0056416

U.S. Department of Energy
Office of River Protection
P.O. Box 450
Richland, Washington 99352

01-REQ-032

JUL 12 2001

Mr. Michael A. Wilson, Program Manager
Nuclear Waste Program
State of Washington
Department of Ecology
1315 W. Fourth Avenue
Kennewick, Washington 99336

Dear Mr. Wilson:

SUBMITTAL OF DRAFT FUNCTIONS AND REQUIREMENTS DOCUMENT (F&R) TO THE STATE OF WASHINGTON DEPARTMENT OF ECOLOGY (ECOLOGY) FOR REVIEW AND COMMENT IN SUPPORT OF MILESTONE M-045-03-T04, "SUBMIT C-104 SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL DEMONSTRATION FUNCTIONS AND REQUIREMENTS DOCUMENT"

This letter submits a draft F&R Document in support of Hanford Federal Facility Agreement and Consent Order Milestone M-045-03-T04, which is due December 31, 2001 (Enclosure). The C-104 F&R document establishes the demonstration system specifications, including Leak Detection Monitoring and Mitigation (LDMM) system specifications, for the C-104 waste retrieval demonstration. In addition, this document includes a scoping level Retrieval Performance Evaluation, develops the C-104 demonstration LDMM and retrieval strategy, and addresses lessons learned from related experience from both the U.S. Department of Energy (DOE) and industry.

Since the final version of this document is scheduled for delivery to Ecology by December 31, 2001, we request Ecology's review of this draft and would appreciate receiving your comments within 45 days of the date you receive this letter. In order to submit the final version of the F&R Document in a timely fashion so that project critical path is not affected, we are hopeful that this process will provide adequate time for Ecology's review, revision, and approval.

If you have any questions, please contact me, or your staff my contact Robert Lober, DOE Office of River Protection (ORP), (509) 373-7949, or Joe Cruz, ORP, (509) 372-2606.

Sincerely,

Mary E Burandt for

James E. Rasmussen, Director
Environmental Management Division

REQ:RWL

Enclosure

cc: See page 2

cc w/encl:
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Administrative Record

SINGLE-SHELL TANK C-104
FULL SCALE SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL DEMONSTRATION
FUNCTIONS AND REQUIREMENTS

EXECUTIVE SUMMARY

The Hanford Site has 149 single-shell tanks (SSTs) and 28 double-shell tanks (DSTs) containing high-level radioactive waste produced from nuclear fuel reprocessing. The U.S. Department of Energy Office of River Protection is responsible for operating the tank farms, retrieving the waste from the tanks, treating and immobilizing the waste for safe storage and ultimate disposal. The SSTs are not equipped with a secondary containment structure or capability, are beyond their design life, and many of the tanks have leaked or are suspected of leaking waste to the surrounding soil.

This document establishes for the life of the project the functions and requirements (F&Rs), required by Milestone M-45-03-T04 of the Hanford Federal Facility Agreement and Consent Order, (DOE et al, 1989, as amended), for the retrieval of radioactive waste stored in SST tank C-104, a sound tank located in the 200 East Area of the Hanford Site. The systems proposed to retrieve the tank waste will demonstrate alternate technologies and approaches to retrieving the waste and to leak detection, monitoring, and mitigation (LDMM). This functions and requirements document is a primary document as agreed among the U.S. Department of Energy, the Washington State Department of Ecology, and the U.S. Environmental Protection Agency. Upon approval, this document allows final design of the retrieval system to commence.

This document also presents lessons learned from other government and industry retrieval projects which are tabulated in Appendix A. The scoping level Retrieval Performance Evaluation (RPE) for 241-C tank farm, which focuses on tank C-104, is in Appendix B. The LDMM and retrieval strategy for tank C-104 is contained in Section 5.

The goals of this demonstration include the retrieval to safe storage of approximately 99% of the existing tank contents by volume and 89 kilograms of Plutonium. This will leave a residual waste volume of approximately 360 cubic feet or less depending on the limits of the retrieval technology.

The SSTs, including tank C-104, do not meet all state or Federal requirements for storage or operation of hazardous waste facilities, particularly those regulatory requirements for secondary containment and leak detection. In order to develop health-based limits for waste remaining in the tank after retrieval and for leakage that could occur during retrieval operations, a scoping level RPE was prepared. The RPE includes a human health and environmental risk assessment, and establishes the risks from waste remaining in the tank after retrieval and risks posed by leakage during retrieval for several exposure scenarios. The RPE methodology is an iterative process that can be applied before waste retrieval to help develop criteria for the extent of retrieval and leak loss, and then after retrieval to evaluate performance measures using actual retrieval and leak loss data. The results of the pre-retrieval RPE are incorporated into this functions and requirements document as risk-based requirements applicable to the design of the retrieval and LDMM systems.

The RPE indicates that waste remaining in the tank will exceed Class C limits (10 CFR 61.55) even after 99% of the waste has been removed. According to 10 CFR 61.7, waste that

exceeds Class C limits is "generally unacceptable for near surface disposal. There may be some instances where waste with concentrations greater than permitted for Class C would be acceptable for near-surface disposal with special processing or design. These will be evaluated on a case-by-case basis." This will require the establishment of near surface, greater than Class C closure criteria, which is beyond the scope of this document.

The waste retrieval system design for the tank C-104 retrieval demonstration will incorporate alternatives to past practice sluicing. A confined sluicing system that minimizes the volume of free liquid in the tank during operations will be used to retrieve the tank waste. Minimizing the tank free liquid will minimize the potential for leaks to the environment, and demonstrate the viability of an alternate technology for retrieving SST wastes.

Mass and volumetric measurement techniques are the current EPA reference standard used for leak detection for petroleum and chemical process storage tanks. These methods will be incorporated into the tank C-104 waste retrieval system design. Alternate technologies, if economically available and developed to a level that adds confidence and increased capability to the EPA reference methods, will also be incorporated into the tank C-104 retrieval system design.

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FIGURES

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Acronyms

BBI	Best Basis Inventory
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DST	Double Shell Tank
ECOLOGY	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
F&R	Functions & Requirements
ILCR	Incremental Lifetime Cancer Risk
LDMM	Leak Detection, Monitoring & Mitigation
MOU	Memorandum of Understanding
ORP	Office of River Protection
RCRA	Resource Conservation and Recovery Act of 1976
RPE	Retrieval Performance Evaluation
RPP	River Protection Project
SST	Single-Shell Tank
TPA	Tri-Party Agreement - Hanford Federal Facility Agreement and Consent Order (Also called HFFACO)
WAC	Washington Administrative Code
W.G.	Water-gauge. Unit of measure for pressure or vacuum given as "Inches of water-guage"

1.0 INTRODUCTION

The River Protection Project (RPP) mission includes retrieval, immobilization, storage 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 the more reliable DSTs to serve as feed material for the waste immobilization process. SST waste retrieval activities will be conducted, to the extent required, to meet requirements that allow ultimate closure of the tank and the tank farm. 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. Ecology is the lead agency in this work. This approach includes:

- Demonstrating alternative 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 demonstrations for future SST retrieval approaches.
- Retrieving tanks that pose the highest risk to minimize the impact of potential releases to the environment. Tank C-104 represents the highest amount of Plutonium in any SST.
- Using human health and environmental risk analysis tied to ongoing vadose zone, characterization, and contaminant transport independently reviewed to establish LDMM and retrieval system performance requirements and operating strategies.

1.1 Background

During the 1950's, 1960's and 1970's, waste from SSTs was retrieved from 58 SSTs 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 retrieval, the LDMM approach used a static liquid surface measurement along with ex-tank monthly dry well 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.

Numerous technologies have been identified for retrieving the various SST waste types to minimize the potential impacts to the environment. In addition to evaluating these technologies for their recovery capability and feasibility, the associated waste retrieval strategies and equipment must also integrate the means to detect, monitor, and mitigate detectable leaks that exceed performance based risk levels. LDMM is legally agreed to by DOE, Ecology, and EPA in the *Hanford Federal Facility Agreement and Consent Order* (DOE et al, 1989, as amended), referred to as the Tri-Party Agreement (TPA).

The development of a risk-based retrieval release protection strategy and the retrieval performance evaluation (RPE) process are the basis for establishing functions and requirements (F&Rs). The RPE process is an out-growth of procedures negotiated in 1994 to evaluate the 99% retrieval goal, following completion of retrieval demonstration activities. The procedures included determining if an alternative retrieval goal was appropriate if the interim 99% 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 between Ecology and DOE that acknowledged the uncertainty with the ability to attain the 99% interim retrieval goal and LDMM requirements. Under the memorandum of understanding, 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). The design, development, screening, and assessment of alternative technologies according to these F&Rs will result in a preferred LDMM and retrieval system design that is protective of human health and the environment.

The SST Retrieval Program Mission Analysis Report (HNF-2944, 1998) documents a technically defensible approach 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 C-104 retrieval demonstration has the following goals:

- Establish the feasibility and limits of a confined sluicing robotics system designed to meet the Hanford Federal Facility Agreement and Consent Order M-45-03F milestone retrieval goals: retrieve approximately 99% or more of the existing tank contents by volume from the SST, including approximately 89 kilograms of plutonium or the limit of waste retrieval technology capability, whichever is more.
- Establish performance characteristics and limits of an integrated retrieval and LDMM system designed to minimize leakage during retrieval, if it occurs, and detect leakage within a risk-based performance envelope.
- Upon completion of retrieval activities, provide a basis, along with other SST retrieval projects and demonstration lessons learned, for deploying retrieval and LDMM technologies in the remaining SSTs.
- Demonstrate sludge/hard heel tank retrieval using confined sluicing of robotic techniques (DOE/Ecology, 2000, milestone M-45-03-T04).

Closure requirements for SSTs, including acceptable levels of residual waste in the tanks and residual contamination in surrounding soils, as well as cumulative risks posed to human health and the environment from the 241-C Tank Farm, other tank farms, and other waste management sites in the 200 Area, have not yet been agreed to by DOE, Ecology, and EPA. In absence of these requirements, the results of the RPE are used to determine the risk posed by residual waste (i.e., past leaks, leak losses, and residual tank waste) in the 241-C Tank Farm to establish performance requirements that are protective of human health and the environment. Risk results include the residential farmer post-closure land use scenario. The strategy used to incorporate the RPE results into the retrieval requirements is discussed in Section 3.0.

In addition to the RPE, nuclear safety requirements and existing SST and DST system operational limits are imposed on the waste retrieval system design and are contained in this F&R (see Section 4.0).

The SSTs have been declared unfit-for-use in previous Ecology audits. Additions of liquids for retrieval purposes and actions are discussed in the RCRA Part A, Form 3 "Interim Status Permit Application".

1.2 Purpose

The purpose of this document is to 1) establish the F&Rs and 2) establish the LDMM and retrieval strategy for the tank C-104 retrieval demonstration specified in Hanford Federal Facility Agreement and Consent Order Milestone M-45-03-T04. Approval of this document allows start of design. Definition of design start, for purposes of the TPA milestone, is the initiation of final design as defined in DOE Order 413.3 (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 demonstration waste retrieval system for tank C-104. This document also provides the strategy used to define the functions and requirements for retrieval and leak detection based on the RPE (Appendix B). This document satisfies the requirements established in Hanford Federal Facility Agreement and Consent Order milestone M-45-03-T04 by:

- Establishing the demonstration system requirements including the LDMM requirements (Section 4),
- Including a scoping level RPE (Appendix B) to help Ecology assess the adequacy of the tank C-104 demonstration system,
- Including a design and operating approach that takes into consideration a range of leak losses 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 C-104 retrieval demonstration (Section 5), and
- Addressing mitigation strategies and decision thresholds for potential leaks during retrieval (Section 3).

The F&Rs identified in this document provide the foundation for the design criteria and design requirements documented in Level 2 design specifications. Design specifications are used to develop the project engineering concepts, scope, and boundaries. The content of the design 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 design specifications for the tank C-104 retrieval system will be developed during pre-design and Title I design activities based on this approved functions and requirements document.

Figure 1-1 provides a plan view of the 241-C tank farm and nearby RCRA groundwater monitoring wells. Groundwater monitoring activities will be consistent with the Hanford Soil and Groundwater Monitoring Work Plan (WHC, 1999). Drywell monitoring will occur prior to and following tank C-104 retrieval.

