L (40,000 gal) would not exceed 9,000 pCi/L (10 times DWS) for technetium-99 at the 200 West Area fence line or at the 200 Area exclusion boundary.

B.6.2 TANK S-102 CONCLUSIONS BY AREA OF ANALYSIS

Conclusions specific to the areas of short-term human health risk, groundwater impacts, long-term human health risk, intruder risk, and regulatory compliance specific to tank S-102 are provided in the following sections.

B.6.2.1 Tank S-102 Short-Term Human Health Risk Conclusions

This section provides the conclusions reached in the tank S-102 short-term human health risk analysis for occupational risk, routine radiological risk, routine chemical risk, radiological accident risk, and chemical accident risk. Only the human health risk associated with retrieval operations are calculated for comparison. The results of the analysis indicate that, overall, short-term human health risk is not a driver for establishing tank S-102 waste retrieval and LDMM system criteria. The differences are not significant in light of the inherent uncertainties in the analysis and assumptions. The analysis results are presented in Section B.5.2.1.

B.6.2.1.1 Occupational Accident Conclusions. A comparison of the occupational risks (i.e., TRCs, LWCs, and fatalities) associated with the waste retrieval cases results in the following conclusions.

- None of the waste retrieval cases result in a TRC, LWC, or fatality. Therefore, the analysis results indicate that this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank S-102.

- As less sludge is retrieved from tank S-102 in comparison to the cases with 10,000 L (2,700 gal) residual waste (Cases 1, 2, 4, 6, 7, 8, 9, 10) the occupational risk from retrieval operations is reduced by as much as 5% for Cases 4 and 6 and 10% for Case 7.

- Adding the occupational risk from constructing an interim barrier for Case 10 increases the TRC, LWC, and fatality incidences by 25% as compared to the cases that assume 10,000 L (2,700 gal) residual waste without an interim barrier (Cases 1, 2, 4, 6, 7, 8, 9).

B.6.2.1.2 Routine Radiological Risk Conclusions. A comparison of the routine radiological risks (LCFs) to the involved worker, noninvolved worker, and general public associated with the waste retrieval cases results in the following conclusions.

- There is no LCF among the worker population, noninvolved worker population, nor general public population resulting from waste retrieval operations. The LCF risk to the involved worker MEI (2.0×10^{-4}), noninvolved worker MEI (1.5×10^{-11}), and general public MEI (1.9×10^{-10}) is small. Therefore, the analysis results indicate that this

performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank S-102.

- As less sludge is retrieved from tank S-102 in comparison to that assumed in the cases with 10,000 L (2,700 gal) residual waste (Cases 1, 2, 4, 6, 7, 8, 9, 10) the LCF risk from waste retrieval operations is reduced by less than 5%.

B.6.2.1.3 Routine Chemical Risk Conclusions. A comparison of the routine carcinogenic health risk (ILCR) to the involved worker MEI, noninvolved worker MEI, and general public MEI during retrieval operations associated with the waste retrieval cases results in the following conclusions.

- The ILCR for all the cases is small (i.e., less than 1.0×10^{-7}). Therefore, the analysis results indicate that this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank S-102.

- As less sludge is retrieved from tank S-102 in comparison to that assumed in the cases with 10,000 L (2,700 gal) residual waste (Cases 1, 2, 4, 6, 7, 8, 9, 10) the ILCR risk from waste retrieval operations is reduced by 5% for Case 5.

It should be noted that depending on the level of organic compounds contained in the sludge, operating plans should include a phased start-up of the waste retrieval system to limit the potential release of volatile organic compounds and/or ammonia emissions to within the prescribed limits. Such safeguards would help prevent a potential release that occurred in the C tank farm with tank C-106 retrieval operations when the air permit limit was immediately exceeded when waste retrieval began (RPP-5687).

B.6.2.1.4 Radiological Accident Risk Conclusions. The severity of a given accident and the frequency of the accident is common to all waste retrieval cases (Table B.3.1); however, the probability of the accident occurring varies slightly because of the slight variation in duration of operations between the cases. The variation is so slight that there is no change in frequency categories. Therefore, this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank S-102.

B.6.2.1.5 Chemical Accident Risk Conclusions. The severity of a given accident and the frequency of the accident is the same for all waste retrieval cases; however, the probability of the accident occurring varies slightly because of the slight variation in duration of operations between the cases. The variation is so slight that there is no change in frequency category. Therefore, this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank S-102.

B.6.2.2 Tank S-102 Groundwater Impact Conclusions

The groundwater impact evaluations presented in Section B.5.0 result in several observations and conclusions relative to waste retrieval from tank S-102. The conclusions associated with the near-field groundwater impacts of tank S-102 are provided in this section. Conclusions associated with the far-field impacts of the composite sources from the entire S tank farm,

including those from tank S-102, are provided in Section B.6.3.1. For tank S-102, conclusions are discussed in the following.

- Mobile contaminants such as technetium-99 and nitrate associated with retrieval losses exhibit two concentration pulses or a bimodal peak (see Figures B.5.1 and B.5.2) in the groundwater at the S tank farm fence line. The larger leak loss volumes evaluated resulted in an early time peak that dominated the later peak. The first peak, or early time peak, typically occurs in about the year 2070 (within the institutional control period) and the second in about the years 3100 to 3450. The early time peak is in the form of a sharp peak. The second peak is broader and of lower maximum concentration compared to the early time peak.

- The relationship between mobile contaminant near-field concentration and retrieval loss volume (from the focus tanks only) is relatively linear and predictable as illustrated in Section B.5.0 (see Figure B.5.4). Based on the trend line for the early peak concentration versus volume in Figure B.5.4 it would be necessary to limit retrieval volume to about 11,400 L (3,000 gal) to not exceed the technetium-99 DWS of 900 pCi/L. If the action levels identified in the 200-UP-1 interim Record of Decision of 10 times the DWS were used then the leak volume would be limited to approximately 87,000 L (23,000 gal). The trend line slope for the late time peak concentration versus volume is not as steep resulting in a retrieval volume limit of about 22,700 L (6,000 gal) to meet the 900 pCi/L DWS.

- Significant groundwater impacts from uranium-238 associated with both the retrieval and residual source terms do not begin to appear until the year 7000 or later and would not overlap with the mobile contaminant peaks associated with retrieval leakage or residual waste. The uranium-238 groundwater impacts associated with the residual waste volume (see Figure B.5.7) source term are similar to that of the retrieval loss (see Figure B.5.3) source term except that their increase occurs over 500 years later due to the later release of the residual waste. Uranium-238 from retrieval and residual source terms would be present at extremely low concentrations (i.e., on the order of 10^{-17} pCi/L) beginning in the year 4850 and still be low (i.e., on the order of 10^{-7} pCi/L) until about the years 7000 to 8000 and would not have peaked over the 10,000-year period of interest.

- Mobile contaminants such as technetium-99 and nitrate (see Figures B.5.5 and B.5.6) associated with residual waste will exhibit one concentration peak typically at about the year 4000. The concentration peak is in the form of a relatively broad peak compared to the early time retrieval loss concentration peak.

- The relationship between mobile contaminant near-field concentration and residual waste volume (from tank S-102 only) is relatively linear and predictable as illustrated in Section B.5.0 (see Figure B.5.8). For tank S-102, it would be necessary to limit residual waste volume to some value less than 75,700 L (20,000 gal) to not exceed the technetium-99 DWS of 900 pCi/L.

- The mobile contaminants such as technetium-99 and nitrate will exhibit two concentration pulses or a bimodal peak for the composite of retrieval loss and residual waste source terms. As shown in Figures B.5.10 and B.5.11 there is a difference between the technetium-99 and nitrate peaks, even though they are both treated as mobile contaminants in the transport model. The reason for this is that the BBI (BBI 2000) wash factors used to develop source term inventory estimates indicate that the proportion of technetium in the residual solids is greater compared to nitrate and the methodology used to estimate post-retrieval inventories assumes preferential salt cake dissolution.

- The uranium-238 groundwater impacts associated with the composite of the retrieval loss and residual waste source terms have similar concentration versus time trends. Uranium-238 from the composite of the retrieval and residual source terms would be present at extremely low concentrations (i.e., on the order of 10^{-7} pCi/L) until about the years 6000 to 7000 and would not have peaked over the 10,000-year period of interest. The large retrieval loss scenario (i.e., 150,000 L [40,000 gal]) and large residual loss scenario (i.e., 102,000 L [27,000 gal]) would result in uranium-238 concentrations ranging from about 9.7 pCi/L to 27 pCi/L at 12,000 years, which are above the DWS of 6.7 pCi/L. None of the other scenarios would exceed the DWS for uranium-238 over the 10,000-year period of interest.

B.6.2.3 Tank S-102 Long-Term Human Health Risk Conclusions

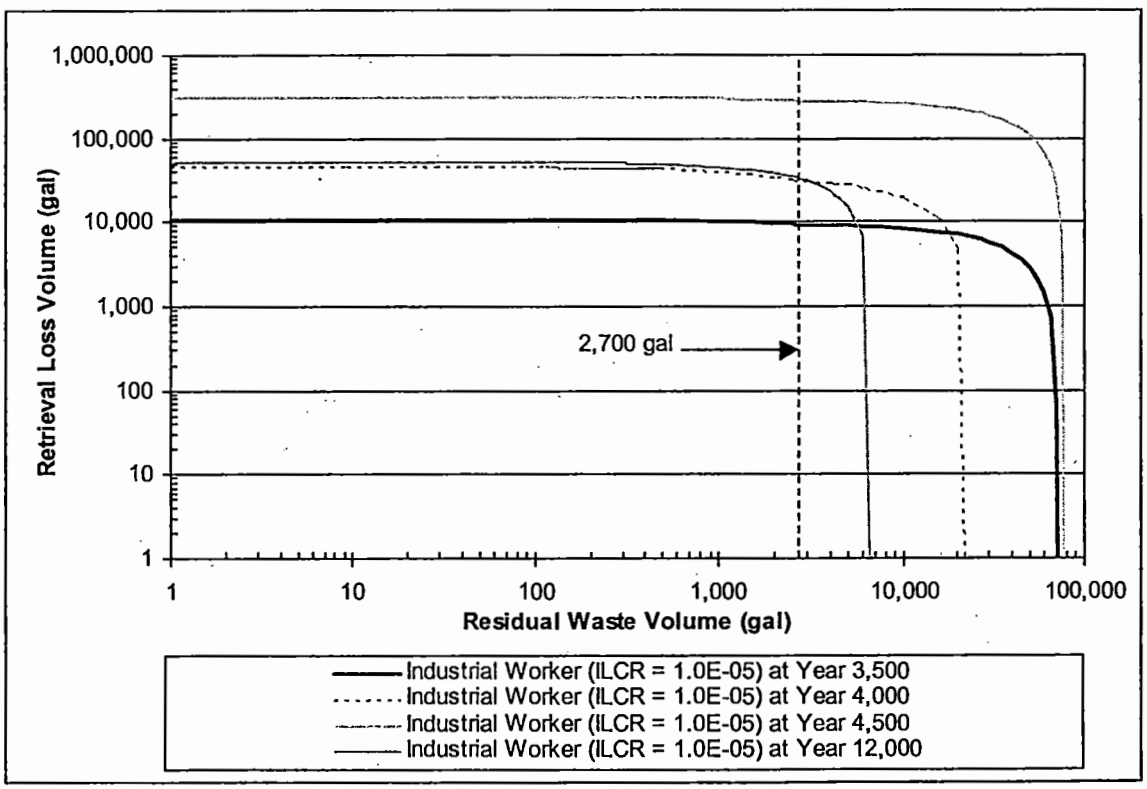
This section identifies tank S-102 retrieval performance requirements based on the results of the long-term human health risk analysis presented in Section B.5.1.3. Risk-based retrieval requirements are specified in terms of the volume limits on the two primary system components for the tank S-102 retrieval (i.e., retrieval leakage and residual waste). Residual waste volume targets for the tank S-102 retrieval demonstration have been established in the HFFACO. The emphasis in this section is therefore on establishing limits on tank S-102 retrieval leakage. Such limits provide a means for identifying an acceptable leakage envelope for moving forward with waste retrieval of tank S-102.