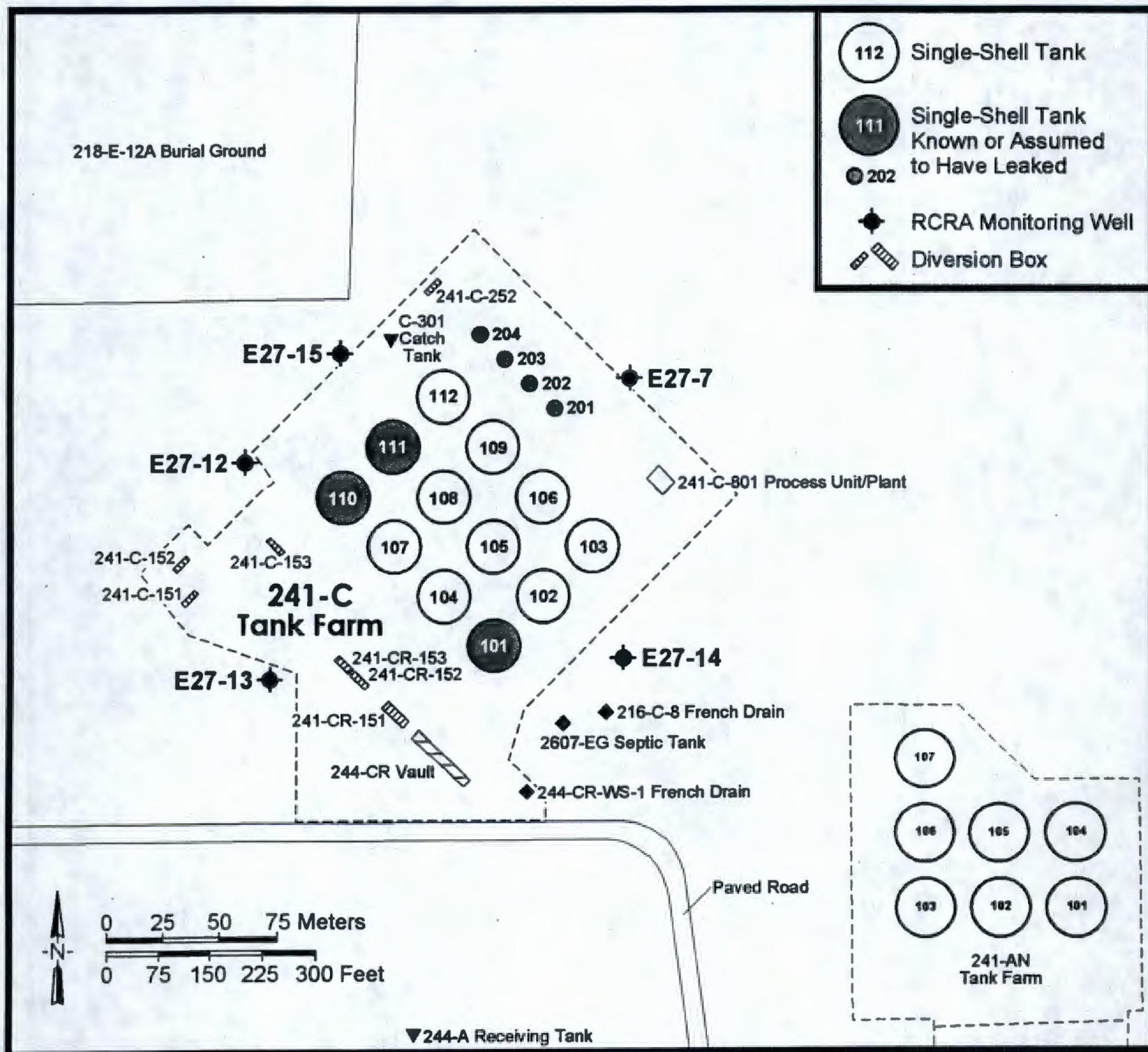

Figure 1-1. 241-C Tank Farm Plan View and RCRA Monitoring Wells

1.4 Tank C-104 Conditions

The 241-C Tank Farm was constructed between 1943 and 1944, as one of the first generation Tank Farms. (Tank C-104 is one of twelve 100-series, 530,000-gal, 75-ft-diameter SSTs in the 241-C Farm.) Tank C-104 operated in support of various fuel reprocessing and radionuclide recovery campaigns from 1946 through 1980, when the tank was declared inactive in March 1980. Tank C-104 was declared "interim stabilized" in September 1989, with the remaining waste categorized as sludge. Currently, tank C-104 is categorized as sound.

Tank C-104 contains approximately 263,000 gallons of sludge produced from Plutonium and Uranium production, as described in the Tank Interpretive Report (TIR, 2000). Primary contaminants of concern include Plutonium, Americium, Cesium, and Strontium. The tank currently contains approximately 23,500 curies of Plutonium, 6,400 curies of Americium-241, 114,000 curies of Cesium-137, and 579,000 curies of Strontium-90, with a total inventory of 1,470,000 curies from all isotopic constituents. Sample analysis data, along with estimates based on process modeling and flow sheets, have been used to develop the best basis inventory (BBI) for all Hanford underground tank waste from which the above data is taken (TWINS Website, 2001). The RPE provides additional information on tank waste constituents.

Figure 1-2 shows a plan view of tank farm 241-C with bore-hole (drywell) locations shown inside the tank farm. The drywells around tank C-104 will be used in addition to other methods (see Section 5) for leak detection and monitoring of possible leaks. Ten dry wells (also called vadose zone monitoring boreholes) were installed around tank C-104 between March of 1970 and October of 1974 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. Two are 50 ft deep, one is 60 ft deep, four are 100 ft deep, two are 135 ft deep and one is 145 ft deep (Vadose, 2001). Leak detection was accomplished through periodic geophysical logging of the dry wells (e.g., to detect radiation and moisture increases).

1.5 Document Organization

This document is organized as follows:

- Section 1 provides an introduction, background, purpose, and scope to this document, as well as a summary of current tank C-104 conditions.
- Section 2 identifies the regulatory framework and governing requirements documents under which the retrieval demonstration of tank C-104 will be conducted.
- Section 3 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 lists the F&Rs, which will govern the design of the tank C-104 retrieval demonstration.

- Section 5 defines the retrieval and LDMM strategy, including a description of the retrieval and LDMM systems, which will guide the design of the demonstration retrieval system for tank C-104.
- Section 6 includes a discussion of the change control procedures that will govern changes to this document.
- Section 7 lists the references cited throughout the 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 C-104.
- Appendix B is the draft scoping level RPE for 241-C tank farm, which supports the technical approach to the development of the retrieval and LDMM strategy for tank C-104.

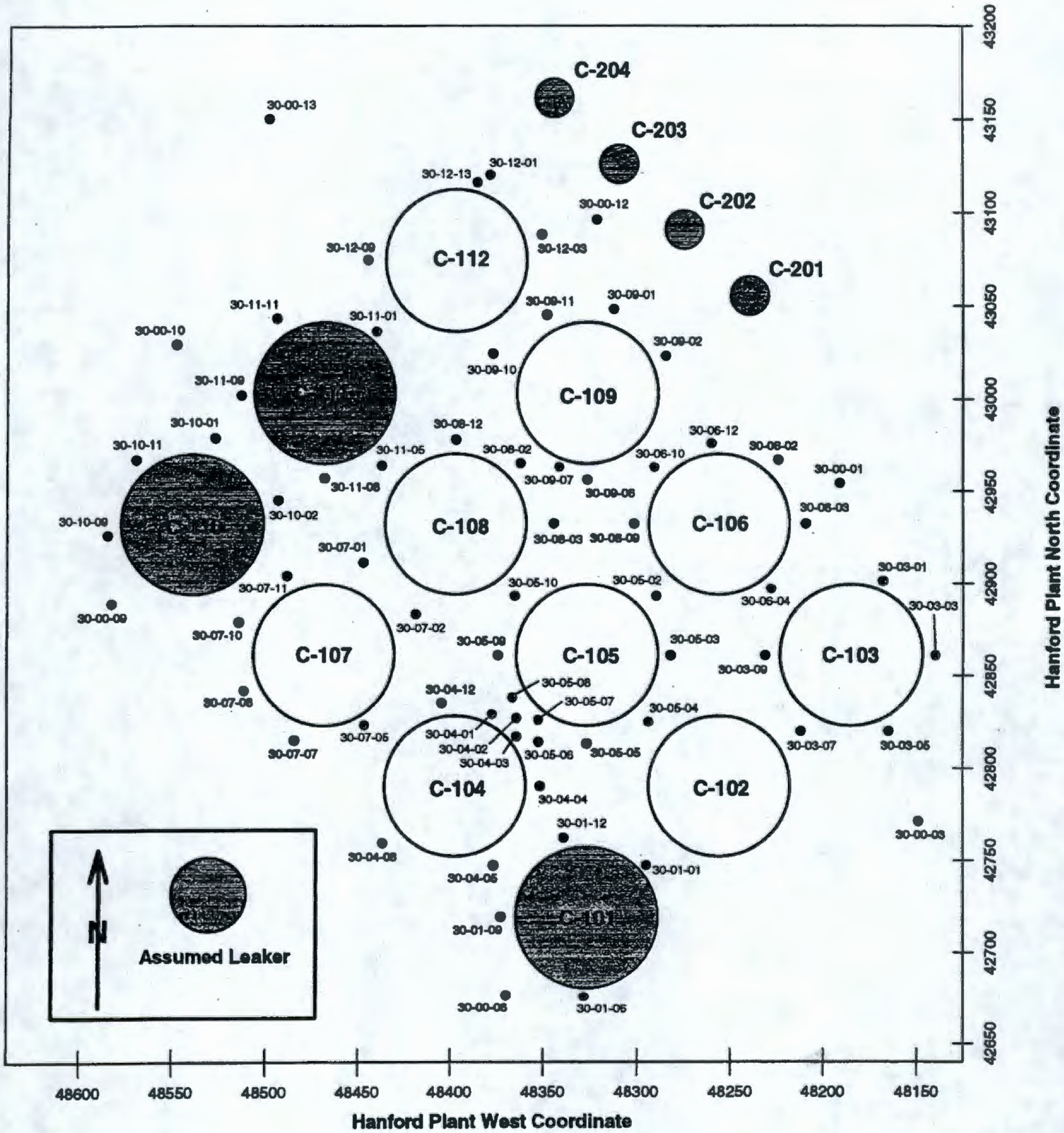

Figure 14-11. Plan View of the C Tank Farm Showing Borehole Locations

DOE/Grand Junction Office
July 1998

C Tank Farm Report
Page 97

Figure 1-2. 241-C Tank Farm Plan View and Borehole (Drywell) Locations

2.0 REQUIREMENTS FRAMEWORK

This section defines the requirements framework under which the tank C-104 retrieval demonstration 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. 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, which states:

> "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."

This agreement allows the project to apply appropriate design and construction standards that are relevant to the retrieval and LDMM of tank C-104 and that emphasize protection of human health and the environment. The following subsections identify the requirements framework that will govern the design and operation of the tank C-104 waste retrieval system.

2.1 Hanford Federal Facility Agreement and Consent Order Requirements

Table 2-1 lists the milestones for the tank C-104 waste retrieval demonstration. This document meets the submittal requirements identified by Milestone M-45-03-T04 of the Hanford Federal Facility Agreement and Consent Order.

Table 2-1. Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank C-104.

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 WILL REDUCE 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. 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	9/30/2024

Table 2-1. Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank C-104.

Milestone	Description	Required Completion
	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 PRECEDING 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	
M-45-03-T04	SUBMIT C-104 SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL DEMONSTRATION 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 C-104 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.	12/31/2001
M-45-03G	COMPLETE C-104 SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL COLD DEMONSTRATION. THIS FULL SCALE DEMONSTRATION WILL BE SUFFICIENT TO SUPPORT FINAL DESIGN AND TESTING OF ALL EQUIPMENT, INCLUDING THE LDMM APPROACH USED IN THE ACTUAL SYSTEM. THE DEMONSTRATION MUST ESTABLISH THE PERFORMANCE OF THE EQUIPMENT SPECIFIED IN THE FUNCTIONS AND REQUIREMENTS DOCUMENT. A LETTER REPORT WILL BE SUBMITTED TO ECOLOGY TO DOCUMENT THE RESULTS OF THE COLD DEMONSTRATION.	6/30/2004

Table 2-1. Hanford Federal Facility Agreement and Consent Order Milestones Applicable to Tank C-104.

Milestone	Description	Required Completion
M-45-03H	COMPLETE C-104 SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL DEMONSTRATION DESIGN (TO INCLUDE ALL PHYSICAL SYSTEMS INCLUDING DESIGN AND OPERATING STRATEGIES NECESSARY FOR LEAK DETECTION MONITORING AND MITIGATION (LDMM)). DESIGN WILL BE CONSIDERED COMPLETE WHEN 90% OF THE DESIGN HAS BEEN APPROVED FOR FABRICATION AND/OR CONSTRUCTION.	9/30/2004
M-45-03I	COMPLETE C-104 SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL DEMONSTRATION CONSTRUCTION (TO INCLUDE ALL PHYSICAL SYSTEMS INCLUDING THOSE NECESSARY FOR LEAK DETECTION MONITORING AND MITIGATION). CONSTRUCTION WILL BE CONSIDERED COMPLETE WHEN ALL PROCESS EQUIPMENT IS INSTALLED AND ACCEPTANCE TESTS ARE COMPLETED.	9/30/2006
M-45-03F	COMPLETE FULL SCALE SLUDGE/HARD HEEL, CONFINED SLUICING AND ROBOTIC TECHNOLOGIES, WASTE RETRIEVAL DEMONSTRATION AT TANK C-104. WASTE SHALL BE RETRIEVED TO THE DST SYSTEM TO THE LIMITS OF THE TECHNOLOGY (OR TECHNOLOGIES) SELECTED. SELECTED SLUDGE/HARD HEEL TECHNOLOGY (OR TECHNOLOGIES) MUST SEEK TO IMPROVE UPON THE PAST-PRACTICE SLUICING BASELINE IN THE AREAS OF EXPECTED RETRIEVAL EFFICIENCY, LEAK LOSS POTENTIAL, AND SUITABILITY FOR USE IN POTENTIALLY LEAKING TANKS. CONFINED SLUICING IS DEFINED AS THE LOCALIZED ADDITION AND RETRIEVAL OF LIQUIDS AND WASTE. THIS DEMONSTRATION SHALL ALSO INCLUDE THE INSTALLATION AND IMPLEMENTATION OF FULL SCALE LEAK DETECTION, MONITORING, AND MITIGATION (LDMM) TECHNOLOGIES. THE PARTIES RECOGNIZE AND AGREE THAT THIS ACTION IS FOR DEMONSTRATION AND INITIAL WASTE RETRIEVAL PURPOSES. COMPLETION OF THIS DEMONSTRATION SHALL BE BY APPROVAL OF DOE AND ECOLOGY. GOALS OF THIS DEMONSTRATION SHALL INCLUDE THE RETRIEVAL TO SAFE STORAGE OF APPROXIMATELY 89 KG OF PLUTONIUM WHICH REPRESENTS APPROXIMATELY 17% OF THE TOTAL PLUTONIUM INVENTORY WITHIN THE SST SYSTEM), AND 99% OF TANK CONTENTS BY VOLUME (PER DOE'S BEST-BASIS INVENTORY DATA OF 8/01/2000).	TBE (This milestone shall be established during the parties' M-45-00C negotiations.)

2.2 Regulatory Requirements

Table 2-2 identifies the state and Federal regulations (i.e., WAC and CFR respectively) that apply to the retrieval of tank C-104. These regulatory requirements are imposed on the design of the tank C-104 waste retrieval system via the requirement statements in Section 4 of this document.

Table 2-2. State and Federal Regulations.