Based on extrapolation of the analysis results, the impacts from tank S-102 retrieval leakage losses, when considered by themselves, exceed an ILCR of 1.0×10^{-5} for the industrial worker scenario at the S tank farm fence line at volumes greater than approximately 15,000 L (4,000 gal). Similarly, the impacts from tank S-102 residual waste, when considered by themselves, exceed an ILCR of 1.0×10^{-5} for the industrial worker at the S tank farm fence line at volumes greater than approximately 25,700 L (6,800 gal). It is important to note that the peak impacts from tank S-102 retrieval leakage are projected to occur during the time period when the tank farm would be under active post-closure care and access to the groundwater exposure pathway at the tank farm fence line for industrial or residential use would be restricted. Peak impacts from tank S-102 residual waste are projected to occur well beyond the end of the active post-closure care period.

The compliance status of tank S-102 relative to the risk-based regulatory standards will be based not on the impacts from any one source term alone but on the impacts from all source terms combined. Determining risk-based retrieval requirements for tank S-102 therefore necessitates

considering the source terms in composite rather than individually. Considering the composite source term necessitates selecting a discrete point in time at which the risks from the individual source terms are to be combined. Simply adding the peak risk values from the individual source terms is not meaningful because these peaks arrive at the S tank farm fence line at different points in time and a receptor would in reality never see these peaks in combination. To identify an appropriate point in time for considering the composite source term, a set of curves showing the relationship between tank S-102 retrieval leakage volume and residual waste volume was generated by extrapolation of the analysis results at different points in time. Curves for the years 3500, 4000, 4500, and 12000 are shown in Figure B.6.1. All three curves are based on a risk threshold of 1.0×10^{-5} at the S tank farm fence line for the industrial worker scenario. Curves for these and several additional time periods were evaluated to identify the time period that yielded the most restrictive (i.e., lowest and most conservative) retrieval leakage volume for a residual waste volume equal to the interim retrieval goal of 10,200 L (2,700 gal) of residual waste. As can be seen in Figure B.6.1, the year 3500 is more restrictive than the other time periods and is therefore used as the basis for the conclusions that follow.

Figure B.6.1. Industrial Worker 1×10^{-4} ILCR at S Tank Farm Boundary at Different Points in Time for Tank S-102 Retrieval Leakage Volume and Residual Waste Volume



The primary method for determining the tank S-102 risk-based retrieval requirements is shown in Figure B.6.2. Like Figure B.6.1, Figure B.6.2 was generated by extrapolation of the analysis results and shows the relationship between tank S-102 retrieval leakage volume and residual waste volume at the S tank farm fence line. Unlike Figure B.6.1, Figure B.6.2 shows curves representing different risk thresholds at one point in time (year 3500) rather than one risk threshold at different points in time. Using Figure B.6.2, the tank S-102 retrieval leakage volume that could occur in combination with a given residual waste volume without exceeding a specified risk threshold can be readily determined. The risk thresholds illustrated on Figure B.6.2 are based on the federal and state cancer risk standards of 1.0×10^{-4} and 1.0×10^{-5}, respectively. Tank S-102 retrieval leakage limits are identified in the following discussion by applying these two risk standards at the S tank farm fence line and assuming waste is retrieved from tank S-102 to the HFFACO interim retrieval goal of 10,200 L (2,700 gal) of residual waste (shown on Figure B.6.2 with a dashed vertical line).

Figure B.6.2. Industrial Worker and Residential Farmer ILCR Levels at S Tank Farm Boundary at Year 3500 for Tank S-102 Retrieval Leakage Volume and Residual Waste Volume

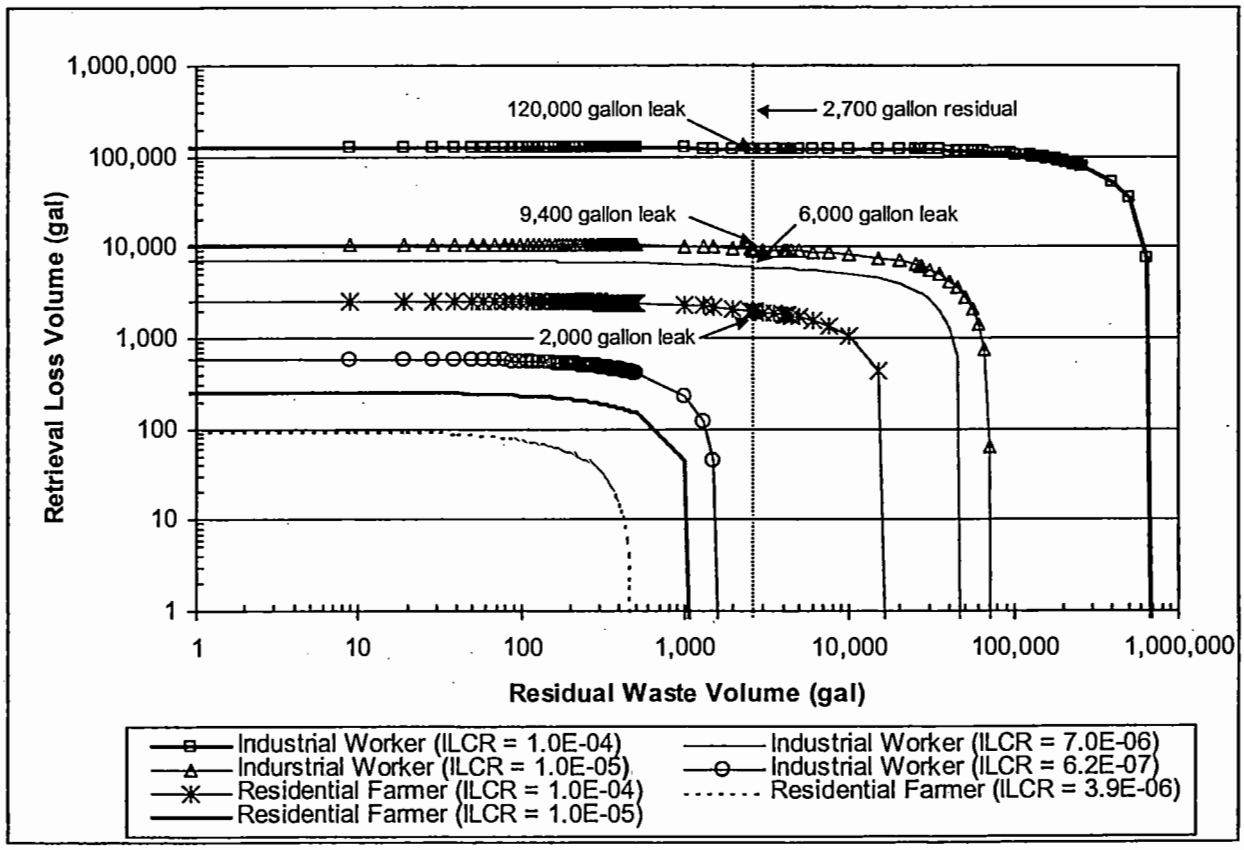


Figure B.6.2 indicates that retrieving waste to the HFFACO interim retrieval goal would allow up to 454,000 L (120,000 gal) of retrieval leakage from tank S-102 without exceeding a risk threshold of 1.0×10^{-4} for the industrial worker scenario at the S tank farm fence line. However, avoiding exceedance of a 1.0×10^{-5} risk threshold for the industrial worker scenario at the tank farm fence line would require limiting retrieval leakage to 35,600 L (9,400 gal) or less (Figure B.6.2).

For a given risk threshold, retrieval requirements are significantly more restrictive for the residential farmer scenario than the industrial worker scenario. For example, Figure B.6.2 indicates that for a 1.0×10^{-4} risk threshold, using a residential farmer scenario instead of an industrial worker scenario lowers the tank S-102 retrieval leakage limit from 454,000 L (120,000 gal) to 7,600 L (2,000 gal), assuming retrieval to the interim retrieval goal. In addition, the analysis results indicate that avoiding exceedance of a 1.0×10^{-5} risk threshold for the residential farmer scenario would not be possible unless waste were retrieved from tank S-102 to considerably lower residual waste levels than specified in the HFFACO interim retrieval goal (approximately 4,000 L [1,000 gal]) and no leakage occurred during waste retrieval.

Retrieval requirements identified in the preceding paragraphs assume the specified risk threshold is apportioned entirely to tank S-102. When the risk threshold is applied to the S tank farm as a whole and apportioned across all of the tanks using the risk allocation methodology discussed in Section B.3.6.5, the retrieval requirements on tank S-102 are significantly more restrictive. For example, a tank farm risk threshold of 1.0×10^{-4} for the industrial worker scenario allocates to a tank S-102 risk budget of 7.0×10^{-6}. Using this apportioned risk budget lowers the tank S-102 retrieval leakage limit from 450,000 L (120,000 gal) to 23,000 L (6,000 gal), assuming retrieval to the HFFACO interim retrieval goal (Figure B.6.2).

Tank farm risk thresholds of 1.0×10^{-5} for the industrial worker scenario and 1.0×10^{-4} for the residential farmer scenario allocate to tank S-102 risk budgets of 6.2×10^{-7} and 3.9×10^{-6}, respectively (Figure B.6.2). Analysis results indicate that avoiding exceedance of both of these apportioned risk budgets would not be possible unless waste were retrieved to lower residual waste levels than specified in the HFFACO interim retrieval goal and no leakage occurred during retrieval.

It is not possible to allocate a tank farm risk threshold of 1.0×10^{-5} for the residential farmer scenario using the methodology discussed in Section B.3.6.5 because at the year 3500 the risk to the residential farmer from the tank S-104 past leak alone exceeds 1.0×10^{-5}, leaving no risk to allocate to the other tanks or source terms. Although impacts from the tank S-104 past leak are projected to peak within the time period when the tank farm would be under active post-closure care, risk levels would exceed 1.0×10^{-5} for the residential farmer at the S tank farm fence line until approximately the year 4000.