Document Number	Title
40 CFR 700	"Toxic Substances Control Act", *Code of Federal Regulations*
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 61	"National Emission Standards for Hazardous Air Pollutants", *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 280	"Technical Standards and Corrective Action Requirements for Owners and Operations of Underground Storage Tanks", *Code of Federal Regulations*, as amended
WAC 173-303-640	"Dangerous Waste Regulations - Tank Systems", *Washington Administrative Code*, as amended.
WAC 173-400	"General Regulations for Air Pollution Sources," *Washington Administrative Code*, as amended.
WAC 173-460	"Controls for New Sources of Toxic Pollutants," *Washington Administrative Code*, as amended.
WAC-246-247	Radiation Protection-Air Emissions, *Washington Administrative Code*, as amended.

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 series milestones. It discusses how the current strategy evolved from the initial strategy embodied in the 1994 Hanford Federal Facility Agreement and Consent Order M-45 milestones. In addition, this section describes the approach that DOE-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. Finally, lessons learned from other projects are presented.

3.1 Integrated SST Waste Retrieval and LDMM 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 loss of waste to the environment. These challenges would require DOE to demonstrate alternative retrieval technologies and develop and test methods to detect, monitor, and mitigate potential leaks during waste retrieval. 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, and
- Space becoming available in DSTs as waste from DSTs is transferred to waste treatment facilities.
- A phased approach to capture lessons learned for 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 (CHG, 2000b),
- Completed retrieval of waste from tank C-106 to resolve safety issues and demonstrate retrieval using past practice sluicing,

- Modified the Hanford Federal Facility Agreement and Consent Order to initiate Corrective Actions for eight (8) of the twelve (12) 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 implementation of LDMM to ensure integration of LDMM with retrieval systems and to establish of LDMM requirements based on protection of human health and the environment (CHG, 2000b), 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 loss. The methods/decisions will not restrict final decisions associated with tank farm closure under WAC 173-303 or DOE Order 435.1 (DOE/RL-98-72) (See Section 3.2 below).

In 1998, 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, 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 meeting tank-specific physical constraints,
- Comply with applicable regulatory requirements (e.g., Hanford Federal Facility Agreement and Consent Order interim waste retrieval and LDMM requirements),
- Accelerate reduction of potential risks to human health and the environment, and
- Enhance integration with the planning and scheduling for waste processing, which 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 2000 Update (CHG, 2000c), the Fiscal Year 2000 Progress Report On The Development of Waste Tank Leak Monitoring /Detection and Mitigation Activities In Support of M-45-08 (CHG, 2000b), 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 requirements for extent of waste retrieval (i.e., volume of residual waste) and potential retrieval leak loss, based on a screening level assessment of threats to human health, that serve as minimum performance requirements for design and operation of retrieval and LDMM systems,
- Demonstration technology deployments early in the SST retrieval program to provide a basis for selection of cost-effective, tank-specific retrieval and LDMM technologies, and
- Integration of retrieval activities with tank farm Corrective Action and tank farm closure to mitigate potential risks to human health and the environment (see Figure 3-1 below).

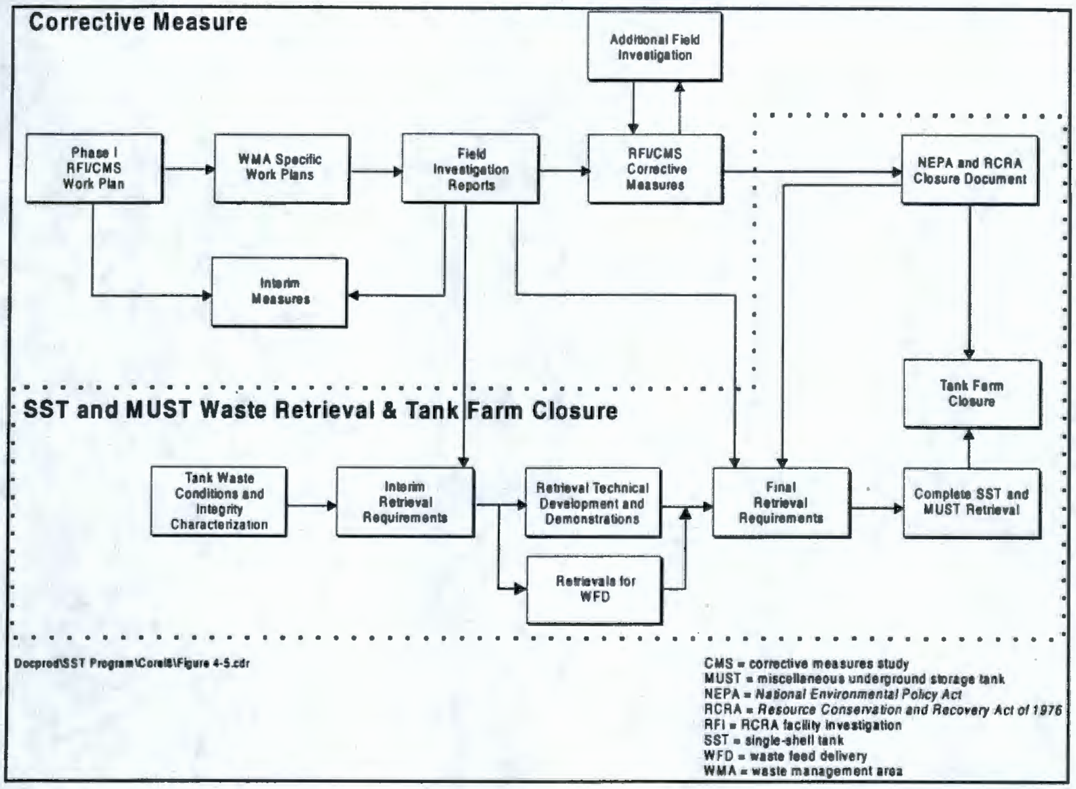

Figure 3-1 Corrective Actions for Tank Farm Closure

In 2000, the Hanford Federal Facility Agreement and Consent Order was modified to reflect the updated 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 10 relatively empty SSTs, and to establish a risk-based strategy and initial actions necessary for DOE to demonstrate alternative SST waste retrieval technologies. The technologies are targeted to be suitable to use in suspect or leaking SSTs to minimize the potential for large leak losses to the environment, and to develop performance and cost data necessary for application to future retrieval actions. These initial retrievals also include development and demonstration of LDMM methods. In addition to demonstrating waste retrieval technologies, the initial actions will focus on single-shell tanks that pose the greatest risk to the environment and on maximizing available DST space.

The risk-based strategy is founded on methods for evaluating retrieval performance that were developed in response to an August 1996, Memorandum of Understanding (MOU) 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% of the waste volume from SSTs and to establish tank-by-tank retrieval leakage loss limits (MOU, 1996). The RPE of one tank farm (241-AX) was used to identify methods to establish tank-by-tank performance measures associated with short- and long-term human health impacts, closure requirements, technology limitations, and cost (DOE/RL-98-72).

The 241-AX Tank Farm RPE established three screening level performance measures that are drivers for decisions on leak loss limits and residual waste volume. This methodology and these performance measures are used in the 241-C Tank Farm RPE, and include:

- **Farmer Risk**. Long-term human health risks posed by mixed waste (hazardous and radioactive) resulting from past tank leaks, retrieval losses and residual waste migrating through the soil to groundwater and reaching a human receptor following closure of the tank farms (Hanford Federal Facility Agreement and Consent Order and State Dangerous Waste Regulations). This performance measure is sensitive to changes in the total waste inventory (i.e., past leaks, retrieval losses and residual waste) and thus drives limits on leak losses 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). The contaminants that most influence this performance measure tend to be highly mobile in the environment (e.g., nitrates, Technetium-99).
- **Intruder Risk**. Human health risks posed by residual waste in the tank or ancillary equipment that exceed contaminant concentration limits associated with near surface disposal. Residual waste above the concentration limits would pose a threat to inadvertent human intruders into the waste site per NRC near surface disposal requirements in 10 CFR 60 and requirements in DOE Order 435.1. 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).
- **Worker Risk**. Human health risks posed by past tank leaks, retrieval losses, and residual waste to remediation workers required to excavate contaminated soils and remove the tank and its residual waste to meet closure requirements under State Dangerous Waste Regulations (i.e., clean close the tank farm to a residential standard or remediate areas of concern within a tank farm to support either a modified or landfill closure of the tank farm). This performance measure is sensitive to changes in the residual waste and retrieval loss inventories and tends to be most influenced by contaminants that are less mobile in the environment (e.g., Cesium, Strontium, Plutonium).

Figure 3-2 represents the concepts for application of these screening level performance measures. The minimum performance requirements for waste retrieval leak loss and residual waste limits should fall somewhere under the 10^{-5} Incremental Lifetime Cancer Risk (ILCR) curve shown in Figure 3-2. The 10^{-5} curve intersects the vertical (Y) axis at the maximum leak loss limit allowed ("Retrieval Release Criterion (Gallons)") and the horizontal (X) axis at the maximum residual waste allowed ("Residual Waste (Gallons)"). These are the maximum upper limits which will bound the design criteria for the LDMM and retrieval systems minimum performance. As long as the combined risk remains at or below the curve, the retrieval activity can go forward to completion. Barring any other considerations, if the residual waste is less than the maximum (to the left of the intersection of the curve with the X axis) and the retrieval leak loss or release is less than the maximum (below the intersection of the curve with the Y axis), then the risk-based approach is satisfied. While the anticipated results will be well below either of these limits, there may be extreme cases (i.e., at other tanks) where either limit may be below what is achievable with available technology. If readily deployable and well-understood LDMM and retrieval technologies hold the combined risk below the curve, then risk and cost are held at reasonable levels, regardless of the calculated health-based design criteria. In any case, the goal of the tank C-104 retrieval demonstration project is to retrieve at least 99% of the tank contents by volume or the maximum possible to the "the limit of waste retrieval technology capability" (Table 2-1, milestones M-45-00 and M-45-03F).

3.2 Development and Use of Performance Requirements Through the RPE

Risk-based goals for SST waste retrieval have been incorporated into the Hanford Federal Facility Agreement and Consent Order through the change package for the M-45 series milestones (DOE/Ecology, 2000). Milestone M-45-03-T04 for tank C-104 (Table 2-1) requires a scoping level RPE as part of this F&R document.

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 losses and residual waste and then after retrieval to evaluate performance measures using actual retrieval leak loss and residual waste data. The RPE process for the 241-C SST tank farm follows these steps:

1. A scoping level RPE defines the tank farm risk on a tank-by-tank basis with the 241-C farm RPE starting with tank C-104. The scoping level RPE focusing on tank C-104 establishes the minimum retrieval and LDMM system performance requirements necessary to stay within the risks allotted for the entire tank farm. These performance requirements for the entire tank farm are divided by the number of tanks in the farm (sixteen (16) for 241-C tank farm in the initial RPE, since C-104 is the first to be retreived). These tank-specific performance requirements are given in terms of the maximum leak loss during retrieval and maximum residual waste after retrieval for tank C-104.
2. After the tank C-104 waste retrieval demonstration is complete, the tank farm RPE is updated to reflect the actual residual waste volume and estimated retrieval leak loss, if any. The risk associated with the remainder of the farm tanks is recalculated.
3. Steps one through three are repeated for each tank to be retrieved in the tank farm with the final RPE amended to include tank farm specific performance data a 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 application of the RPE focuses on developing retrieval leak loss and residual waste criteria for tank C-104 within the C Tank Farm. The impact analysis conducted for each of the retrieval cases includes assessing the screening performance measures from Section 3.1 (used to establish limits), as well as considering additional impacts, as listed below.

- Short-term human health risk – Risks to workers and the public from chemical and radiological exposures that are expected to occur during routine remedial actions (e.g., waste retrieval) or that could result form postulated accidents, and injuries and fatalities resulting from industrial type accidents.
- Long-term human health risk – Human health risks to future Site users (at the current 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 contaminated groundwater. Contaminants of concern to long-term human health risks are those that are persistent and mobile in the environment. Long-term human health risks are evaluated over a 10,000-yr period of interest based on the lifestyle of a residential farmer and an industrial worker. 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 risk from 241-C Tank 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.

- Groundwater quality – Impacts on groundwater quality 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.
- Compliance assessment – The applicable and appropriate regulatory requirements have been identified including areas where open issues and specific quantitative performance measures exist.
- Technical constraints – For each of the cases an assessment of the technical constraints (e.g., effectiveness, implementability) is provided.

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, assumptions were developed to complete the analysis. These 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 C-104, and the241-C Tank 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.
- 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.
- Comparing performance of the total system to requirements established by Federal and State regulations, the Hanford Federal Facility Agreement and Consent Order, and stakeholder and Tribal Nation values.
- Evaluating the ability of static (measurements while pumping is shut down) and dynamic (measurements during pumping) leak detection methods to compare with risk-based leak limits.

The RPE for the 241-C Tank Farm is provided as Appendix B to this report. Figure 3-2 shows three curves, depicting the risks from residual waste and waste leakage to a future onsite worker, a farmer, and an inadvertent intruder plotted from RPE data.

Based on the RPE, the most conservative release criterion with 360 ft^3 of residual waste is taken from the curve presented in Figure 3-2 for the farmer risk scenario. The farmer scenario is considered conservative. It was chosen due to its conservatism and due to the uncertainties associated with the current information available regarding past tank leaks and spills, the in-tank inventories, postulated tank leaks, and cumulative inventories from other waste sites. The farmer scenario does not take into account cumulative impacts from other tank farms and closure sites. Non-tank farm source term contributions, which are additive to the C-Farm contribution, have not been quantified. Based on this, the farmer scenario is a reasonable approach for the scope of this document. Cumulative source term impacts from non-tank farm sources will be taken into account in the closure work plan.

The upper leak detection limit for the farmer scenario "*Farmer (ILCR* $\leq$ *10^{-5})*" in Figure 3-2 is approximately 12,600 gallons. The performance criterion for the leak detection system shall therefore be 12,600 gallons or less. Even with the best deployable leak detection technology currently available, it is uncertain whether a leak of this size can be detected in a timely manner. Different LDMM technologies are being tested by the Tank Focus Area program, however, and eventually a new LDMM technology may be found that can deliver enhanced performance compared to currently deployable technologies. If a new technology is available and deployable within the context of the tank C-104 retrieval demonstration design and construction schedule then it will be implemented. See Section 5 for further discussion of the limits of the current LDMM technologies.