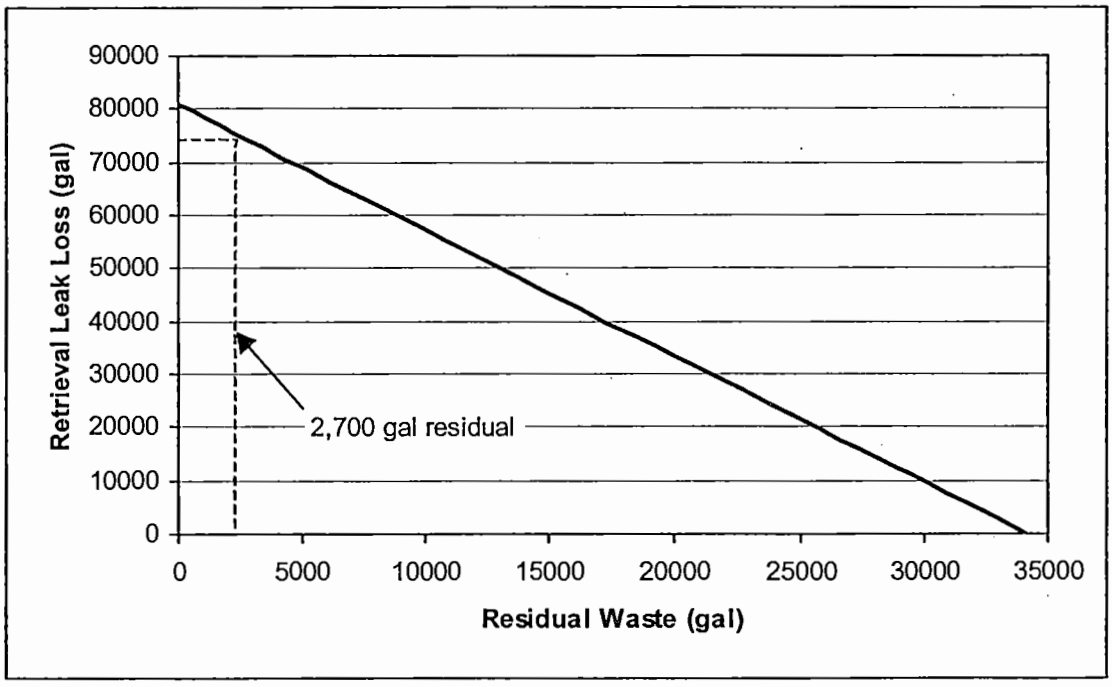
B.6.2.4 Tank S-102 Intruder Risk Conclusions

This section provides the conclusions based on the tank S-102 inadvertent human intruder analysis for the DOE intruder scenario and the NRC requirements. The analysis results are presented in Section B.5.2.4.

B.6.2.4.1 U.S. Department of Energy Intruder Scenario Conclusions. DOE regulations require that exposure to the inadvertent human intruder do not exceed 500 mrem for an acute or single event (well driller) and 100 mrem/yr from chronic exposure (post-driller resident) (DOE O 435.1). The relationship between retrieval leak loss and residual waste is shown in Figure B.6.3. Figure B.6.3 shows that retrieving waste to the interim retrieval goal of 10,000 L (2,700 gal) of residual waste would allow up to 280,000 L (75,000 gal) of retrieval leakage loss without exceeding the 100 mrem/yr dose to the post-driller receptor. Figure B.6.3 also shows if retrieval leakage losses are minimized to 30,000 L (8,000 gal) the 100 mrem/yr dose to the post-driller receptor would not be exceeded if the residual waste is kept under 100,000 L (27,000 gal). The analysis results indicate that this performance measure is a significant driver for establishing tank S-102 waste retrieval and LDMM system criteria. A comparison of the well driller and post-driller resident doses to the DOE regulations for the waste retrieval cases results in the following conclusions.

- None of the well driller cases exceed the 500 mrem acute dose limit set in DOE O 435.1.
- None of the post-driller resident cases exceed the 100 mrem chronic dose limit set in DOE O 435.1.

Figure B.6.3. DOE Inadvertent Human Intruder Post-Driller Threshold Dose (100 mrem/yr) for Tank S-102



B.6.2.4.2 U.S. Nuclear Regulatory Commission Requirement Conclusions. The NRC standard for upper concentration limits for Class C LLW disposal is not exceeded in any of the waste retrieval cases. Therefore, this performance measure is not a significant driver for establishing tank S-102 waste retrieval and LDMM system criteria.

B.6.2.5 Tank S-102 Regulatory Compliance Conclusions

The tank S-102 retrieval demonstration goals as specified in HFFACO Milestone M-45-05A are to remove to safe storage approximately 490 curies of mobile, long-lived radioisotopes and 99% of the tank S-102 contents by volume. The more restrictive of these two goals from a retrieval performance perspective is the removal to safe storage of 490 curies of radionuclides. Using the CoC list of long-lived mobile radionuclides evaluated, removal of 490 curies cannot be achieved because the BBI (BBI 2000) for the identified mobile, long-lived radionuclides (technetium-99; iodine-129; selenium-79; carbon-14; and uranium-233, -234, -235, -236, and -238) totals 487 curies. Assuming the 490 curies HFFACO goal was meant to represent removal to safe storage of 99% of the total inventory of the CoCs, 482 curies of the 487 curies would need to be removed to meet the goal. Leaving a residual of 10,200 L (2,700 gal) or less, all cases except Case 5 will retrieve approximately 487 curies. Based on the current inventory (Hale 2001) used in this RPE, the contaminants of interest contain a total of 275 curies. All cases except Case 5 will retrieve approximately 275 of the curies. The methodology used to calculate the inventory of CoCs in residual waste could affect these calculations (see the Attachment to this Appendix). The uncertainties associated with the inventory are discussed in Section B.6.4.

Removing 99% of the tank contents by volume would require retrieving at least 1.84 ML (487,000 gal) of waste from tank S-102, leaving a maximum residual waste volume of 18,600 L (4,920 gal). That residual waste volume would be less restrictive (i.e., require less waste to be retrieved) than the Milestone M-45-00 interim retrieval goal of 360 ft^3 (10,000 L [2,700 gal]) of residual waste. However, given the precision of the available methods for quantifying residual waste volume, for all practical purposes the two goals are the same.

B.6.2.5.1 Tank S-102 Short-Term Human Health Risk Compliance Conclusions.
The short-term human health risks associated with routine retrieval operations assumed in each of the waste retrieval cases does not exceed standards for the general public MEI.
The incremental dose for the MEI at the Site boundary from tank S-102 retrieval operations (duration 170 days) is 3.8×10^{-7} rem; therefore, the total is below the International Commission on Radiological Protection standard of 0.1 rem/yr (ICRP 1991).

B.6.2.5.2 Tank S-102 Groundwater Protection Compliance Conclusions. Analysis results of the maximum groundwater concentration value for each CoC in tank S-102 were compared to the EPA MCLs and DWSs for nitrates. Technetium-99 exceeds the EPA regulatory MCL (900 pCi/L) for all cases except Cases 1 and 6 with no retrieval loss. Greatest technetium exceedance is Case 8 with 16,800 pCi/L, and least exceedance occurs in Cases 1 and 6 with 119 pCi/L. In all cases except Cases 1 and 6 the technetium-99 peak concentration occurs between the years 2070 and 2080, within the timeframe of institutional controls. Uranium-238 exceeds the EPA regulatory MCL (6.7 pCi/L) only in Cases 5 and 8. Uranium-238 groundwater impacts would not peak over the 10,000-year period of interest. Nitrate concentrations exceed the regulatory standard of 45 mg/L in all cases except Case 3. Only in Case 8 does the exceedance occur within the timeframe of institutional controls.

B.6.2.5.3 Tank S-102 Long-Term Human Health Risk Compliance Conclusions. Long-term human health risk standards may be exceeded even though groundwater quality standards

(i.e., MCLs, derived concentration guide) are not exceeded because the groundwater quality standards are strictly based on drinking water ingestion, whereas the long-term human health risk calculations for future land use scenarios are based on multiple exposure pathways (e.g., drinking water ingestion, milk and meat ingestion, leafy vegetable ingestion). Long-term human health risk exceedance for tank S-102 occurs for the industrial worker scenario in all cases except Cases 1 and 6; exceedance occurs for all cases for cross-section S-101 in the industrial worker scenario. Exceedance of the hazard index standard occurs for both tank S-102 and the S-101 cross-section in the industrial worker scenario in Cases 5 and 8. The long-term human health risk associated with the residential farmer scenario exceeds risk standards and the hazard index for both tank S-102 and the S-101 cross-section. The driver for long-term human health risk is retrieval leakage; cases with the least leakage have lower long-term human health risk values than cases with higher leakage volumes.

B.6.2.5.4 Tank S-102 Inadvertent Human Intrusion Conclusions. The analysis results indicate that none of the cases would exceed the exposure performance objective for the post-driller resident (100 mrem/yr). The performance objective for the well driller indicates none of the 10 waste retrieval cases exceed the performance objective for the acute dose (500 mrem/yr). Under the NRC intruder scenario, used to establish Class C concentration limits for CoCs, all of the waste retrieval cases achieve satisfaction of the criteria.

B.6.2.5.5 Additional Tank S-102 Regulatory Issues. Tank S-102 regulatory issues beyond the four performance measure drivers are addressed in the following sections.

B.6.2.5.5.1 Residual Waste Issues. The NRC incidental waste criterion one specifies that:

> ...wastes have been processed (or will be processed) to remove key radionuclides to the maximum extent that is technically and economically practicable.

The first step in evaluating removal of radionuclides is establishing initial waste volumes and concentrations. The fluidic mixing system will preferentially remove soluble tank waste constituents. To the extent that the CoCs are soluble the fluidic mixing system will likely remove them. However, until further testing and the actual retrieval are completed the extent of CoC removal will not be known. Chemical treatment that removes key radionuclides may need to be considered to supplement the retrieval technology employed for tank S-102 to remove key radionuclides to the extent that is technically and economically practical.

B.6.2.5.5.2 Inadvertent Intruder Scenario Issues. The NRC regulatory requirements for the classification of Class C LLW are analyzed for tank S-102. The analysis reveals that 10 m^3 (360 ft^3) of residual waste will meet Class C standards. The NRC incidental waste Criterion 2 states that:

> ...wastes have been processed (or will be processed) to remove key radionuclides to the maximum extent that is technically and economically practicable.

Using grout will ensure the waste will be in a solid physical form, but uniformly mixing the residual grout may not be technically feasible.

The NRC staff recommend the following alternative waste classification be administered at the Savannah River Site for HLW tank residuals similar to that provided for in 10 CFR 61.58. The reclassification redefines the maximum allowable radionuclide concentration as follows: no radionuclide concentration shall exceed 10 times the value specified in Table 1 of 10 CFR 61.55, at 500 years following the proposed closure for each tank grouping, and no radionuclide concentration shall exceed the value specified in Table 2 Column 3 in 10 CFR 61.55.

The procedure established in 10 CFR 61.55(a)(7) shall be followed such that the sum-of-fractions for all Table 1 radionuclides shall not exceed 10, and the sum-of-fractions for all Table 2 radionuclides shall not exceed 1. This standard is attainable with tank S-102 in all waste retrieval cases; the sum-of-fractions is less than 1 in all cases (Table B.5.1.4).

B.6.2.5.5.3 Long-Term Human Health Risk Issues. None of the waste retrieval cases considered for tank S-102 satisfy both scenarios for evaluating acceptable risk to long-term human health. This is an issue because, although leak loss is the driver for long-term human health risk, even with no leakage and the minimum residual waste both the risk standards and the hazard index are exceeded in the residential farmer scenario.

B.6.3 S TANK FARM CONCLUSIONS

Conclusions specific to the groundwater impacts, long-term human health risk, and regulatory compliance for the S tank farm are provided in this section. The short-term health risks and intruder risks are tank-specific and are not addressed for the tank farm as a whole.