The 12,600 gallon leak volume is based on the farmer being located at the tank farm boundary. This is a conservative assumption. If the location of the farmer is subsequently agreed to be moved away from this boundary, an updated RPE might increase the leak volume limit. The increased volume could be one that is more easily detected.

The uncertainties that contribute to the dynamic and static testing ranges include:

- Physical and chemical properties of the waste, including dissolution characteristics and solution densities, waste layering within tank C-104, and hydraulic conductivity of the sludge (the density of the waste can change with temperature, dilution and mixing with other wastes),
- Time to reach equilibrium during static testing (retrieval is halted and any leaks continue unabated), and
- Ability to obtain a free liquid surface and maintain a constant liquid surface during static testing (confined sluicing/robotic retrieval technology minimizes the free liquid surface in the tank making it much more difficult to form a free liquid surface in a location convenient to instrumentation).

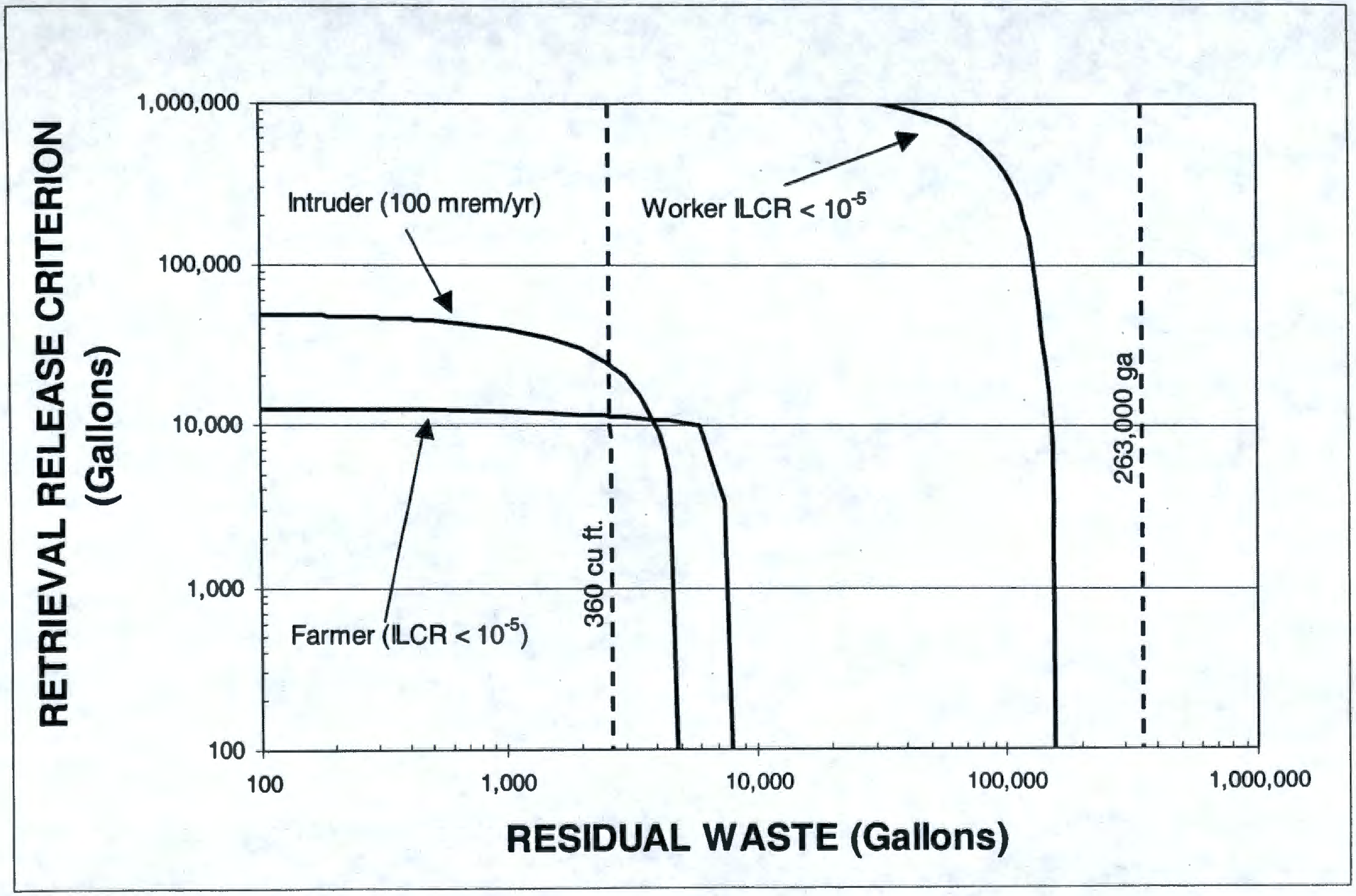

Figure 3-2. Tank C-104 Retrieval Release Criterion vs. Residual Waste

3.3 Use of Lessons Learned in Supporting Selection and Implementation of Retrieval and LDMM Technologies

DOE requires that lessons learned from previous activities will 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 incorporated into the design 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 C-104 retrieval demonstration. This experience will guide the design team in the selection of the best retrieval and LDMM technologies. Lessons learned have shown that waste retrieval from any tank has not caused the tank to leak, including tanks in comparable or worse condition than tank C-104.

The lessons learned evaluation for SST tank C-104 focuses on gathering information and experience that is categorized as follows:

- Operational effectiveness of retrieval systems and approaches,
- Retrieval system and demonstration technology effectiveness,
- Leak detection systems used and developments in leak detection technologies,
- Leak monitoring approaches and systems used and developments in leak monitoring technologies, and
- Leak mitigation approaches and systems used and developments in leak mitigation 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. DOE will incorporate these lessons learned during the design and operation of the tank C-104 waste retrieval system. The best available and deployable LDMM technology will be used for tank C-104 retrieval.

Lessons learned has already provided some design and operational features that are being given consideration for implementation in the retrieval demonstration system for tank C-104. These features are highlighted in Appendix A. Key considerations include, but are not limited to:

- Place more than one camera in the tank for maximum visibility during retrieval.
- Once retrieval has begun, do not stop for any but critical safety reasons.
- Initiate static leak detection testing only if retrieval has stopped for some other reason.

4.0 FUNCTIONS & REQUIREMENTS

The functions and requirements included in this document are derived from the need to satisfy the Hanford Federal Facility Agreement and Consent Order Milestone requirements to retrieve as much of the current tank C-104 waste inventory as technically possible with a goal of retrieving to safe storage approximately 89 kilograms of Plutonium and 99% of the tank C-104 contents by volume (per the DOE Best Basis Inventory data of 8/1/00) while maintaining a tank and waste retrieval system that safely isolates the waste from the workers, the environment, and the public. Some of these requirements are derived from regulatory documents such as the CFRs, and the resulting certification in the WAC while others are based on the design limitations of tank C-104 and the DST receiver tank. The functions and requirements identified below are focused on appropriately driving the design of the tank C-104 waste retrieval system so that the aforementioned needs are met.

4.1 Control Tank C-104 Structure and Waste Temperature

The tank C-104 waste retrieval system shall control the tank C-104 structure and waste temperature to within the following specified design limits to prevent structural damage to the tank:

Temperatures:

- Maximum 149 °C (300 °F) for waste
- Maximum 121 °C (250 °F) for dome
- Maximum change of 11 °C (20 °F) per day

[Basis: OSD-T-151-00013]

4.2 Control Tank C-104 Waste Level

The tank C-104 waste retrieval system shall control the waste level in tank C-104 to prevent waste overflow and limit the hydrostatic head-induced stresses in the tank and provide for leak detection monitoring. The retrieval system shall minimize the net positive suction head requirement for the retrieval pump. The tank C-104 waste retrieval system shall prevent the waste level in tank C-104 from exceeding 4.7 m (185 in.) for waste with a specific gravity (SpG) of less than or equal to 2.0.

[Basis: HNF-4712, Rev. 0]

4.3 Control Tank C-104 Vapor Space Pressure

The Tank C-104 waste retrieval system shall control the vapor space pressure in tank C-104 to within the following specified design limits to prevent structural damage to the tank:

- If waste level divided by the waste SpG ≥ 38.1 cm (15 in.),

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

- If waste level divided by the waste SpG < 38.1 cm (15 in.),

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

  (Note: Operational limits on in-tank vapor space pressure will be established as part of conceptual design. If active ventilation is required for tank C-104 during waste retrieval, then it is expected that a negative vapor space pressure with respect to atmosphere will be required at all times during retrieval system operation, as this is the preferred method for verifying that ventilation is operable and ensures confinement.)

  [Basis: HNF-4712, Rev. 0]

4.4 Control Tank C-104 Gaseous Discharges

The tank C-104 waste retrieval system shall control the vapor space pressure in tank C-104 and filter the air exhaust to restrict emissions to the environment in accordance with WAC 173-400 and WAC 173-460 (non radioactive airborne emission limits); and 40 CFR 61 and WAC 246-247 (radioactive airborne emission limits).

[Basis: RPP-6665, Rev. 0]

4.5 Remove Waste from Tank C-104

The tank C-104 waste retrieval system shall be capable of removing (i.e., retrieving and transferring waste to the DST System) as much of the tank C-104 waste inventory (see DOE BBI data of 8/01/2000 (TWINS Website, 2000)) as technically feasible with a target goal of removing 99% of the tank contents by volume. The demonstration will be considered complete when the retrieval technology is no longer recovering waste or the residual waste in tank C-104 is less than 5,000 gallons. Recovery limits will be documented. 5,000 gallons is the maximum allowable residual volume under the intruder scenario (which is a lower volume than that indicated under the farmer scenario). Retrieval system design shall be capable of retrieving the waste within a maximum of 145 days (nominally 60 GPM at 10% solids concentration).

[Basis: DOE/ECOLOGY 2000 (Milestone M-45-03F)]

4.6 Control and Monitor the Tank C-104 Waste Removal Process

The tank C-104 waste retrieval system shall monitor and control the process parameters for retrieving waste from tank C-104. This includes the detection and monitoring of tank C-104 leaks during waste removal as well as the controlling and monitoring of waste removal process parameters. Provisions shall be made to sample waste during retrieval operations.

[Basis: DOE/ECOLOGY 2000 (Milestone M-45-03F)]

4.6.1 Detect Leaks During Tank C-104 Waste Removal.

The tank C-104 waste retrieval system shall be capable of detecting liquid waste releases from tank C-104 during all waste removal operations.

- The system shall be designed to detect a total leak loss of 12,600 gallons.

  [Basis: Section 3.2]
- Probability of Detection: The tank C-104 waste retrieval system shall have a probability of leak detection of greater than 95%.
- Probability of False Alarm: The tank C-104 waste retrieval system shall have a probability of false alarm less than or equal to 5%.

  [Basis: 40 CFR 280]

4.6.2 Monitor Leaks From Tank C-104 During Waste Removal.

The tank C-104 waste retrieval system shall quantify liquid waste release volumes from tank C-104 if a release is detected during waste retrieval operations. The data shall be collected, in the event of a leak, to support a post-retrieval RPE, which will be used to address retrieval of the next C-Farm tank. Data collected will address estimates of the volume and composition of leaked material, as well as the residual waste in the tank.

4.6.3 Control And Monitor Tank C-104 Waste Retrieval.

The tank C-104 waste retrieval system shall monitor and control the process and equipment parameters for retrieving waste from tank C-104. Waste removal process parameters (e.g., waste transfer line pressures, flow rates, waste densities) and equipment parameters (e.g., transfer pump speed and motor amperage) shall be monitored for safe and effective operation of the tank C-104 waste retrieval system.

4.7 Measure and Estimate Residual Waste in Tank C-104

The tank C-104 waste retrieval system shall measure and estimate the residual waste in tank C-104 to verify that the target retrieval goals have been met (see Section 4.5). The tank C-104 waste retrieval system shall be capable of measuring and estimating residual waste on the walls of the tank; on and under the stiffening rings of the tank; on exterior surfaces of in-tank debris, hardware and components; and on the bottom of the tank. Techniques may include video surveillance and topographic mapping.

[Basis: DOE/ECOLOGY 2000 (Milestone M-45-03F)]

4.8 Waste Minimization

The tank C-104 waste retrieval system shall minimize waste generation to the greatest extent possible, e.g., transfer DST System supernatant liquids to tank C-104 for confined sluicing purposes during retrieval and use 241-C-106 for drain-back of flush water during and after sluicing.

4.9 Mitigate Leaks During Tank C-104 Waste Retrieval Process

The tank C-104 waste retrieval system shall mitigate leaks as the primary means of minimizing environmental impact caused by releases during retrieval of SST waste. If a leak occurs, the release shall be evaluated according to the RPE and the appropriate actions implemented (e.g., continue retrieval). As the primary mitigation means, the retrieval pump shall be designed to allow continuous pumping for a sufficient amount of time (to be determined during design) to remove all pumpable liquids from tank C-104.

[Basis: DOE/ECOLOGY 2000 (Milestone M-45-03F)]

4.10 Nuclear Safety

The tank C-104 waste retrieval system shall be designed to protect workers, the public, the environment, and equipment from exposure to tank radioactive waste during retrieval as set forth in 10 CFR 830 and 10 CFR 835.

[Basis: see referenced code]

4.11 DST Design Limits

The tank C-104 waste retrieval system shall not adversely affect the function of the DST System or exceed the DST Design and operational limits. The DST design and operational limits are as follows:

4.11.1 DST Waste Temperature.

The DST waste temperature shall not exceed:

- 195 degrees F in all levels of the waste, or
- 195 degrees F in the top 15 ft of waste and 215 degrees F below 15 ft.