B.6.3.1 S Tank Farm Groundwater Impact Conclusions

Conclusions associated with the far-field composite groundwater impacts from the entire tank farm (i.e., releases from 12 tanks in the S farm) are provided in this section. Three combinations of source terms have been assumed for potential far-field groundwater impacts. As noted in Section B.5.0, two contaminants, technetium-99 and uranium-238, were selected as representative of the range of far-field groundwater impacts based on their mobility in the Hanford subsurface. Technetium-99 is mobile and would move with groundwater. The mobility of uranium-238 is somewhat less than that of technetium-99 but much more mobile than contaminants such as cesium-137. Each of the three combinations were considered with and without the past leak from tank S-104. Two potential far-field compliance points that were considered are as follows:

- 200 West Area fence line located about 1.8 km (1.12 mi) east of the S tank farm
- 200 Area exclusion boundary located about 10.5 km (6.52 mi) east of the S tank farm.

The three source term combinations that are considered are described in Table B.5.14. The peak concentration from the past leak component dominates all other far-field impacts considered and makes it difficult to assess impact changes associated with the other source terms (i.e., the retrieval loss and residual waste). With the impacts from the past leaks included, the peak technetium-99 groundwater concentration from all 3 cases would be in the years 2200 and 2350 at the 200 West Area fence line and 200 Area exclusion boundary, respectively. Technetium-99

peak groundwater concentrations corresponding to the 200 West Area fence line and 200 Area exclusion zone boundary potential compliance points would be within 1 and 10 times the DWS of 900 pCi/L.

The 3 cases described in Table B.5.14 were re-evaluated without the contribution from the tank S-104 past leak, because of the dominance of the past leak source term on the far-field groundwater impacts. Conclusions from this evaluation are as follows.

- Technetium-99 groundwater concentrations at the two potential far-field compliance points did not exceed the DWS of 900 pCi/L when the same 3 cases were considered without the past leak source term.

- A bimodal peak is observed for the technetium-99 groundwater concentration versus time traces for Cases 1 and 2 which each include a retrieval loss and residual volume (see Figures B.5.25 and B.5.27). The late time peak concentration is always greater than the early time peak for these 2 cases.

- The time from peak technetium-99 groundwater concentration at the 200 West Area fence line to the peak technetium-99 groundwater concentration at the 200 Area exclusion boundary is about 170 years. The peak technetium-99 concentrations are reduced by a factor of about 4.25 from the 200 West Area fence line to the 200 Area exclusion boundary.

- The impacts of large retrieval losses (i.e., 150,000 L [40,000 gal]) from tank S-102 are manifested primarily in the early time peaks and would have comparatively little impact on the late time technetium-99 groundwater concentration peaks. From the S tank farm perspective the impacts in terms of peak concentration are not sensitive to a relatively large leak loss from tank S-102.

- Peak uranium-238 groundwater concentrations, within the 10,000-year period of interest, are dominated by the residual waste volume source term and are not sensitive to retrieval leakage. The far-field uranium-238 concentrations only increase by factors from 1.2 (200 West Area fence line) to 1.4 (200 Area exclusion boundary), with the addition of a 30,000 L (8,000 gal) retrieval loss from each of the 12 tanks (Case 1).

B.6.3.2 S Tank Farm Long-Term Human Health Risk Conclusions

Based on the results of S tank farm long-term human health risk analysis presented in Section B.5.2.2, long-term human health risk on a tank farm level appears to have a low sensitivity to changes in retrieval leakage, either from tank S-102 or from the S tank farm as a whole. A limited set of whole-farm analysis cases is evaluated for the S tank farm in this RPE. A common assumption for these cases is that waste is retrieved from all S farm tanks to the HFFACO interim retrieval goal of 10,200 L (2,700 gal) of residual waste. Results of the analysis suggest that if the S tank farm were closed with 10,200 L (2,700 gal) of residual waste remaining in all tanks, the residual waste contribution would dominate the retrieval leakage contribution at the time of peak farm wide human health impacts. Analysis results indicate that a large retrieval

leak from tank S-102 would have a negligible effect on peak farm-wide impacts at the two far-field compliance points evaluated. Additionally, a nominal retrieval leak from all of the tanks would have only a minor effect. These results suggest that a retrieval leak from tank S-102 is unlikely by itself to trigger a need for mitigative action when considered from the perspective of the peak human health impacts projected for the S tank farm as whole.

Results of the S tank farm analysis can also be used to make several higher-level observations regarding alternative points of compliance. At compliance points beyond the tank farm fence line, peak human health impacts will decrease as a result of natural attenuation of contaminant concentrations in the unconfined aquifer. A sense of the magnitude of this decrease in peak impacts can be gained by comparing the analysis results at the S tank farm fence line with the analysis results at the two far-field points of compliance. Because it was determined not to be credible to analyze the impacts for the whole tank farm at the tank farm fence line, a direct comparison between the near- and far-field analysis results is not possible (i.e., near-field impacts are evaluated only for tank S-112 and its cross-section whereas far-field impacts are evaluated only for the whole tank farm). Nevertheless, comparing near-field cross-section impacts with far-field tank farm impacts provides an informative perspective on the potential implications of selecting alternative compliance points. The comparison is made between analysis results from like waste retrieval scenarios as follows. For the cross-section, analysis Case 2 represents a scenario where waste is retrieved to the interim retrieval goal with a 30,000 L (8,000) retrieval leak from each tank (Section B.5.1.3). For the S tank farm, analysis Case 1 represents this same waste retrieval scenario applied to all tanks in the S tank farm (Section B.5.2.2). The peak residential farmer ILCR for Case 2 at the tank farm fence line is projected to exceed 1.0×10^{-3} for the tank S-112 cross-section (Table B.5.12). The peak residential farmer ILCR for Case 1 at the 200 West Area fence line is projected to be between 1.0×10^{-4} and 1.0×10^{-5}; the peak at the 200 Area exclusion boundary is projected to be between 1.0×10^{-5} and 1.0×10^{-6} (Table B.5.19). This comparison suggests that the potential decrease in peak human health impacts resulting from natural attenuation between the S tank farm fence line and compliance points on the east side of the Central Plateau could range from one to over two orders of magnitude.

B.6.3.3 S Tank Farm Regulatory Compliance Issues

This section presents regulatory compliance conclusions relative to the analysis results presented in Section B.5.3 for the S tank farm. The analysis was performed by constructing three new cases with composite source terms, calculating groundwater concentrations and long-term human health risk at two points of compliance, the west side of the 200 West Area (fence line), and the west side of the 200 Area exclusion zone boundary. Because the past leak from tank S-104 dominates all other impacts making it difficult to assess impact changes associated with the other source terms, the analysis was also performed excluding the past leak.

B.6.3.3.1 S Tank Farm, Including Past Leak from Tank S-104. Groundwater concentrations for technetium-99 exceed the regulatory MCLs (900 pCi/L) in all three cases, both at the 200 West Area fence line and at the 200 Area exclusion zone boundary. Uranium-238 and nitrates do not exceed regulatory limits in any case at either boundary. The technetium-99 peaks are early, at about the year 2173, because of the dominance of the past leak. Long-term human health risk regulatory standards are exceeded in both ILCR and hazard index at both boundary

points for the residential farmer scenario. In the industrial worker scenario, ILCR standards are exceeded in all cases at both boundaries, but hazard index is not exceeded.

B.6.3.3.2 S Tank Farm, Excluding Past Leak from Tank S-104. Groundwater concentrations for technetium-99 do not exceed the regulatory MCLs (900 pCi/L) in any of the three cases, at either of the boundaries. Peak concentrations occur late, between the years 4070 and 4335. Uranium-238 and nitrate standards are not exceeded. Long-term human health risk regulatory standards for ILCR are exceeded at the 200 West Area fence line in the three cases using the residential farmer scenario. The hazard index standard is exceeded in Case 1, with 10,000 L (2,700 gal) residual waste in all tanks, and assuming a 30,000 L (8,000 gal) at for the residential farmer scenario at the 200 West Area fence line. In the industrial worker scenario, neither ILCR nor hazard index standards are exceeded in any case at either boundary.

B.6.4 UNCERTAINTIES

The long-term human health risk analysis presented in this RPE is based on the following:

- Inventory projections for what would remain in the three-tank S-101 cross-section (i.e., tanks S-101, S-102, S-103) following waste retrieval
- Leakage that could occur during waste retrieval.

The inventory estimates have been developed using tank-specific wash factors; there is some uncertainty associated with those wash factors because the basis for the wash factors is approximate. Tank-specific chemical modeling could provide a better basis for calculating residual waste and retrieval leakage inventories and should be considered in future RPE analyses.

The risk assessment performed for this RPE is based on best available information and data. The inventory estimates for retrieval leakage and residual waste are based on the current BBI (Hale 2001) and a methodology designed to provide a best estimate for retrieval leakage concentrations and residual waste concentrations that consider tank-specific wash factors (see the Attachment to the Appendix). Source terms or release rates from the residual waste volumes are conservative in that no credit is taken for stabilization of the residual wastes (e.g., grouting). Additionally, the tanks are assumed to completely degrade at the same time providing a conservative estimate of residual waste impacts across the S-101 cross-section. The groundwater concentrations calculated through the numerical transport model are based on a unit width at the tank farm. This approach does not account for the lateral dispersion of contaminants as they migrate toward the S tank farm fence line. Taking this into account would tend to spread the contaminant plume out and reduce the peak concentration. Taking lateral dispersion into account would not be expected to significantly reduce the groundwater concentrations because the tanks are relatively close to the tank farm fence line. There is emerging information that selenium-79 is not as mobile as assumed in this RPE; recent laboratory tests conducted for the immobilized low-activity waste program indicate that selenium has an average distribution coefficient of 6.7 mL/g (PNNL-13037). This indicates that selenium-79 would not reach the groundwater in the timeframe evaluated and would not contribute to the long-term human health risk.

The risk factors used in the industrial worker and residential farmer exposure scenarios for this evaluation were taken from DOE/RL-98-72 and DOE/EIS-0189. Both of those documents have undergone extensive review.

Risk assessments are inherently uncertain in that a number of enabling assumptions and estimates have to be made to assess potential risks to a future site user. For a point estimate risk assessment the inputs used are typically conservative point estimates and those conservative estimates combine to produce a conservative or bounding result. A stochastic uncertainty and sensitivity analysis was performed for the AX tank farm RPE (DOE/RL-98-72) to evaluate how variation and uncertainty in model input parameters translates into uncertainty in long-term human health risk projections. Both uncertainty (lack of knowledge about a parameter) and variability (naturally occurring variations such as receptor bodyweight) contribute to the overall risk uncertainty. Based on the sensitivity analysis results from DOE/RL-98-72 the input parameters (ranked in order from highest to lowest influence) were exposure, source term, and transport parameters. Based on the AX tank farm uncertainty analysis results it was observed that variation and uncertainty in the exposure parameters (e.g., milk consumption, water consumption, exposure duration) resulted in 2.5 orders of magnitude overall uncertainty. The results of the DOE/RL-98-72 uncertainty analysis are generally applicable to this RPE in that the parameters that tended to dominate the uncertainty at the AX tank farm would be expected to drive the uncertainty at the S tank farm.

One of the conclusions drawn from the DOE/RL-98-72 uncertainty analysis was that additional data collection would provide limited reduction in the overall uncertainty and that the uncertainty should not be used as an argument for delaying interim decisions to move forward with waste retrieval.