[Basis: HNF-SD-WM-TSR-006, LCO 3.3.2]

4.11.2 DST Pressure Limits.

The tank C-104 waste retrieval system shall not cause the following internal DST pressure limits to be exceeded:

Primary Tanks:

- -15.2 cm (6 in) w.g. ≤ vapor space pressure ≤ -0.76 cm (0.3 in) w.g. during normal operating conditions and ≤ 0 during required maintenance or off-normal conditions (AN, AW, AY, AZ farms)

- -24.1 cm (9.5 in) w.g. ≤ vapor space pressure ≤ -0.76 cm (0.3 in) w.g. during normal operating conditions and ≤ 0 during required maintenance or off-normal conditions (AP farm)

[Basis: HNF-3350]

4.11.3 DST Hydrostatic Load Limits.

The tank C-104 waste retrieval system shall not cause the internal DST hydrostatic loads limits specified in Table 4-1 to be exceeded.

Table 4-1. Existing Double-Shell Tank Hydrostatic Load Limits

Tank Farm	Hydrostatic Load
AN, AW	Maximum hydrostatic load as exerted by 4410 m^3 (1.16 Mgal) of fluid @ 1.7 SpG and a depth of 10.7 m (422 in.)
AP	Maximum hydrostatic load as exerted by 4410 m^3 (1.16 Mgal) of fluid @ 2.0 SpG and a depth of 10.7 m (422 in.)
AY, AZ	Maximum hydrostatic load as exerted by 3790 m^3 (0.998 Mgal) of fluid @ 1.22 SpG. and a depth of 9.25 m (364 in.)

[Basis: HNF-3350]

4.12 Tank C-104 Waste Retrieval System Design

The tank C-104 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(3).

[Basis: RPP-6665]

- The retrieval system design shall be constructed of modular and easily replaceable subsystem components.

[Basis 430.1A LCAM]

- The retrieval system shall be designed for reuse.

[Basis 430.1A LCAM]

4.13 Occupational Safety and Health

The tank C-104 waste retrieval system shall incorporate design features that comply with the requirements of 29 CFR 1910.

[Basis: see referenced code]

4.14 SST and DST Dome Loading

The tank C-104 waste retrieval system shall not exceed the maximum dome loading on existing SSTs and DSTs specified in HNF-IP-1266, 5.16, Rev. 3a.

[Basis: HNF-SD-WM-SAR-067]

4.15 Prohibited Materials.

Materials that are restricted or prohibited from use in manufacturing and construction under regulations promulgated pursuant to 40 CFR 700, shall not be used in the design of the tank C-104 waste retrieval system.

[Basis: see referenced code above.]

4.16 Waste Retrieval System Secondary Containment and Leak Detection

The tank C-104 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 (4).

[Basis: RPP-6665, (Environmental Permits and Approvals Plan)]

4.17 Waste Retrieval System Deactivation and Decontamination

The tank C-104 waste retrieval system equipment deactivation shall be compatible with decontamination, reuse and/or disposal requirements, e.g., in-tank disposal.

[Basis: DOE G 430.1-3, Deactivation Implementation Guide, 9-29-99.]

5.0 LDMM AND RETRIEVAL STRATEGY

This section of the document describes the LDMM and retrieval strategy for the tank C-104 demonstration system, and presents a preliminary design description of the integrated retrieval and LDMM system. The preliminary tank C-104 demonstration design satisfies the requirements defined in Section 4. The progression of design, development, and testing may influence the overall design. However, the demonstration system deployed for tank C-104, as it evolves, will continue to meet the requirements including any changes instituted via the change control process described in Section 6.

The tank C-104 demonstration retrieval release protection strategy is based on the "Proposed Strategy for Leak Detection, Monitoring, and Mitigation During Hanford Single-Shell Tank Waste Retrieval" and concepts first presented in 1996 and updated in 1999 and 2000 (WHC, 1996). The integrated LDMM and retrieval strategy uses the risk-based strategy presented in Section 3.2 of this document to define a minimum leak detection requirement. By also adopting risk-based release response criteria, the LDMM/Retrieval strategy uses quantitative decision criteria for making appropriate operational responses if and when releases are detected.

5.1 Integrated Strategy for LDMM and Retrieval

A goal of this document is to develop and define an LDMM strategy for the SST tank C-104 waste retrieval demonstration system that meets requirements specified in the M-45 series of milestones (DOE/Ecology, 2000). The purpose of the LDMM strategy is to ensure that the demonstration waste retrieval system:

- Minimizes hazardous waste releases to the environment,
- Complies with applicable regulations and requirements,
- Is technically practicable and defensible, and
- Meets the programmatic needs of the DOE Office of River Protection.

Leak detection, monitoring, and mitigation definitions were established in RPP-7012 (CHG, 2000b):

- **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.

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. 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.

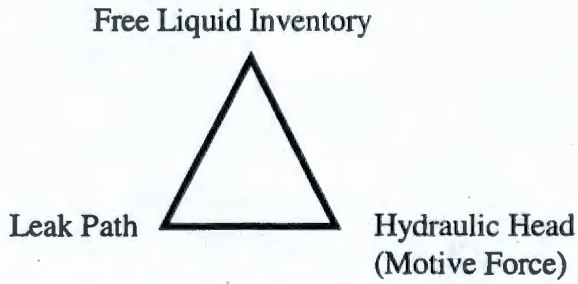

Figure 5-1. Leak Minimization Triangle

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 is used to establish quantitative performance requirements. When integrated with a retrieval technology, the risk-based approach establishes leak detection limits as a function of potential retrieval leak loss volume and residual waste remaining in the tank following completion of retrieval activities.

The LDMM strategy for tank C-104 is intended to be a combined approach, using leak detection, leak monitoring, and leak mitigation to reduce the risk to human health and the environment from retrieval leak loss. However, leak detection and leak monitoring using the currently best available technology require a free liquid surface within the tank to accurately measure liquid volumes. The retrieval technology selected for the tank C-104 demonstration is designed to minimize the liquid volume and does not provide a free surface. The demonstration retrieval system for tank C-104 relies on the principles presented in Figure 5-1 and:

- Minimizes the amount of liquid required for retrieval,
- Reduces the liquid volume in the tank, and
- Incorporates a retrieval strategy that reduces the free liquid surface and hydraulic head.

The retrieval and LDMM strategy relies on minimizing the retrieval duration to reduce the overall risk to human health and the environment. In addition to using the best proven and available technology for leak detection and leak monitoring, leak mitigation is strengthened by this reduction in the retrieval duration, which reduces the time available for leakage to occur.

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

1. Minimize liquid in tank - Leak mitigation will be accomplished by minimizing the liquid inventory in the retrieval tank to limit the volume of waste that could leak in the event that a leak developed.
2. Use retrieval strategy -The system shall be operated in such a way that it can pump from the lowest achievable level in the tank if a leak should occur. This is a mitigation activity because it allows removal of the greatest amount of liquid from the tank in the event of a leak. The result is that less liquid would be lost.
3. Minimize retrieval campaign duration - The campaign duration shall be minimized to the extent possible to reduce the time available for an undetected leak to contaminate the soil column. (A shorter time frame further limits the volume of waste that can leak.) Operating the system as continuously as is reasonable and minimizing the frequency of static leak testing will accomplish this.
4. Risk evaluation - If a leak occurs, the risk (cancer risk to the exposed individual) shall be evaluated from the anticipated leak volume, the residual waste in the tank, and the impact of continuing or terminating retrieval operations. The options for continuing/ending operations will be weighed and the one presenting the lowest risk approach will be followed.

5.1.1 Leak Detection

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. These accepted and available methods include monitoring liquid and waste inventories while waste is actively being retrieved (i.e., dynamic test) and when operations are temporarily suspended (i.e., static test).

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 for the SSTs. In 1998, a review of previous LDMM investigations and new information regarding LDMM technologies applicable to SST retrieval (LMHC, 1998a) 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 (LMHC, 1999a) repeated these recommendations. These recommendations are 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 C-104 (See Appendix A). The approved EPA methods for leak detection where a free liquid surface exists are:

<u>Volumetric Inventory Balance (Dynamic)</u>

Akin to the mass balance technology, the 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 this technique has not been evaluated for SSTs and the complexities of waste solubility and evaporation combined with the scale difference between a local gas station tank and a 75-ft-diameter SST are significant. The advantage of this technology is that it provides a continuous online measurement. This technique will be sensitive to a number of environmental and operational interferences, and require compensation for those interferences to achieve acceptable performance levels. Based upon the tank C-106 retrieval experience [HNF-SD-WM-PCP-013, 1999], some of the influences, such as uncondensed evaporation, may be beyond a reasonable compensation effort. Evaluation of this technique for SST retrieval may show that it will not be useful.

Volumetric (Static)

This technology is used extensively in industry leak detection. Volumetric methods measure the liquid surface 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 "tight." Differential pressure measurements are one type of sensor used by the DOE to measure liquid level and conduct leak detection tests [ORNL/ER/Sub/92-SK236/1, 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 with a continuous liquid surface and are well suited for the volumetric method in tanks with a measurable air-liquid interface.

In-tank volumetric technologies, which can include adaptation of elements of the mass-based technology, were recommended for leak detection 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 has not been determined without a liquid surface.

Understanding the performance of the leak detection method is important. It determines whether risk-based leak detection requirements are met, and how to successfully meet them (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 ASTM and EPA standard test procedures (ASTM 1993; EPA, 1990a, 1990b, 1996).

The tank C-104 RPE establishes a leak detection goal of 12,600 gallons, based on the Farmer Scenario. The Farmer Scenario is the case that reaches the 10^{-5} Incremental Lifetime Cancer Risk criterion at the smallest leak volume. This leak detection objective is based on a retrieval goal of 99% or more of the waste in the tank by volume, or retrieval to a residual waste of approximately 2,760 gallons. Based on industry experience for large volume tanks, at the most extreme estimate (lowest probability of succeeding), and with the presence of a free liquid surface, static testing has a projected capability to detect as small as a 2,000 gallon leak over the retrieval campaign. However, the tank C-104 demonstration retrieval technology will not produce a free liquid surface. For the purpose of risk reduction, the liquid inventory will not be increased solely for improved detection capabilities. The increased liquid inventory required to produce a free liquid surface imposes a greater potential leak volume and hydraulic head and is contrary to the strategy of mitigating the risks associated with a release event.

In the absence of a uniform free liquid surface and including other uncertainties, the static leak detection performance is more likely to be in the approximately 18,000-gallon range over the retrieval duration, or a full order of magnitude higher, than for the free liquid surface case (HND, 2001). The 18,000 gallon estimated detection capability is above the established 12,600 gallon detection goal. The circumstances and uncertainties that force the system toward a less accurate leak detection include:

- Lack of a uniform free liquid surface,
- Potential for increased false alarms,
- Uncertainties associated with the tank physics,
- Uncertainty of the waste characterization data,
- Uncertainty of waste pore volume and capillary height,
- Uncertainty of soluble to non-soluble waste retrieval rates, and
- Uncertainty of interstitial liquid movement.

The retrieval demonstration for tank C-104 is expected to require from four weeks to three months to complete. Table 5-1 provides calculated total leak volumes for various leak rates and retrieval duration. For example, if an undetected leak of 5.0 gal/hr were to occur at the beginning of a 4-week-long retrieval campaign, the table shows that 3,360 gallons of liquid would be released during the 4-week period.

Leak Rate (gal/hr)	1 wk (gal)	2 wk (gal)	4 wk (gal)	6 wk (gal)	12 wk (gal)	6 mo (gal)
0.5	84	168	336	504	1,008	2,016
1.0	168	336	672	1,008	2,016	4,032
2.0	336	672	1,344	2,016	4,032	8,064
5.0	840	1,680	3,360	5,040	10,080	20,160
10.0	1,680	3,360	6,720	10,080	20,160	40,320
50.0	8,400	16,800	33,600	50,400	100,800	201,600

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

Based on Table 5-1, a leak rate, during retrieval, greater than 5 gal/hr (12-week retrieval campaign) will exceed the risk based performance criteria of 12,600 gallons (Section 3.2, Figure 3-2). The non-catastrophic postulated leak loss (95% confidence) for Hanford SSTs is less than 1.8 gallons per hour (RHO, 1981). This analysis was reviewed again in 1998 and found consistent with SST leak data (LMHC, 1999). This leak loss leak rate is based on estimated averages of leaks in the 1960s-1970s from tanks with significant free liquids and are inclusive of catastrophic leaks for a few tanks (e.g. A-105, BX-102, and T-106). Therefore, this number should be a much larger leak rate than would be expected today. Based on the 1.8 gal/hr leak loss rate and an estimated retrieval duration of 4 weeks to 12 weeks (30 to 90 days), a potential leak of this magnitude during retrieval operations would not be detectable using current best available technology.

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 3 inches of fluid needed to support pump operations, is estimated at 271,000 gallons. Lessons learned indicate that catastrophic leaks are caused by improper design, construction or material composition. There have been no catastrophic failures in the Hanford C-Farm, and there is no evidence to indicate a catastrophic failure in C-104 is likely.

Barring a catastrophic failure, and when considering waste porosity, capillary height of the waste, and the fluid properties of the waste that can leak, the maximum potential leak is estimated to be 33,000 gallons.

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 risk-based leak loss performance criteria of 12,600 gallons would only be exceeded after a 291-day retrieval campaign. Both Table 5-1 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.

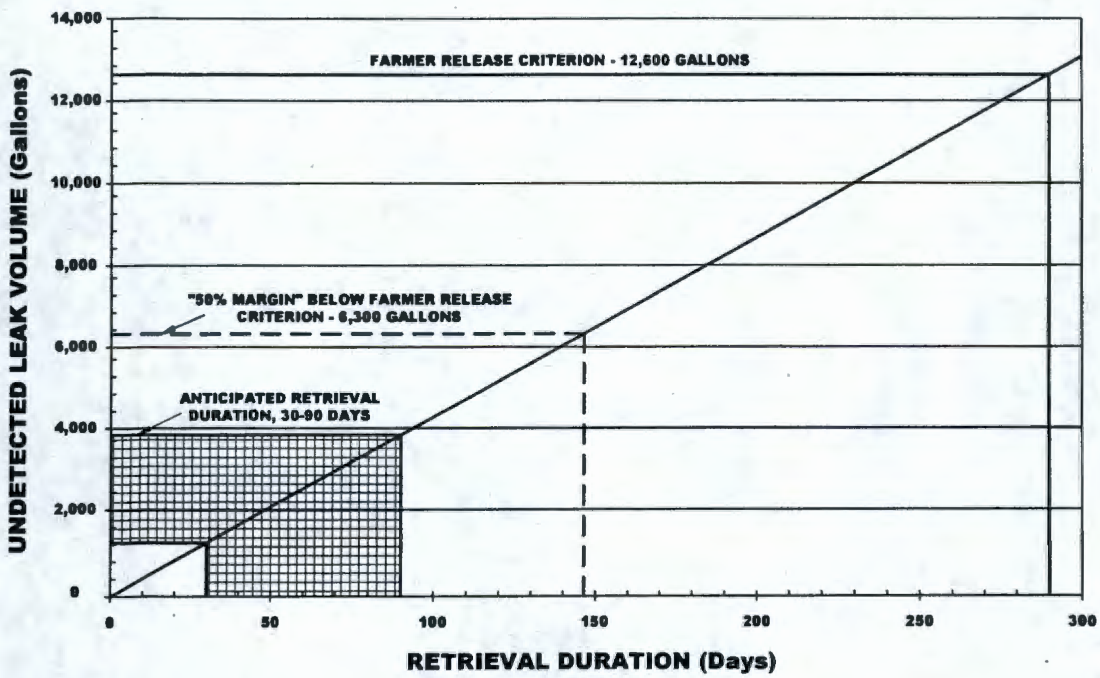

Figure 5-2. Undetected Leak Volume vs. Retrieval Duration At Loss of 1.8 Gal/Hr

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. Minimize the amount of liquid in the tank,
2. Reduce the retrieval duration,
3. Test the tank frequently for the possibility of a catastrophic release while waste is actively being retrieved (dynamic testing),
4. Use existing drywell and ground water monitoring wells for detection[1] and monitoring,
5. Minimize activities that require suspending retrieval operations,
6. Statically test the tank at appropriate intervals during the retrieval campaign (e.g. when retrieval operation is suspended for a different reason) and
7. Use static leak detection if the dynamic or external tank leak detection system indicates a probable leak.

[1] The present dry well and groundwater monitoring system is not designed for real time detection and response, and so would be used as a back up. Alternate ex-tank methods are being evaluated (see section 5.3.4) and if the proof-of-concept tests are successful, will be utilized.

Regarding Item 4, above, logging of drywells will be employed only as a secondary leak detection system because radiation detected in a drywell may be difficult to interpret for the following reasons:

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

Due to this uncertainty, ex-tank methods using existing drywells will not be the primary method of leak detection. Even with these interpretation drawbacks, periodic scans will be obtained in existing wells before, during and after retrieval operations. When used in conjunction with other leak detection systems, they can be helpful in assessing the existence, extent, and mitigation of a leak.

5.1.2 Leak Monitoring

Leak monitoring is the quantification of a liquid waste release volume from a SST after detection of a leak during waste retrieval operations. A leak volume estimate must be predicted to quantify the environmental impact resulting from a leak. Dynamic, static, and ex-tank methods will be applied to quantify a potential leak volume during retrieval operations. The limitations associated with leak detection, as discussed above, apply to leak monitoring.

5.1.3 Leak Mitigation

Based on above discussions, the primary strategy for mitigation is a retrieval technology that limits the liquid volume and accelerates retrieval. The backup strategy for mitigation is to evaluate techniques to reduce contaminant migration. Items under consideration are reactive barriers, other barriers, or ex-tank treatment options.

5.2 Tank C-104 Retrieval and LDMM System Descriptions

The retrieval and LDMM systems described in this section represent a conceptual view of the systems currently planned for deployment in tank C-104. Detailed design will result in enhancing the definition of the system and may result in changes to the features described below. However, the final design will comply with the requirements established in this document and any subsequent changes established throughout the change control process described in Section 6.

5.2.1 Tank C-104 Retrieval System Description

A confined sluicing, robotic type waste retrieval system, termed the mobile retrieval system, will be demonstrated to remove sludge from tank C-104 (CHG, 2000a). The mobile retrieval system incorporates hydraulic nozzles to dislodge and mobilize the waste and a slurry removal mechanism to recover and transfer the resultant slurry. The retrieval system configuration is anticipated to include a waste transfer system that relies on a re-circulating waste stream between tank C-104 and the receiving DST. Supernatant from the DST system is used as the mobilization fluid for the mobile retrieval system, and the resulting retrieved slurry from tank C-104 is pumped back to the receiver DST. This arrangement allows for reuse of DST supernatant as sluicing media, thereby minimizing the volume of liquid waste generated during retrieval that requires storage in the DST system. This significantly reduces generation of secondary waste and the volume required to be sent to the DST receiver tank, thus allowing more SST waste to be retrieved. Figure 5-3 presents a conceptual sketch of the waste retrieval system. The primary system components are listed below:

- DST Transfer Pumping System - A submersible pump or several pumps in series will be installed in the receiver DST and will draw clear supernatant from the DST and deliver it to tank C-104 for use by the mobile retrieval system. The flow rate selected will provide fluid velocity in excess of critical solids settling velocity, yet below the velocity that could cause excessive corrosion of the transfer piping.
- Mobile Retrieval System - The mobile retrieval system will perform the confined sluicing during the retrieval operations. It will deliver sluicing fluid using hydraulic nozzles. A slurry removal mechanism will also be located as close as is reasonable to the nozzles and waste to minimize liquid use and hydraulic head, and maximize slurry recovery.
- Sluice Nozzles - Sluice nozzles on the mobile retrieval system or on a mast in the tank are positioned to direct the sluice stream to the desired location. The nozzles are sized to produce a cohesive sluice stream. This will enable the mobile retrieval system to effectively wash waste from the tank walls and in-tank hardware.
- SST Slurry Booster Pump System - A booster pump mounted on or near C-104 will provide the motive force to transfer the retrieved slurry from tank C-104 to the receiver DST.
- Slurry Distributor - A slurry distributor, installed in the receiver DST, introduces the retrieved waste from tank C-104 into the DST.

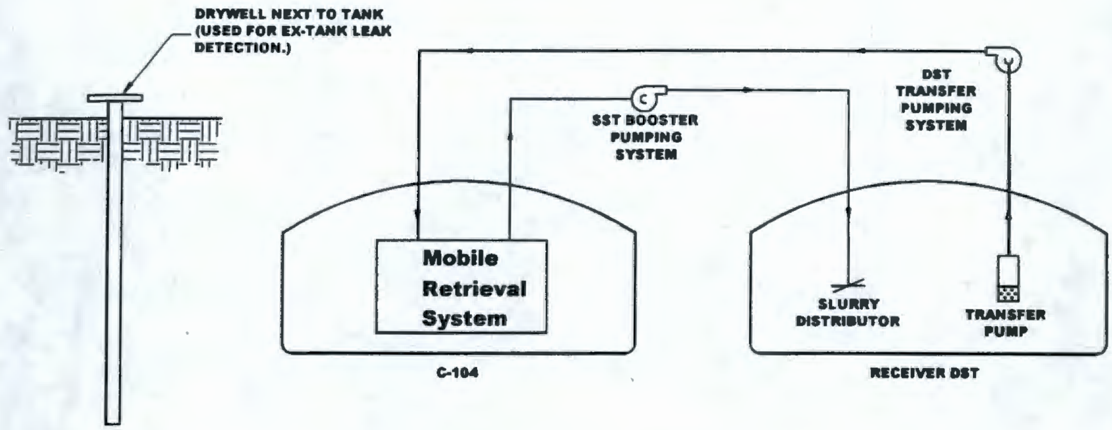

Figure 5-3. Tank C-104 Mobile Retrieval System

5.2.2 LDMM System Description

As stated earlier, 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 calculate waste volume discrepancies between the SST being retrieved and the receiving DST (see Figure 5-4). 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 (see Figure 5-5) and a free liquid surface to measure against. Drywells outside of tank C-104 will be monitored to establish a pre-retrieval baseline for the SST and then periodically monitored to detect variation in radiation levels in the soil column.

Currently, tank level measurement is done with Enraf-Nonius® level instruments (Enraf). The Enraf instrument is mounted on a tank riser dedicated to that purpose. The Enraf is remotely controlled by a computer, which causes the instrument to raise, and lower a displacer suspended on a stainless-steel 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 1400 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 C-104 and the receiver DST can be compared with tank volumes calculated from tank levels. Differences outside of the instrument error bands would indicate a leak. Any flush water additions or volume additions from other sources must also be accounted for in the volumetric balance calculations.

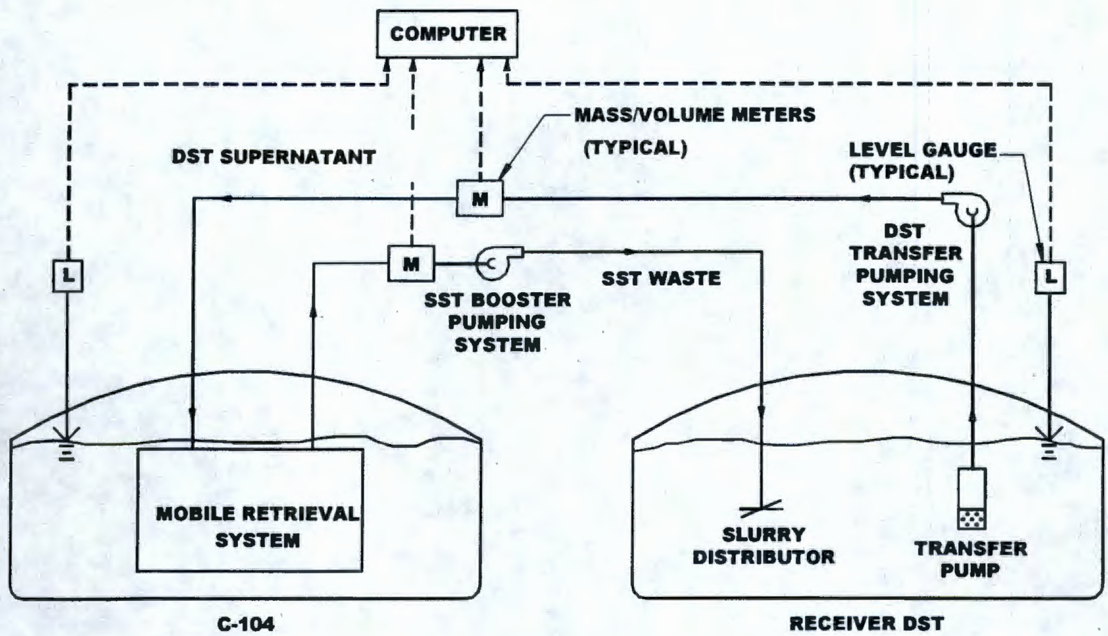

Figure 5-4. Tank C-104 Dynamic Leak Detection (Based on Mass/Volumetric Flow & Tank Liquid Level)

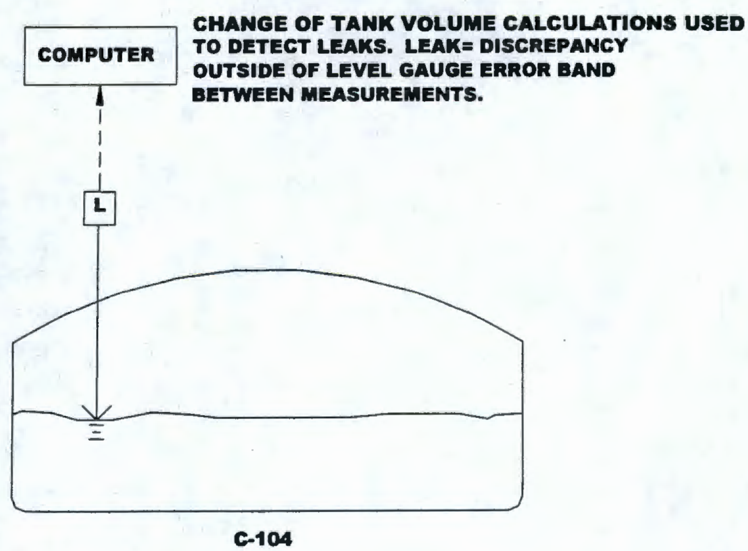

Figure 5-5. Tank C-104 Static Leak Detection (Based on Changes in Tank Liquid Level Only)

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. A conductivity probe will be placed beneath each low point pit drain to monitor for overflowing leaks in the primary line.

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

5.3 LDMM and Retrieval Operating Strategy

The operating strategy for performing LDMM and retrieval applies to pre-retrieval and retrieval steps as described below.

5.3.1 Pre-Retrieval

A pre-retrieval LDMM assessment will be undertaken for tank C-104 prior to the start 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:

- Establish an ex-tank baseline condition using gamma monitoring in existing drywells
- Calculate the volume (liquid, solid, and total) for both tank C-104 and the DST receiver tank
- Measure/calculate tank C-104 waste inventory via topographical or other mapping and survey techniques.

In addition, an operational history review to look for evidence of leaks, and a review of existing leak detection, drywell, and Tank Farm Vadose Zone Project instrumentation and data will be performed. An initial leak test and/or confirmation of "soundness" will be performed 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 C-104 conditions prior to retrieval.

5.3.2 Retrieval

The overall retrieval strategy will consist of reducing the tank liquid inventory during retrieval operations, monitoring liquid inventories while waste is actively being retrieved (dynamic test), and monitoring liquid inventories when retrieval operations are intermittently suspended (static test). (See Figure 5-6) Dynamic testing will be performed throughout the retrieval operations. Static testing will be performed when the waste configuration and the location of the liquid surface is such that instrumentation can contact the liquid surface. The opportunities for conducting static tests, as well as dynamic tests, will be established in a process control plan.