The long-term impacts from ancillary equipment are not quantitatively addressed in this scoping level RPE. The contribution of the ancillary equipment to the tank farm closure inventory is an area that will require consideration in future versions of the tank S-102 RPE and in performance assessment calculations for S tank farm closure. Currently there is no available data on the contaminant inventory in the S tank farm ancillary equipment.

The fate and transport analysis is based on a two-dimensional vadose zone combined with saturated zone modeling approach and its interpretation. The S-101 cross-section taken through the centerline of tanks S-101, S-102, and S-103 has a unit width of 0.3 m (1 ft). The calculated contaminant concentration at the fence line in the aquifer is calculated by considering the instantaneous mass flux that would be passing an area that is 5 m (16 ft) tall by 0.3 m (1 ft) thick. The contaminant concentration determined from a sample from a groundwater monitoring well or a water supply well located at the fence line and along the cross-section would be expected to be smaller than the model results. This is because the sample would include groundwater from a 360° circumference around the well. The amount of the resulting dilution would vary as a function of the pumping rate used to collect the sample, well diameter, and well screen length.

The approach also assumes the groundwater gradient direction is exactly parallel to the cross-section over the 10,000-year period of interest. This results in the comingling of releases from all three cross-section tanks in the groundwater. The groundwater gradient direction is

expected to be predominately west to east but is also a transient that changes with changes in recharge and discharge. The amount of contaminant comingling from the cross-section tanks could vary greatly as the gradient direction changes slightly and the time of release for the different source term releases is varied.

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ATTACHMENT B-1

RETRIEVAL AND RESIDUAL INVENTORY CALCULATIONS

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LIST OF TERMS

BBI	best-basis inventory
HFFACO	*Hanford Federal Facility Agreement and Consent Order*

B1.1.0 INTRODUCTION

Waste composition calculations were made for each of the S farm tanks, estimating waste tank contents after retrieval to 10 m^3 (360 ft^3), the maximum residual waste heel allowed by the *Hanford Federal Facility Agreement and Consent Order* (HFFACO; Ecology el al. 1989). Calculations also included inventory estimates for a 30,300 L (8,000 gal) leak to ground. Additional residual waste heel amounts and leak loss inventories were calculated for tanks S-112 and S-102 because they have been assigned alternate retrieval technologies and are the focus of retrieval performance evaluations. Tank S-112 is treated separately from the other S farm tanks because it is being evaluated in parallel in a separate retrieval performance evaluation. These calculations support the evaluation of the various cases reviewed in this retrieval performance evaluation. The source of the starting inventory information for tanks S-112 and S-102 calculations was an advance interim update to the August 2000 best-basis inventory (BBI) data provided by the Hanford site BBI organization (Hale 2001). The advance interim BBI update reflected inventory changes that were in development at the time this RPE analysis was performed and was provided in advance of the formal BBI update to support the RPE completion schedule. The updated BBI was used as the starting inventory for analysis of tanks S-112 and S-102. Analysis of the remaining C Farm tanks was based on inventory information in the August 2000 BBI.

New retrieval methods have been proposed for tanks S-112 and S-102. Differences between the previous baseline retrieval method (sluicing) and the demonstration retrieval methods caused the development of two different calculation methods: one for tanks S-112 and S-102, and one for the remainder of the S farm tanks. The calculation differences are driven by the amount of agitation assumed to take place in the tanks during retrieval, and the assumption that the new retrieval methods will preferentially dissolve salt cake leaving the sludge essentially untouched.

The following are the basic assumptions used in making the waste inventory estimates.

1. Retrieval liquid requirement for each tank is based on the amount required to ensure the concentration of sodium is less than 5 molar and the concentration of undissolved solids is less than 10 wt% in the waste solution transferred out of the tank.

2. Water is used for retrieval of all S farm tank wastes.

3. The baseline retrieval endpoint of 99% retrieval is as defined in the HFFACO; specifically a wet sludge heel of 360 ft^3 (10,000 L [2,700 gal]) is assumed.

4. The initial conditions in the tanks are as defined in the BBI.

5. Each component in the waste solids currently in all the tanks except tanks S-112 and S-102 will be dissolved according to the BBI wash factors upon addition of the waste retrieval liquid. The methodology for tanks S-112 and S-102 is to preferentially dissolve salt cake prior to any sludge retrieval.

6. Post-retrieval residual waste will have the same physical characteristics (e.g., interstitial volume) as the dry waste heels left in the 200-series tanks of the S farm. Final heel

porosity was calculated for the 200-series tanks to be 58.5%, which is comparable to *Chemical Engineers' Handbook* (Perry 1963) values for similar solids (e.g., sand, dirt).

7. Tanks not yet interim stabilized will be interim stabilized prior to waste retrieval. Interim stabilization is defined for single-shell tanks as (HNF-EP-0182, Rev. 150):

> A tank which contains less than 50,000 gal of drainable interstitial liquid and less than 5,000 gal of supernate liquid. If the tank is jet pumped to achieve interim stabilization, then the jet pump flow or saltwell screen inflow must also have been at or below 0.05 gpm before interim stabilization criteria is met.

B1.2.0 INVENTORY FROM TANK S-104 PAST LEAK

In the S tank farm, tank S-104 has leaked waste to the ground. The total inventory leaked from tank S-104 is estimated in *Groundwater/Vadose Zone Integration Project – Hanford Soil Inventory* (BHI-01496) published in March 2001. The values in Table B1.1 are from BHI-01496.

Table B1.1. Tank S-104 Past Leak Inventory

Constituent of Concern	Units	Inventory
Cr	kg	7.73E+02
Na	kg	1.80E+04
NO_2	kg	6.79E+03
NO_3	kg	1.68E+04
Total U	kg	1.18E+02
^{14}C	Ci	5.46E-01
^{60}Co	Ci	2.18E-01
^{63}Ni	Ci	6.45E+00
^{79}Se	Ci	1.16E-01
^{90}Sr	Ci	4.46E+03
^{90}Y	Ci	4.46E+03
^{99}Tc	Ci	3.83E+00
^{126}Sn	Ci	1.78E-01
^{129}I	Ci	7.35E-03
^{137}Cs	Ci	1.12E+04
^{137}mBa	Ci	1.07E+04
^{233}U	Ci	7.28E-06
^{234}U	Ci	4.05E-02
^{235}U	Ci	1.72E-03
^{236}U	Ci	9.61E-04
^{238}U	Ci	3.92E-02
^{238}Pu	Ci	2.25E-02
^{239}Pu	Ci	1.42E+00
^{240}Pu	Ci	2.05E-01
^{241}Pu	Ci	1.27E+00
^{242}Pu	Ci	5.44E-06
^{241}Am	Ci	1.95E+00
^{243}Am	Ci	1.84E-05
^{243}Am	Ci	2.13E-05
^{244}Am	Ci	6.50E-04

Source: BHI-01496.

B1.3.0 RETRIEVAL AND RESIDUAL INVENTORY CALCULATIONS FOR RETRIEVAL OF TANKS S-112 AND S-102

Residual waste estimates for tanks S-112 and S-102 were calculated using a different methodology than that used to calculate residual estimates for other S farm tanks. The methodology used for tank S-102 was also applied to tank S-112. This difference is designed to respect the mechanical differences between the proposed retrieval technologies for these tanks and the traditional sluicing technology assumed to be used for the other S farm tanks.

The residual waste inventory estimate for tanks S-112 and S-102 were calculated using the same methodology as was used to generate the inventory estimates for the AX tank farm (DOE/RL-98-72). Like the AX farm tanks, tanks S-112 and S-102 contain both sludge and salt cake waste. To calculate the residual waste inventory, it was assumed that the use of salt cake dissolution technology as the retrieval mechanism would preferentially remove salt cake from the tank. Retrieval of the sludge waste would require a second retrieval effort using a different technology.

Advance updates to the BBI for tanks S-112 and S-102 were used as the starting point for these calculations, and the inventory associated with the salt cake and sludge waste types was apportioned from the total tank waste inventory identified (Hale 2001). The inventory estimate was then reduced to account for the tanks being interim stabilized before waste retrieval from that tank. The salt cake and sludge waste volumes remaining after interim stabilization were obtained by calculating and removing enough liquid inventory to bring the tank into compliance with the definition of interim stabilization.

It was assumed that the inventory associated with each waste type (i.e., salt cake and sludge) was uniformly distributed within the waste type and that the waste types were segregated. The residual waste inventory for the tanks were calculated by determining what volume of each waste type would remain after waste retrieval (dependent upon the case being evaluated) and then scaling down each waste type inventory.

For example, total tank S-112 waste retrieval of 80% would remove 87.3% of the salt cake and none of the sludge in the tank. The residual waste inventory was then determined by adding the remaining inventory of the salt cake (12.7% of the original salt cake inventory) to the sludge inventory (100% of the original). The estimates represent the following:

- Tank post-retrieval inventory estimates are based on the best-estimate inventory methodology and reported in BBI
- The waste retrieval process preferentially removes salt cake and then sludge (not a factor in tank S-102 because it has such a large amount of sludge)
- Residual inventory estimates are proportional to the volume of sludge and salt cake remaining after waste retrieval that do not account for preferential removal of water-soluble contaminants.

Beginning inventory for tank S-102 is contained in Table B1.2. Tables B1.3 and B1.4 contain calculated residual waste and retrieval leak loss inventory for tank S-102. Tank S-112 beginning inventory and estimates are reported with the balance of the S farm tanks for clarity.

Table B1.2. Pre- and Post-Stabilization Inventories for Tank S-102

Constituent of Concern	Units	Pre-Stabilization Inventory	Post-Stabilization Inventory
Cr	kg	4.73E+03	2.53E+03
Na	kg	3.64E+05	1.88E+05
NO_2	kg	8.84E+04	4.62E+04
NO_3	kg	1.00E+06	7.43E+05
Total U	kg	4.95E+03	4.24E+03
^{14}C	Ci	4.78E+01	2.40E+01
^{60}Co	Ci	1.76E+01	8.82E+00
^{63}Ni	Ci	2.75E+02	1.81E+02
^{79}Se	Ci	3.88E-01	1.96E-01
^{90}Sr	Ci	9.29E+04	7.66E+04
^{90}Y	Ci	9.29E+04	7.66E+04
^{99}Tc	Ci	2.18E+02	1.10E+02
^{126}Sn	Ci	2.35E+00	1.19E+00
^{129}I	Ci	6.81E-01	3.42E-01
^{137}Cs	Ci	2.55E+05	1.32E+05
^{137m}Ba	Ci	2.41E+05	1.25E+05
^{233}U	Ci	5.80E+00	4.98E+00
^{234}U	Ci	1.81E+00	1.55E+00
^{235}U	Ci	7.36E-02	6.31E-02
^{236}U	Ci	5.64E-02	4.83E-02
^{238}Pu	Ci	2.97E+00	1.52E+00
^{238}U	Ci	1.65E+00	1.42E+00
^{239}Pu	Ci	1.15E+02	5.89E+01
^{240}Pu	Ci	1.91E+01	9.78E+00
^{241}Am	Ci	1.50E+01	8.99E+00
^{241}Pu	Ci	1.50E+02	7.67E+01
^{242}Pu	Ci	1.14E-03	5.83E-04
^{243}Am	Ci	4.20E-03	2.15E-03
^{243}Cm	Ci	2.42E-02	1.24E-02
^{244}Cm	Ci	2.18E-01	1.11E-01

Table B1.3. Tank S-102 Case Residual Waste Inventory Summary

Constituent of Concern	1,300 gal Heel	2,700 gal Heel	27,000 gal Heel
Cr (kg)	4.19E+00	8.67E+00	8.67E+01
Na (kg)	1.51E+02	3.13E+02	3.13E+03
NO^2 (kg)	5.07E+01	1.05E+02	1.05E+03
NO^3 (kg)	6.22E+03	1.29E+04	1.29E+05
Total U (kg)	4.56E+01	9.44E+01	9.44E+02
^{14}C (Ci)	1.95E-03	4.03E-03	4.03E-02
^{60}Co (Ci)	3.06E-04	6.34E-04	6.34E-03
^{63}Ni (Ci)	1.13E+00	2.35E+00	2.35E+01
^{79}Se (Ci)	4.14E-05	8.57E-05	8.57E-04
^{90}Sr (Ci)	7.77E+02	1.61E+03	1.61E+04
^{90}Y (Ci)	7.77E+02	1.61E+03	1.61E+04
^{99}Tc (Ci)	1.36E-02	2.82E-02	2.82E-01
^{126}Sn (Ci)	2.54E-04	5.26E-04	5.26E-03
^{129}I (Ci)	2.63E-05	5.44E-05	5.44E-04
^{137}Cs (Ci)	1.16E+02	2.39E+02	2.39E+03
^{137}mBa (Ci)	1.09E+02	2.27E+02	2.27E+03
^{233}U (Ci)	5.38E-02	1.11E-01	1.11E+00
^{234}U (Ci)	1.67E-02	3.46E-02	3.46E-01
^{235}U (Ci)	6.78E-04	1.40E-03	1.40E-02
^{236}U (Ci)	5.20E-04	1.07E-03	1.07E-02
^{238}Pu (Ci)	9.30E-04	1.92E-03	1.92E-02
^{238}U (Ci)	1.53E-02	3.16E-02	3.16E-01
^{239}Pu (Ci)	3.62E-02	7.49E-02	7.49E-01
^{240}Pu (Ci)	6.01E-03	1.24E-02	1.24E-01
^{241}Am (Ci)	3.84E-02	7.95E-02	7.95E-01
^{241}Pu (Ci)	4.70E-02	9.72E-02	9.72E-01
^{242}Pu (Ci)	3.58E-07	7.41E-07	7.41E-06
^{243}Am (Ci)	1.31E-06	2.72E-06	2.72E-05
^{243}Cm (Ci)	7.59E-06	1.57E-05	1.57E-04
^{244}Cm (Ci)	6.83E-05	1.41E-04	1.41E-03

Table B1.4. Tank S-102 Case Retrieval Leak Loss Inventory Summary

Constituent of Concern	4,000 gal Retrieval Leak	8,000 gal Retrieval Leak	40,000 gal Retrieval Leak
Cr (kg)	8.82E+00	1.76E+01	8.82E+01
Na (kg)	6.57E+02	1.31E+03	6.57E+03
NO_2 (kg)	1.61E+02	3.23E+02	1.61E+03
NO_3 (kg)	2.56E+03	5.12E+03	2.56E+04
Total U (kg)	1.45E+01	2.91E+01	1.45E+02
^{14}C (Ci)	8.39E-02	1.68E-01	8.39E-01
^{60}Co (Ci)	3.09E-02	6.18E-02	3.09E-01
^{63}Ni (Ci)	6.26E-01	1.25E+00	6.26E+00
^{79}Se (Ci)	6.85E-04	1.37E-03	6.85E-03
^{90}Sr (Ci)	2.63E+02	5.25E+02	2.63E+03
^{90}Y (Ci)	2.63E+02	5.25E+02	2.63E+03
^{99}Tc (Ci)	3.84E-01	7.67E-01	3.84E+00
^{126}Sn (Ci)	4.15E-03	8.30E-03	4.15E-02
^{129}I (Ci)	1.20E-03	2.39E-03	1.20E-02
^{137}Cs (Ci)	4.62E+02	9.24E+02	4.62E+03
^{137}mBa (Ci)	4.36E+02	8.72E+02	4.36E+03
^{233}U (Ci)	1.71E-02	3.41E-02	1.71E-01
^{234}U (Ci)	5.32E-03	1.06E-02	5.32E-02
^{235}U (Ci)	2.16E-04	4.32E-04	2.16E-03
^{236}U (Ci)	1.65E-04	3.31E-04	1.65E-03
^{238}Pu (Ci)	5.31E-03	1.06E-02	5.31E-02
^{238}U (Ci)	4.85E-03	9.70E-03	4.85E-02
^{239}Pu (Ci)	2.06E-01	4.12E-01	2.06E+00
^{240}Pu (Ci)	3.42E-02	6.84E-02	3.42E-01
^{241}Am (Ci)	3.12E-02	6.24E-02	3.12E-01
^{241}Pu (Ci)	2.68E-01	5.37E-01	2.68E+00
^{242}Pu (Ci)	2.04E-06	4.08E-06	2.04E-05
^{243}Am (Ci)	7.52E-06	1.50E-05	7.52E-05
^{243}Cm (Ci)	4.34E-05	8.68E-05	4.34E-04
^{244}Cm (Ci)	3.90E-04	7.79E-04	3.90E-03

B1.4.0 RETRIEVAL AND RESIDUAL INVENTORY CALCULATIONS FOR RETRIEVAL OF REMAINING S FARM TANKS

Water was used in the calculations as the retrieval liquid for all the S farm tanks because most of the tanks contain significant quantities of salt cake in addition to sludge. The amount of water calculated for retrieval was the amount required to result in both (1) a concentration of less than 5 molar sodium and (2) 10 wt% solids or less in the retrieved waste. These limits were established to minimize the possible crystallization of sodium-rich salts in the waste transfer lines and to minimize problems transferring slurries.

Tank-specific water wash factors have been developed for each component in the waste and are documented in *Best-Basis Wash and Leach Factor Analysis* (HNF-3157). These estimates were derived from a variety of sources, including analytical data; large-scale sludge washing experiments; thermodynamic solubility models; comparison of similar wastes; and the use of chemical analogs for certain chemicals and for most radionuclides. Separate wash factors do not exist for the salt cake and sludge portions of the solids currently in the tanks. The wash factors apply to the total solids. Therefore, the solids remaining after retrieval water is added to the S farm tanks will be the sum of each component times one minus the wash factor.

This method for determining residual waste inventories was chosen because it relies on the same data currently being used in the Hanford tank waste operations simulator model to simulate all of the tank farm retrieval operations. The Hanford tank waste operations simulator model is not only being used to model various retrieval scenarios, but to estimate the volume and composition of waste derived from each tank and the amount of high-level and low-activity waste glass produced from each batch of tank waste.

Residual sludge heels were assumed to be physically similar to the dry heels left in the C tank farm 200-series tanks, with a similar porosity. The average calculated heel porosity for the C tank farm 200-series tanks is 58.5%, meaning that the final heel will be 58.5% interstitial liquid and 41.5% washed solids. The 58.5% volume was calculated to be filled with retrieval liquid, contributing the final retrieval liquid concentrations of chemical and radionuclide constituents for the estimated volume.

Residual tank waste volumes evaluated included 10 m^3 (360 ft^3). This tank residual waste volume represent retrieval performance equal to the HFFACO interim retrieval goal of 360 ft^3. The residual waste solids were calculated for the 10 waste retrieval cases.

The conceptual model for final waste composition is similar to sand left in a bucket. Even with the bucket full of sand, it can still contain a certain additional volume of liquid. This is because there is space (interstitial volume) between the particles of sand. The calculation is designed to leave a sludge heel of some volume, saturated with either retrieval fluid or the final rinse fluid.

The estimating calculation method follows the following process.

1. Calculate the amount of liquid needed to make a 10 wt% solids slurry or a 5 molar sodium solution with the amount of waste presently in the tanks.

2. Use the best-basis wash factor (a tank-specific value) to estimate the amount of solids that would dissolve into the total volume of retrieval fluid.

3. Calculate the retrieval fluid concentration. This is done by adding the three inventories (average supernate inventory [which is equal to the average supernate concentration times the amount of supernate introduced into the tank], the solids inventory fraction dissolved into the supernate [using best-basis wash factors], and inventory from liquid already in the tank [retrieved directly from BBI]) and dividing the sum by the total amount of liquid required to retrieve the tank.

4. Reduce (by ratio) the new calculated volume of solids (diminished by dissolution into the retrieval fluid) to the desired residual waste heel volume.

5. Using an assumed average porosity calculated from dry sludge in C farm 200-series tanks (assumed to be 58.5%) calculate the heel interstitial volume.

6. Using the final retrieval fluid concentration (calculated in step 3), calculate the heel inventory contribution of the final retrieval fluid filling the interstitial volume of the reduced heel volume (calculated in step 4).

7. If the final heel volume is calculated to be the HFFACO maximum allowable volume (which would leave approximately 2.54 cm [1 in.] of waste at the bottom of the tank) or less it is assumed that the heel would be washed to reduce inventory addition from the retrieval fluid (1:3 dilution). If the final heel volume calculated for is greater than that allowed by the HFFACO, the retrieval fluid filling the interstitial volume of the heel is left at full strength on the assumption that something would have gone wrong for the retrieval effort to be terminated early.

8. Final heel inventory is estimated as the sum of waste constituents calculated in step 4 plus the waste constituents from either step 6 or 7, depending on the final heel volume calculated for.

9. Retrieval leak loss inventory is found by multiplying the concentration of the retrieval fluid (calculated in step 3) times the volume leaked during retrieval.

This calculation method assumes that all the waste in the tank will be aggressively agitated to fully contact with the retrieval fluid during retrieval operations.

Table B1.5 presents the BBI inventories for the S farm tanks (except tanks S-112 and S-102). Table B1.6 presents estimated inventory in a 10,200 L (2,700 gal) wet sludge residual heel for S farm tanks (except tanks S-112 and S-102). Table B1.7 presents the estimated inventory loss to ground that would result from a 30,300 L (8,000 gal) leak during retrieval.

Tank S-112 information is presented separately because the residual heel and retrieval leak inventory estimates were calculated using a different methodology (the same as used for tank S-102). Table B1.8 presents tank S-112 pre- and post-stabilization inventories. Table B1.9 presents tank S-112 inventory estimates associated with a 10,200 L (2,700 gal) residual waste heel. Table B1.10 presents estimated inventory loss to ground of a 30,300 L (8,000 gal) leak loss volume for tank S-112.