5.3.2.1 Retrieval Strategy

To reduce the tank liquid inventory during retrieval operations, nozzle(s) will be oriented to attempt to create a cone-shaped "well" in the waste around the slurry removal mechanism, which removes the mobilized sludge material and slurry. This strategy is key to leak mitigation since it minimizes the free liquid in the tank. As the sludge and slurry are removed from the tank, the mobile retrieval system is lowered further into the tank (or moved laterally, or both) to maintain a continual feed to the slurry removal mechanism. In the event a "well" in the waste cannot be created or maintained, supernatant from another tank will be added in sufficient quantities to maintain feed to the slurry removal mechanism. Operations continue in this fashion until insufficient waste remains to provide a constant source of feed for the slurry removal mechanism, at which time bulk retrieval operations will end.

The tank C-104 mobile retrieval system will utilize recycled supernatant from the receiving DST. The transfer lines to the receiving tank and the receiving tank itself are encased and provided with low-point conductivity type leak detection. As discussed previously, the current concept of the mobile retrieval system incorporates an on-board nozzle to dislodge and mobilize the waste and a slurry removal mechanism to recover and transfer the resultant slurry. During initial operation of the retrieval system, dynamic leak detection will be the primary means of leak detection. Once the retrieval operation has proceeded to a point that a "well" has formed in the sludge and free liquid has collected in the "well," a static leak test may be possible. Sampling can also be accomplished during the static leak test.

5.3.2.2 Dynamic Leak Detection

Dynamic leak detection will be implemented during waste retrieval operations. It will consist of liquid waste level measurements, including measurements required to compensate for short term variations in the measurement signals, in both tank C-104 and the DST receiver tank. In addition, flow measurements (also including other measurements required to compensate for short term variations) will be made in both the transfer piping going into and out of tank C-104 and into and out of the DST. This will allow static leak tests to be performed as well as the dynamic estimates based on transferred volumes.

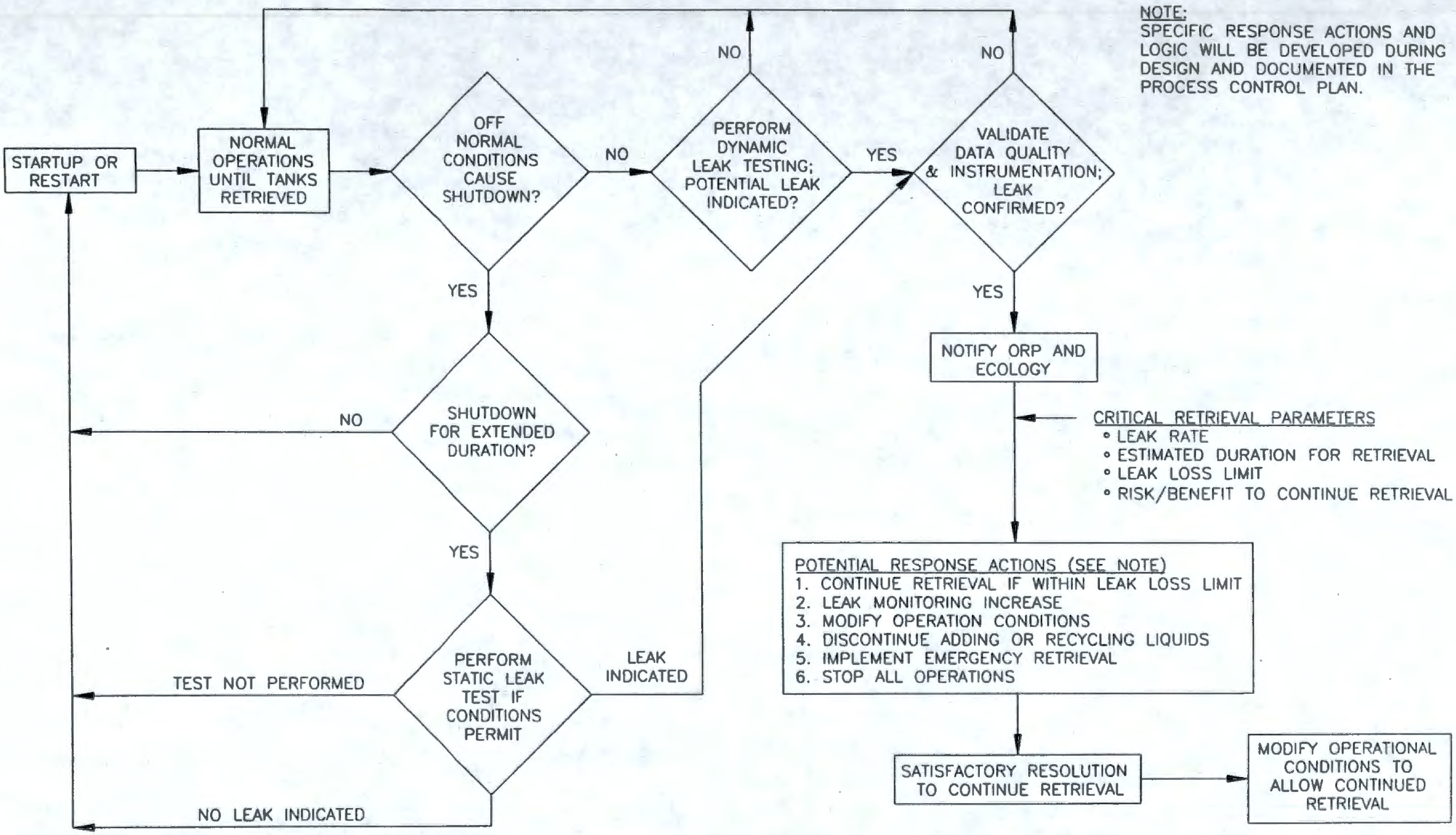

Figure 5-6. Retrieval/LDMM Operational Response Process Diagram

Based on the required leak detection requirements and the capabilities of the instruments, a goal will be established that the analysis result of the dynamic leak detection data being collected during retrieval lags the ongoing operations by no more than 48 to 96 hours, with updates on an 48 to 96 hour basis.

Table 5-2 provides a typical listing of the instrumentation used for dynamic leak testing; the table describes the data and why it may be collected.

Instrument	Measurement Function	Purpose
Level gauge	Free liquid surface level inside SST	Direct measurement
Level gauge	Free liquid surface level inside DST	Direct measurement
Thermocouple	Air temperature inside SST	Instrument error
Thermocouple	Liquid temperature inside SST	Source material compensation
Thermocouple	Air temperature outside SST	Instrument error
Pressure gauge	Barometric pressure	Source material compensation
Pressure gauge	Static pressure inside SST (ventilation system)	Source material compensation
Pressure gauge	Static Pressure Inside DST (ventilation system)	Source material compensation
Pressure gauge	Transfer pipeline pressure	Source material compensation
Flow meter	Volumetric/mass flow out of SST	Direct measurement
Flow meter	Volumetric/mass flow into SST	Direct measurement
Psychrometrics	Evaporation / condensation in SST	External inflow/outflow
Batch sample	Liquid/sludge density inside SST	Source material compensation
Sensor and switch	Data acquisition and alarm	Record and process data inputs

Table 5-2. Instrumentation Requirements for Dynamic Leak Detection

For dynamic leak detection, the retrieval system will be treated like a closed loop system consisting of the recovery tank, tank C-104, the receiving tank, a DST, and the connecting transfer lines (see Figure 5-4). Solids loading and specific gravity in the recovery line may be measured and used to compensate/reconcile the recovery volume. The discrepancy between the inflow and outflow from tank C-104 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 C-104 liquid inventory, including the error produced by all compensating measurements (thermal expansion, dissolution, solids loading, etc.), will be considered a leak in tank C-104. This assumes that no leak is detected in the transfer line(s) or the DST. This assumption will be validated during the actual retrieval operations.

If a leak is indicated during retrieval operations process control procedures will be implemented (see Figure 5-6). 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 loss limit, leak loss rate, and estimated duration to completion of retrieval operations when determining the appropriate response action. Potential response actions include 1) continuing retrieval activities if the estimated leak volume would remain within the leak loss limit, 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, or 6) stopping all operations (see Figure 5-6). 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 which will be developed concurrent with the design of the retrieval and LDMM system.

5.3.2.3 Static Leak Testing

A static leak test will require that all sluicing operations be suspended for a period of time to allow the system to reach equilibrium and to conduct the leak detection test. Static leak detection is comprised of liquid waste level measurements in the SST being retrieved, as well as measurement of other liquid collection or dispersion points.

Once retrieval operations have been suspended, a waiting period will be observed to allow the liquids to gravity drain to retrieval system low points. Static testing will be performed once tank C-104 has reached equilibrium. The frequency and duration of the static test will be determined during the design of the retrieval system. Data will be collected over a period of time (48 hours, for example), and measurements will include tank liquid waste levels and temperatures (to account for thermal expansion.) Table 5-3 provides a listing of the representative instrumentation required for static leak testing. The table also describes the data and the reason it is being collected. Once the data collection and analysis are complete and have shown that a leak has not occurred, tank waste retrieval operations are resumed.

Instrument	Measurement Function	Purpose
Level gauge	Free liquid surface level inside SST	Direct measurement
Thermocouple	Air temperature inside SST	Instrument error
Thermocouple	Liquid temperature inside SST	Source material compensation
Thermocouple	Air temperature outside SST	Instrument error
Pressure gauge	Barometric pressure	Source material compensation

Instrument	Measurement Function	Purpose
Pressure gauge	Static pressure inside SST (ventilation system)	Source material compensation
Psychrometrics	Evaporation / condensation in SST	External inflow/outflow
Batch sample	Liquid/sludge density in SST	Source material compensation
Sensor and switch	Data acquisition and alarm	Data Recording and Processing

Table 5-3. Instrumentation Requirements for Static Leak Detection

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 and process control procedures will be implemented. The process control procedures will consider the leak loss limit, leak loss rate, and estimated duration to completion of retrieval operations when determining the appropriate response action. Potential response actions include 1) continuing retrieval activities if the estimated leak volume would remain within the leak loss limit, 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 5-6). 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 which will be developed concurrent with the design of the retrieval and LDMM system.

5.3.2.4 Drywell Monitoring

Drywells will be monitored periodically during retrieval operations to provide additional leak detection and monitoring capability. The frequency of drywell monitoring will be established during the design phase of the project.

5.3.3 Post Retrieval

A post-retrieval LDMM assessment will be undertaken for tank C-104 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 gamma monitoring in existing drywells and compare with the baseline condition

- Measure/calculate tank C-104 residual waste inventory via proposed topographical or other mapping and survey techniques.

When the tank C-104 retrieval demonstration 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. Existing vadose zone contamination is being addressed under a separate program. The SST closure work plan 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.

5.3.4 Alternative Technology

During FY01, DOE/ORP is sponsoring testing and demonstrations to examine alternate LDMM technologies that provide indirect leak detection outside of the tank. These technologies may have potential to augment the existing drywell ex-tank leak detection system. These ex-tank LDMM technologies include:

- Neutron-Neutron (PNNL, 2001)
- Electrical Resistance Tomography (ERT) (PNNL, 2001)
- Crosshole Radar (PNNL, 2001)
- Crosshole Electromagnetic Induction (PNNL, 2000)
- High-Resolution Resistivity (PNNL, 2000)
- Time Domain Reflectrometry (PNNL, 2000)
- Partitioning Interwell Tracer Tests (PITT) (CHG, 2000b)

In addition, further in-tank leak detection technologies will be investigated during the tank U-107 proof-of-concept test and during design and development of the tank C-104 retrieval demonstration. These include:

- Level measurement based on Quartz Oscillating Crystal gauge,
- Liquid Observation Well used with gamma probe, and
- Topographical mapping techniques

If testing during FY01 demonstrates that any of these technologies significantly decreases uncertainty associated with static and dynamic leak testing, they will be evaluated for inclusion in the demonstration. The parameters that will be evaluated are:

- Maturity, accuracy, and precision of the technology,
- Amount of additional development required to deploy the technology,
- Degree by which LDMM is enhanced versus the cost to deploy the technology,
- Impacts to the project schedule, and
- Cost impacts to the project baseline.

6.0 HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER F&R CHANGE CONTROL

This document is a Hanford Federal Facility Agreement and Consent Order Primary Document requiring Ecology review and approval. This document will establish the functions and requirements for the tank C-104 retrieval demonstration for the life of the retrieval project. Document revisions will follow the criteria outlined in section 9.3, "Document Revisions" of the Hanford Federal Facility Agreement and Consent Order. Modifications to this document will be assessed using existing criteria. Minor field changes (as discussed in section 12.4 of the Agreement) 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 not considered minor field changes can be made through use of a change notice in accordance with sections 9.3, Document Revisions and 12.0, Changes to the Agreement. Major changes (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 LDMM criteria).

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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.