Table B1.5. S Farm Non-Focus Tank Beginning Inventories

Analyte	S-101	S-103	S-104	S-105	S-106	S-107	S-108	S-109	S-110	S-111
Cr (kg)	1.9E+04	6.0E+03	4.3E+03	1.4E+04	1.3E+04	8.6E+03	1.3E+04	7.7E+03	1.7E+04	1.2E+04
Na (kg)	4.0E+05	2.7E+05	2.2E+05	5.8E+05	5.0E+05	2.1E+05	5.5E+05	7.0E+05	4.7E+05	4.4E+05
NO_2 (kg)	1.3E+05	8.3E+04	4.7E+04	1.4E+05	6.2E+04	7.5E+04	1.3E+05	5.3E+04	6.6E+04	9.0E+04
NO_3 (kg)	4.3E+05	3.4E+05	3.5E+05	7.6E+05	8.6E+05	1.4E+05	7.2E+05	1.5E+06	7.0E+05	5.1E+05
U(total) (kg)	1.2E+04	8.1E+02	1.2E+04	2.0E+03	7.8E+02	1.7E+04	2.0E+03	4.6E+02	8.2E+03	4.5E+02
^{14}C (Ci)	3.2E+01	3.3E+01	1.6E+00	4.2E+01	4.8E+01	1.3E+01	5.4E+01	6.2E+01	3.9E+01	5.0E+01
^{60}Co (Ci)	3.4E+01	1.7E+02	6.7E+00	4.2E+01	8.1E+01	3.2E+02	6.5E+02	7.1E+01	4.2E+01	5.0E+01
^{63}Ni (Ci)	8.8E+02	2.0E+02	9.7E+02	3.0E+02	5.2E+02	5.9E+02	6.3E+02	6.0E+02	7.0E+02	8.9E+02
^{79}Se (Ci)	5.2E+00	2.8E+00	4.4E+00	4.6E+00	6.4E+00	1.7E+00	7.3.E+00	7.2E+00	3.9E+00	5.2E+00
^{90}Sr (Ci)	6.9E+05	4.0E+04	5.5E+05	2.7E+05	4.0E+04	4.0E+05	6.4E+04	5.9E+04	3.7E+05	4.4E+05
^{90}Y (Ci)	6.9E+05	4.0E+04	5.5E+05	2.7E+05	4.0E+04	4.0E+05	6.4E+04	5.9E+04	3.7E+05	4.4E+05
^{99}Tc (Ci)	2.3E+02	1.9E+02	4.4E+01	3.0E+02	2.3E+02	9.3E+01	2.5E+02	3.6E+02	2.8E+02	3.3E+02
^{126}Sn (Ci)	7.9E+00	4.3E+00	6.8E+00	7.0E+00	9.7E+00	2.7E+00	1.1E+01	1.1E+01	5.9E+00	7.9E+00
^{129}I (Ci)	4.4E-01	3.7E-01	1.2E-01	5.8E-01	4.5E-01	1.8E-01	4.8E-01	6.9E-01	5.4E-01	6.4E-01
^{137}Cs (Ci)	3.6E+05	2.5E+05	1.1E+05	4.5E+05	2.7E+05	2.1E+05	3.6E+05	1.9E+05	2.8E+05	3.7E+05
^{137}mBa (Ci)	3.4E+05	2.4E+05	1.0E+05	4.3E+05	2.6E+05	2.0E+05	3.4E+05	3.3E+05	2.6E+05	3.5E+05
^{233}U (Ci)	3.4E+00	1.0E+00	3.3E-01	1.2E+00	1.8E-01	4.2E-01	1.1E+00	1.8E-01	3.3E+00	2.3E-01
^{234}U (Ci)	4.3E+00	3.0E-01	4.2E+00	7.2E-01	2.7E-01	7.0E+00	7.2E-01	1.6E-01	2.9E+00	1.6E-01
^{235}U (Ci)	1.8E-01	1.2E-02	1.7E-01	3.0E-02	1.1E-02	2.8E-01	3.0E-02	6.8E-03	1.2E-01	6.6E-03
^{236}U (Ci)	1.2E-01	9.3E-03	7.5E-02	2.0E-02	6.9E-03	3.6E-01	2.0E-02	4.3E-03	7.3E-02	4.3E-03
^{238}U (Ci)	4.1E+00	2.7E-01	4.1E+00	6.8E-01	2.6E-01	5.6E+00	6.7E-01	1.6E-01	2.7E+00	1.5E-01
^{238}Pu (Ci)	1.1E+01	4.5E+00	1.1E+01	1.5E+00	8.3E-01	7.4E+01	1.2E+01	1.5E+00	1.0E+01	5.2E-01
^{239}Pu (Ci)	6.6E+02	1.8E+02	4.2E+02	6.1E+01	4.4E+01	1.8E+03	4.8E+02	6.8E+01	6.0E+02	2.7E+01
^{240}Pu (Ci)	9.7E+01	2.9E+01	8.3E+01	9.8E+00	6.5E+00	3.2E+02	7.9E+01	1.0E+01	8.8E+01	4.1E+00
^{241}Pu (Ci)	6.7E+02	3.0E+02	4.6E+02	1.0E+02	5.0E+01	4.0E+03	8.0E+02	9.1E+01	6.1E+02	3.2E+01
^{242}Pu (Ci)	3.1E-03	1.6E-03	6.6E-03	5.3E-04	2.4E-04	2.3E-02	4.3E-03	4.6E-04	2.9E-03	1.6E-04
^{241}Am (Ci)	1.4E+02	1.3E+02	7.5E+01	7.5E+01	1.6E+01	3.2E+01	2.2E+02	6.9E+00	1.1E+02	1.2E+01
^{243}Am (Ci)	4.7E-03	4.6E-03	2.3E-03	2.0E-03	4.9E-04	1.2E-03	6.0E-03	2.0E-04	3.6E-03	3.6E-04
^{243}Cm (Ci)	2.0E-02	3.2E-02	1.5E-03	1.2E-02	2.8E-03	1.1E-02	3.7E-02	1.2E-03	2.5E-02	2.3E-03
^{244}Cm (Ci)	1.8E-01	3.1E-01	1.2E-03	1.3E-01	3.1E-02	1.6E-01	4.0E-01	1.4E-02	2.4E-01	2.4E-02

Table B1.6. S Farm Non-Focus Tank Inventories for 2,700 gal Residual Waste Heel

Analyte	S-101	S-103	S-104	S-105	S-106	S-107	S-108	S-109	S-110	S-111
Cr (kg)	9.0E+01	3.9E+02	3.5E+01	1.1E+03	7.3E+02	1.0E+02	6.4E+02	1.8E+02	4.1E+02	1.1E+02
Na (kg)	7.6E+02	3.9E+02	6.0E+02	8.7E+01	6.4E+02	3.5E+02	6.1E+02	1.6E+03	3.8E+02	7.5E+02
NO_2 (kg)	7.0E+00	1.1E+02	2.3E+01	4.8E+02	5.4E+01	5.7E+01	1.0E+02	3.7E+01	5.6E+01	7.5E+01
NO_3 (kg)	2.3E+02	4.7E+02	1.7E+02	3.2E+02	8.5E+02	1.1E+02	6.2E+02	1.3E+03	6.3E+02	4.3E+02
U(total) (kg)	9.0E+01	9.1E+01	1.0E+02	1.0E+02	7.4E+01	2.8E+02	1.6E+02	7.0E+01	3.3E+02	4.6E+00
^{14}C (Ci)	8.5E-03	2.1E-03	5.0E-04	2.7E-05	3.8E-05	7.8E-03	3.7E-05	3.7E-01	3.2E-05	2.1E-02
^{60}Co (Ci)	2.5E-01	1.3E+01	5.7E-02	6.6E+00	8.3E+00	5.2E+00	5.5E+01	1.0E+01	1.8E+00	6.5E-01
^{63}Ni (Ci)	6.5E+00	1.5E+01	8.2E+00	4.8E+01	5.4E+01	9.6E+00	5.3E+01	7.2E+01	3.0E+01	1.2E+01
^{79}Se (Ci)	4.9E-03	3.9E-06	2.2E-06	2.9E-06	4.7E-02	2.6E-04	2.5E-02	6.9E-03	6.9E-03	2.9E-03
^{90}Sr (Ci)	5.1E+03	1.7E+03	4.7E+03	2.1E+04	3.1E+03	6.7E+03	4.1E+03	9.1E+03	1.2E+04	6.1E+03
^{90}Y (Ci)	5.1E+03	1.7E+03	4.7E+03	2.1E+04	3.1E+03	6.7E+03	4.1E+03	9.1E+03	1.2E+04	6.1E+03
^{99}Tc (Ci)	1.5E-01	2.7E-04	3.2E-02	1.3E+01	1.7E+00	1.3E-01	1.6E+00	3.2E+01	9.0E-01	1.2E+00
^{126}Sn (Ci)	5.4E-02	2.8E-01	5.8E-02	1.1E+00	9.9E-01	4.0E-02	9.3E-01	1.5E+00	2.5E-01	8.2E-02
^{129}I (Ci)	3.3E-03	5.1E-07	5.7E-04	3.6E-07	3.5E-07	1.7E-03	3.3E-07	4.0E-07	4.4E-07	5.1E-07
^{137}Cs (Ci)	8.0E+01	3.5E-01	1.1E+02	1.5E+04	1.0E+03	8.1E+02	1.2E+03	4.0E+00	2.3E-01	1.6E+03
^{137}mBa (Ci)	7.6E+01	3.3E-01	1.1E+02	1.4E+04	9.6E+02	7.7E+02	1.1E+03	2.7E+01	2.1E-01	1.5E+03
^{233}U (Ci)	2.5E-02	7.6E-02	2.8E-03	1.8E-01	1.7E-02	7.0E-03	8.9E-02	2.8E-02	1.3E-01	2.3E-03
^{234}U (Ci)	3.2E-02	2.2E-02	3.6E-02	1.1E-01	2.6E-02	1.2E-01	5.7E-02	2.5E-02	1.2E-01	1.6E-03
^{235}U (Ci)	9.1E-04	9.1E-04	1.5E-03	4.7E-03	1.1E-03	4.6E-03	2.3E-03	1.0E-03	4.9E-03	6.6E-05
^{236}U (Ci)	1.3E-03	7.0E-04	6.4E-04	3.1E-03	6.5E-04	6.0E-03	1.6E-03	6.6E-04	2.9E-03	4.4E-05
^{238}U (Ci)	3.0E-02	2.0E-02	3.5E-02	1.1E-01	2.5E-02	9.2E-02	5.3E-02	2.3E-02	1.1E-01	1.5E-03
^{238}Pu (Ci)	8.5E-02	3.4E-01	9.6E-02	2.4E-01	8.5E-02	1.2E+00	1.0E+00	2.2E-01	4.3E-01	6.7E-03
^{239}Pu (Ci)	4.9E+00	1.3E+01	3.7E+00	9.5E+00	4.5E+00	2.9E+01	4.0E+01	1.0E+01	2.6E+01	3.5E-01
^{240}Pu (Ci)	7.2E-01	2.2E+00	7.1E-01	1.5E+00	6.7E-01	5.2E+00	6.6E+00	1.6E+00	3.7E+00	5.3E-02
^{241}Pu (Ci)	4.9E+00	2.2E+01	3.9E+00	1.5E+01	5.1E+00	6.6E+01	6.7E+01	1.4E+01	2.6E+01	4.2E-01
^{242}Pu (Ci)	2.3E-05	1.2E-04	5.6E-05	8.3E-05	2.4E-05	3.8E-04	3.6E-04	6.9E-05	1.2E-04	2.1E-06
^{241}Am (Ci)	1.1E+00	1.0E+01	6.3E-01	1.2E+01	1.7E+00	5.3E-01	1.8E+01	1.0E+00	4.7E+00	1.6E-01
^{243}Am (Ci)	3.5E-05	3.5E-04	2.0E-05	3.1E-04	5.0E-05	2.0E-05	5.0E-04	3.0E-05	1.5E-04	4.9E-06
^{243}Cm (Ci)	1.3E-04	2.1E-03	1.2E-05	4.2E-05	1.4E-04	1.7E-04	1.5E-03	3.9E-05	5.3E-04	2.3E-05
^{244}Cm (Ci)	1.1E-03	2.1E-02	9.9E-06	4.7E-04	1.6E-03	2.3E-03	1.7E-02	4.3E-04	5.1E-03	2.4E-04

Table B1.7. S Farm Non-Focus Tank 8,000 gal Retrieval Leak Loss Inventories

Analyte	S-101	S-103	S-104	S-105	S-106	S-107	S-108	S-109	S-110	S-111
Cr (kg)	3.4E+01	1.1E+01	6.2E-01	4.4E+01	4.2E+01	1.9E+01	3.8E+01	3.3E+01	5.8E+01	3.2E+01
Na (kg)	1.5E+03	3.6E+02	7.3E+02	3.5E+03	3.5E+03	1.5E+03	3.5E+03	3.5E+03	3.5E+03	3.1E+03
NO_2 (kg)	6.1E+02	1.1E+03	2.2E+02	8.4E+02	4.3E+02	5.8E+02	8.4E+02	2.7E+02	4.9E+02	6.7E+02
NO_3 (kg)	2.0E+03	4.5E+03	1.6E+03	4.6E+03	6.0E+03	1.1E+03	4.6E+03	7.4E+03	5.1E+03	3.8E+03
U(total) (kg)	4.2E-02	4.7E-03	6.1E-04	3.0E-10	4.7E-01	0.0E+00	8.4E-01	5.4E-02	4.2E+00	9.0E-01
^{14}C (Ci)	1.4E-01	4.3E-01	7.2E-03	2.6E-01	3.4E-01	9.8E-02	3.4E-01	3.0E-01	2.9E-01	3.6E-01
^{60}Co (Ci)	0.0E+00	6.7E-02	1.0E-05	9.2E-04	8.4E-03	3.3E-02	4.4E-03	2.4E-02	3.3E-04	2.1E-02
^{63}Ni (Ci)	3.9E-02	9.5E-02	1.5E-03	6.7E-03	4.7E-02	6.1E-02	3.8E-02	6.8E-01	4.9E-02	1.6E-01
^{79}Se (Ci)	2.1E-02	3.7E-02	2.0E-02	2.8E-02	4.2E-02	1.3E-02	4.5E-02	3.6E-02	2.8E-02	3.7E-02
^{90}Sr (Ci)	0.0E+00	2.3E+02	1.9E+00	8.2E+02	7.2E+01	0.0E+00	9.5E+01	2.3E+00	6.3E+02	8.6E-01
^{90}Y (Ci)	0.0E+00	2.3E+02	1.9E+00	8.2E+02	7.2E+01	0.0E+00	9.5E+01	2.3E+00	6.3E+02	8.6E-01
^{99}Tc (Ci)	9.7E-01	2.6E+00	1.8E-01	1.3E+00	1.5E+00	6.6E-01	1.5E+00	7.7E-01	1.9E+00	1.8E+00
^{126}Sn (Ci)	2.8E-03	7.1E-03	6.3E-06	1.0E-04	1.4E-03	1.6E-03	3.3E-04	7.5E-03	2.1E-04	1.5E-02
^{129}I (Ci)	0.0E+00	5.0E-03	2.2E-04	3.5E-03	3.1E-03	5.9E-04	3.1E-03	3.5E-03	4.0E-03	4.8E-03
^{137}Cs (Ci)	1.6E+03	3.4E+03	4.4E+02	2.2E+03	1.8E+03	1.3E+03	2.2E+03	9.7E+02	2.0E+03	1.9E+03
^{137}mBa (Ci)	1.5E+03	3.2E+03	4.2E+02	2.0E+03	1.7E+03	1.2E+03	2.1E+03	1.7E+03	1.9E+03	1.8E+03
^{233}U (Ci)	1.2E-05	5.8E-06	1.6E-08	1.7E-13	1.1E-04	0.0E+00	4.7E-04	2.1E-05	1.7E-03	4.6E-04
^{234}U (Ci)	1.5E-05	1.7E-06	2.1E-07	1.1E-13	1.6E-04	0.0E+00	3.0E-04	1.9E-05	1.5E-03	3.2E-04
^{235}U (Ci)	6.2E-07	6.9E-08	8.5E-09	4.5E-15	6.8E-06	0.0E+00	1.2E-05	7.9E-07	6.2E-05	1.3E-05
^{236}U (Ci)	4.0E-07	5.3E-08	3.7E-09	3.0E-15	4.1E-06	0.0E+00	8.4E-06	5.0E-07	3.7E-05	8.8E-06
^{238}U (Ci)	1.4E-05	1.6E-06	2.0E-07	1.0E-13	1.6E-04	0.0E+00	2.8E-04	1.8E-05	1.4E-03	3.0E-04
^{238}Pu (Ci)	2.1E-05	3.8E-04	2.9E-05	1.1E-04	1.2E-04	3.2E-04	1.2E-03	2.5E-04	1.2E-03	2.2E-04
^{239}Pu (Ci)	1.2E-03	1.5E-02	1.1E-03	4.3E-03	6.2E-03	7.7E-03	4.7E-02	1.2E-02	7.3E-02	1.1E-02
^{240}Pu (Ci)	1.7E-04	2.4E-03	2.2E-04	6.9E-04	9.1E-04	1.4E-03	7.8E-03	1.8E-03	1.1E-02	1.7E-03
^{241}Pu (Ci)	1.2E-03	2.5E-02	1.2E-03	7.1E-03	6.9E-03	1.8E-02	7.8E-02	1.6E-02	7.3E-02	1.4E-02
^{242}Pu (Ci)	5.6E-09	1.4E-07	1.7E-08	3.8E-08	3.3E-08	1.0E-07	4.2E-07	8.0E-08	3.4E-07	6.7E-08
^{241}Am (Ci)	2.6E-04	2.8E-03	3.7E-06	1.1E-11	1.9E-03	0.0E+00	1.7E-02	1.0E-03	1.1E-02	1.8E-03
^{243}Am (Ci)	8.4E-09	9.5E-08	1.1E-10	3.0E-16	5.8E-08	0.0E+00	4.7E-07	2.9E-08	3.5E-07	5.7E-08
^{243}Cm (Ci)	1.2E-05	5.2E-05	4.0E-07	6.9E-05	9.8E-06	8.5E-06	1.2E-04	5.0E-06	9.3E-05	4.6E-06
^{244}Cm (Ci)	1.1E-04	5.1E-04	3.2E-07	7.7E-04	1.1E-04	1.2E-04	1.3E-03	5.5E-05	8.9E-04	4.8E-05

Table B1.8. Pre- and Post-Interim Stabilized Inventories for Tank S-112

Constituent of Concern	Units	Pre-Stabilization Inventory	Post-Stabilization Inventory
Cr	kg	1.49E+04	1.09E+04
Na	kg	6.54E+05	4.78E+05
NO_2	kg	1.71E+05	1.25E+05
NO_3	kg	7.77E+05	5.68E+05
Total U	kg	2.05E+03	1.53E+03
^{14}C	Ci	6.68E+01	4.88E+01
^{60}Co	Ci	3.42E+01	2.50E+01
^{63}Ni	Ci	6.17E+02	4.57E+02
^{79}Se	Ci	8.12E-01	5.92E-01
^{90}Sr	Ci	6.27E+04	5.05E+04
^{90}Y	Ci	6.27E+04	5.05E+04
^{99}Tc	Ci	3.71E+02	2.71E+02
^{126}Sn	Ci	4.92E+00	3.59E+00
^{129}I	Ci	7.14E-01	5.21E-01
^{137}Cs	Ci	4.11E+05	3.01E+05
^{137}mBa	Ci	3.90E+05	2.85E+05
^{151}Sm	Ci	2.72E+04	1.98E+04
^{233}U	Ci	1.06E+00	7.90E-01
^{234}U	Ci	7.26E-01	5.43E-01
^{235}U	Ci	3.02E-02	2.26E-02
^{236}U	Ci	2.02E-02	1.51E-02
^{238}Pu	Ci	1.25E+01	9.17E+00
^{238}U	Ci	6.84E-01	5.12E-01
^{239}Pu	Ci	4.90E+02	3.64E+02
^{240}Pu	Ci	8.08E+01	5.99E+01
^{241}Am	Ci	2.45E+02	1.79E+02
^{241}Pu	Ci	6.36E+02	4.68E+02
^{242}Pu	Ci	4.81E-03	3.54E-03
^{243}Am	Ci	7.79E-03	5.68E-03
^{243}Cm	Ci	2.20E-04	2.08E-04
^{244}Cm	Ci	1.31E-03	9.83E-04

Table B1.9. Tank S-112 Residual Waste Inventory Summary

Constituent of Concern	Units	2,700 gal Heel
Cr	kg	5.84E+01
Na	kg	2.19E+03
NO_2	kg	7.99E+02
NO_3	kg	1.86E+03
Total U	kg	6.69E+01
^{14}C	Ci	9.56E-02
^{60}Co	Ci	2.21E-02
^{63}Ni	Ci	1.16E+01
^{79}Se	Ci	8.71E-04
^{90}Sr	Ci	7.95E+03
^{90}Y	Ci	7.95E+03
^{99}Tc	Ci	8.53E-01
^{126}Sn	Ci	5.30E-03
^{129}I	Ci	1.65E-03
^{137}Cs	Ci	1.79E+03
^{137}mBa	Ci	1.69E+03
^{233}U	Ci	3.44E-02
^{234}U	Ci	2.37E-02
^{235}U	Ci	9.83E-04
^{236}U	Ci	6.55E-04
^{238}Pu	Ci	1.59E-01
^{238}U	Ci	2.23E-02
^{239}Pu	Ci	1.20E+01
^{240}Pu	Ci	1.71E+00
^{241}Am	Ci	4.71E-01
^{241}Pu	Ci	7.23E+00
^{242}Pu	Ci	4.62E-05
^{243}Am	Ci	7.41E-06
^{243}Cm	Ci	7.86E-05
^{244}Cm	Ci	5.21E-05

Table B1.10. Tank S-112 Retrieval Leak Loss Inventory Summary

Constituent of Concern	Units	8 kgal Retrieval Leak
Cr	Kg	7.95E+01
Na	Kg	3.48E+03
NO_2	Kg	9.09E+02
NO_3	Kg	4.14E+03
Total U	Kg	1.07E+01
^{14}C	Ci	3.56E-01
^{60}Co	Ci	1.83E-01
^{63}Ni	Ci	3.26E+00
^{79}Se	Ci	4.33E-03
^{90}Sr	Ci	3.11E+02
^{90}Y	Ci	3.11E+02
^{99}Tc	Ci	1.98E+00
^{126}Sn	Ci	2.62E-02
^{129}I	Ci	3.80E-03
^{137}Cs	Ci	2.19E+03
^{137}mBa	Ci	2.07E+03
^{233}U	Ci	5.53E-03
^{234}U	Ci	3.80E-03
^{235}U	Ci	1.58E-04
^{236}U	Ci	1.06E-04
^{238}Pu	Ci	6.60E-02
^{238}U	Ci	3.58E-03
^{239}Pu	Ci	2.58E+00
^{240}Pu	Ci	4.26E-01
^{241}Am	Ci	1.31E+00
^{241}Pu	Ci	3.37E+00
^{242}Pu	Ci	2.55E-05
^{243}Am	Ci	4.15E-05
^{243}Cm	Ci	9.46E-07
^{244}Cm	Ci	6.81E-06

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