40 CFR 61, *National Emissions Standards for Hazardous Air Pollutants,* Code of Federal Regulations.

40 CFR 265, *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities,* Code of Federal Regulations.

40 CFR 280, *Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks,* Code of Federal Regulations.

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APPENDICES

APPENDIX A

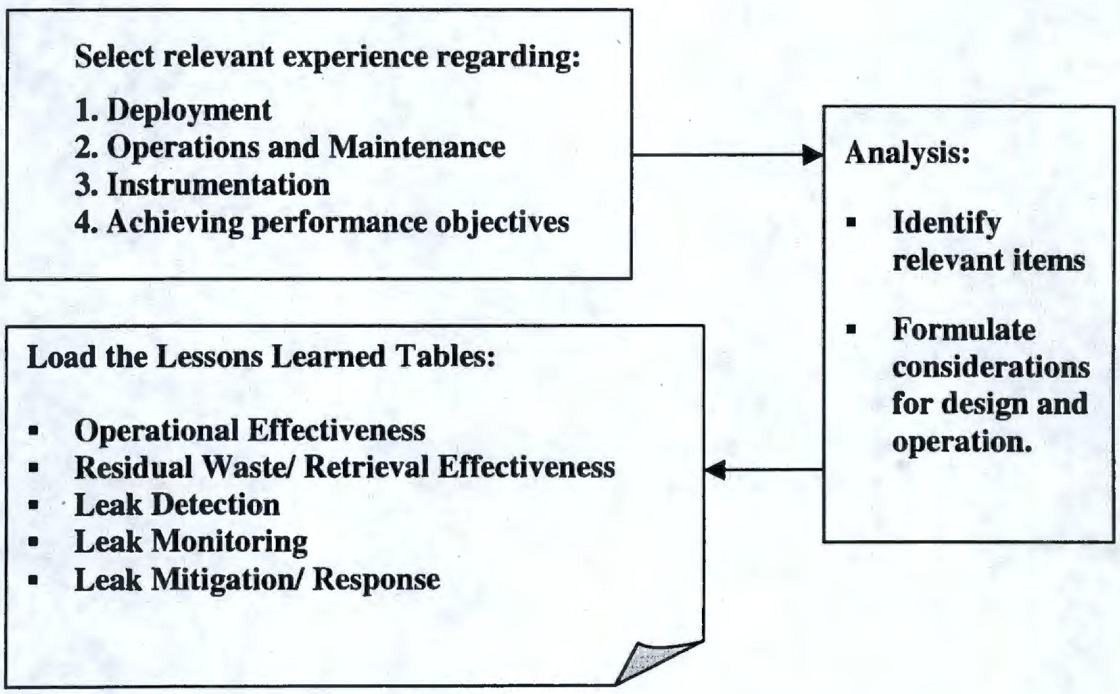
LESSONS LEARNED BASIS FOR SELECTION AND IMPLEMENTATION OF RETRIEVAL AND LDMM TECHNOLOGIES

APPENDIX A - LESSONS LEARNED BASIS FOR SELECTION AND IMPLEMENTATION OF RETRIEVAL AND LDMM TECHNOLOGIES

A lessons-learned summary was prepared to support the development of the F&R for retrieval of Tank 241-C-104. A survey of technology application experience was conducted to identify lessons learned relevant to this planned application of confined sluicing and robotic retrieval technologies.

A.1 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-C-104 retrieval activities were then formulated and presented in tabular format as illustrated below:



Although the selection process was primarily focused on confined sluicing and LDMM volumetric/mass balance systems supporting large-scale tank facilities, other applications also offered relevant information.

A.2 Information Sources.

Candidate items with experience in 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 Tank 241-C-104 retrieval.

A.2.1 Hanford Tank 241-C-106 Retrieval

Project W-320 at Hanford 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. The mass data was run through an algorithm to compare how much sluiced material (by weight) went into the retrieval tank and 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 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 attributed to the causes 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, but the data has not been analyzed in terms of mass transfer. When this data is analyzed, the benefits and limitations of flow rate-augmented data will be more evident. In cases where no liquid interface is measurable, such as might be found in tanks containing stabilized sludges, this technique has limited value. Tank 241-C-106 retrieval operations did not use the mass balance method for leak detection; a heat load management method was used for that project.

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 (W-8 and W-9) in fiscal year 2000.

The GAAT waste retrieval system consists 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 particular Tank 19. Waste mixing and removal using the slurry pumps has left approximately 40 kgal of residual sludge as 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. The schedule calls for mixing to begin in September, with completion of waste retrieval in Tank 19 within approximately 1 month.

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), DOE/NASA collaborations to develop robotic systems for Chernobyl (Osborn 2001), 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), US-EPA development of standards for leak detection on large petroleum tanks, and other remote or robotic systems with operating experience in hazardous environments (Maresca, et al, 1993).

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 indicate that short-lived radiotracers in partitioning interwell tests can 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).

A.3 Tables for Design and Operation Considerations

Lessons learned considerations for design and operation were recorded in one of five "topical" tables consisting of operational 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 retrieval, reference documentation, and the associated project. Although this information was drawn from a variety of sources, industries and applications, the "lessons" to facilitate successful deployment of the 241-C-104 retrieval systems typically fell into one of the categories listed below:

a) 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.

b) 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.

c) 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.

d) *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 of tethered control cables.

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

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	Design an integrated system to be capable of achieving performance criteria through continuous retrieval operations.	ORP W-320 Bailey 2000.
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.	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	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.

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	May adversely impact schedule, operating costs and leak risk.	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.
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.	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact operational safety, schedule, operating costs and leak risk.	Use flexible joints on ridgid 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., 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	May adversely impact operational safety, schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	Provide the capability to flush slurry/supernatant piping systems without excessive preparations or system modifications, and operator activity.	ORP W-320 Bailey 2000.

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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
A.3.1.12	Houdini-II system suffered from inadequate planning and preparations to effectively address needed maintenance and repair activities.	May adversely impact operational safety, schedule, operating costs and leak risk.	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 <u>and</u> anticipated maintenance activities can be achieved in a safe manner consistent with good ALARA principles.	ORNL GTRP Burks, et al 2001, & Falter 1997

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	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/slucier 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.	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	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

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	May adversely impact schedule, operating costs and leak risk.	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 Developmental Test Thompson 1990
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, was limited by MLUDA's ability to counteract pneumatic forces above 20,000 psi.	May adversely impact schedule, operating costs and leak risk.	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

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	May positively impact schedule, operating costs and leak risk.	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.	May positively impact schedule, operating costs and leak risk.	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/slucier operations.* ▪ *Include applicable features as system design requirements."*	ORNL GTRP Lloyd, et. al. 2001

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	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".	May adversely impact schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.*"	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	Design the system for adequate space for the elevator, pivot, and the actuator to be fully utilized.	Hanford HTI GreyPilgrim 1997.

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	May adversely impact operational safety, schedule, operating costs and leak risk.	▪ 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 Cyber-netics Fidani 2001
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.	May positively impact schedule, operating costs and leak risk.	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

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
A.3.1.31	Development of the PIONEER crawler robot for Chornobyl 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).	May positively impact schedule, operating costs and leak risk.	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.	May positively impact schedule, operating costs and leak risk.	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.	May positively impact schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May positively impact schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	▪ 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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May positively impact operational safety, schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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 <u>processes</u> and <u>systems</u> 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.	May adversely impact operational safety, schedule, operating costs and leak risk.	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 and 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.	May positively impact operational safety, schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May positively impact schedule, operating costs and leak risk.	▪ 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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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 sludges 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.	May positively impact schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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	May adversely impact schedule, operating costs and leak risk.	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 can 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".	Inadequate integration may adversely impact performance.	(see item A.3.1.14 regarding integration of required design elements into a system)	Hanford Tank Farms Squires 1990 and 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.	May adversely impact schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May positively impact operational safety, schedule, operating costs and leak risk.	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

Table A-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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.	Actual volume results in a radioactive waste environment.	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 are within safety allowables. ▪ 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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	Applicable retrieval pump operational experience: ▪ Ensure that a tracked vehicle if used can be effectively maneuvered in the SSTwaste 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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	May adversely impact schedule, operating costs and leak risk.	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.....*"	May adversely impact operational safety, schedule, operating costs and leak risk.	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-1 Operating Effectiveness

Section A.3.1	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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 close-out 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.	May adversely impact schedule, operating costs and leak risk.	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.	May adversely impact schedule, operating costs and leak risk.	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-2 Residual Waste/ Retrieval Effectiveness

Section A.3.2	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	Adverse impact on retrieval effectiveness and potential for leaving more residual waste than planned.	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.	Adverse impact retrieval effectiveness and potential for residual waste.	Methods to mobilize tank waste need to be verified prior to acceptance of the final design for procurement.	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.	Positive result with confined sluicing/ robotic retrieval technology.	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-2 Residual Waste/ Retrieval Effectiveness

Section A.3.2	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	Adverse impact to retrieval effectiveness and potential for residual waste.	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-2 Residual Waste/ Retrieval Effectiveness

Section A.3.2	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	Adverse impact to retrieval effectiveness and potential for too much residual waste.	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 Leak Detection Section

Section A.3.3	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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%.	Candidate leak detection system for pipe lines between tank 104-C and receiver tank.	Could be a form of leak detection for the transfer lines provided the lines can 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.	Use existing equipment is qualified to be sound	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

Table A-3 Leak Detection Section

Section A.3.3	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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	May adversely impact Leak Detection Performance.	▪ *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 FMECAs ...".*	

Table A-3 Leak Detection Section

Section A.3.3	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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	Performance criteria for level indication and temperature sensors to be used to monitor the waste level.	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-4 Leak Monitoring Section

Section A.3.4	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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.	Dry well would be required and location would have to be evaluated to determine best location	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.	Evaluate the instrumentation that will be used on tank 241-C-104 and determine its susceptibility to false alarms	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.	Leak monitoring system effectiveness.	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-4 Leak Monitoring Section

Section A.3.4	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	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	May adversely impact Leak Monitoring Performance.	▪ *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-5 Leak Mitigation/ Response Section

A.3.5	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
A.3.5.1	Pipe line (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	Need for an effective working relationship with regulators is essential to maintaining cost and schedule	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.	Need for effective working relationship with regulators is essential to maintaining cost and schedule	Provide a path for effective communication between regulators and technical staff.	ORNL Ref. 98

Table A-5 Leak Mitigation/ Response Section

A.3.5	Lesson Learned from Source/ Reference	Relevancy to 241-C-104 Retrieval	Considerations for Design and Operation	Source/ Reference
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	May adversely impact Leak Mitigation/ Response Performance.	▪ *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 …".*	

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APPENDIX B

RETRIEVAL PERFORMANCE EVALUATION FOR SINGLE-SHELL TANK C-104

Dave

RETRIEVAL PERFORMANCE EVALUATION FOR SINGLE-SHELL TANK C-104

Draft

March 30, 2001

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EXECUTIVE SUMMARY

This *Retrieval Performance Evaluation for Single-Shell Tank C-104* is written to document the results of a scoping-level retrieval performance evaluation for waste retrieval from tank C-104 in the Hanford Site 241-C tank farm. The evaluation was performed to satisfy some of the requirements of Tri-Party Agreement Milestone M-45-03-T04[1] to include a scoping-level retrieval performance evaluation in the tank C-104 waste retrieval demonstration functions and requirements document.

The scoping-level retrieval performance evaluation 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 C-104. Those ranges are intended to provide insight to relationships between risk and volume and provide decision makers with information to support the identification of waste retrieval and leak detection, mitigation, and monitoring system requirements that are protective to human health.

The final extent of retrieval is a tank farm closure issue; however, the extent of retrieval should be considered in the functions and requirements 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 retrieval criteria. This approach does not preclude the retrieval of additional waste from the tank in the future as additional information is gathered during and after waste retrieval activities in the remaining C farm tanks and as closure criteria are established.

The performance measures that influence functions and requirements for defining retrieval leakage limits and the extent of retrieval (i.e., how much waste needs to be retrieved) for tank C-104 are driven by the inadvertent human intruder and regulatory waste classification performance measures. If leakage were to occur during retrieval, then the combination of residual waste and retrieval leakage could contribute to the intruder impacts. These two performance measures are more restrictive than the long-term human health risk under an industrial worker scenario located at the C tank farm fence line. For leak loss, residential farmer exposure scenario, if deemed relevant at the C tank farm fence line, would be more restrictive than the inadvertent human intruder.

The U.S. Department of Energy inadvertent intruder and the U.S. Nuclear Regulatory Commission waste classification issues discussed for tank C-104 are tank-specific and are not cumulative for the tank farm. Regulatory issues associated with classification of the residual waste have been identified and will likely require future regulatory negotiations.

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[1] Ecology, EPA, and DOE, 1989, *Hanford Federal Facility Agreement and Consent Order*, as amended, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

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FIGURES

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LIST OF TERMS

CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CoCs	contaminants of concern
DOE	U.S. Department of Energy
DST	double-shell tank
DWS	drinking water standards
EDTA	ethylenediaminetetraacetic acid
EPA	U.S. Environmental Protection Agency
F&R	functions and requirements
GTCC	Greater Than Class C
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*
RPE	retrieval performance evaluation
SST	single-shell tank
TRC	total recordable case
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRU	transuranic
TSD	treatment, storage, and/or disposal
URF	unit risk factor

1.0 INTRODUCTION

This *Retrieval Performance Evaluation for Single-Shell Tank C-104* is written to document the results of a scoping-level retrieval performance evaluation (RPE) for waste retrieval from tank C-104 in the Hanford Site 241-C tank farm. The evaluation was performed to satisfy some of the requirements of Milestone M-45-03-T04 of the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989). The Order is commonly referred to as the Tri-Party Agreement. Milestone M-45-03-T04 calls for the development of a Tri-Party Agreement functions and requirements (F&R) document for tank C-104 demonstration systems for waste retrieval and leak detection, mitigation, and monitoring (LDMM). A scoping-level RPE is to be included in that F&R document.

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 C-104. These ranges are intended to provide an envelope within which a waste retrieval system can be designed and operated while being protective of human health. This evaluation provides decision makers with information to support the identification of waste retrieval and LDMM system requirements.

The fundamental goal of the tank C-104 waste retrieval technology demonstration is to test the limits of technology for a crawler-based retrieval system. The ideal result of any waste retrieval effort would be 100% waste retrieval with no leak loss to the environment. However, achievement of that ideal goal is highly uncertain given the conditions of tank C-104, physical characteristics of the waste in the tank, and the limitations of the waste retrieval system. Given this uncertainty it is important to develop a design and operating approach that defines waste retrieval and LDMM system requirements.

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. Those decisions are also interrelated with others regarding remediation and closure of a number of other waste sites in the Hanford Site 200 East and 200 West Areas. This analysis focuses on tank C-104 within the context of the C tank farm. The general approach used in this RPE involves definition of nine waste retrieval cases that span a range of retrieval leak loss and residual waste volumes for tank C-104 and include retrieval and leak loss assumptions for the remaining C farm tanks. Table 1.1 shows the areas of analysis considered in this RPE and provides a cross-walk of those areas to the corresponding section numbers that address technical approach, results of analysis, and conclusions. The areas of analysis were selected based on regulatory requirements and/or stakeholder and Tribal Nation values.

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

Area of Analysis	Technical Approach	Analysis Results	Conclusions
Case studies	Section 3.2	Section 4.2	Section 6.0
Source terms	Section 3.3 and the Appendix of this document		
Short-term human health risk	Section 3.4	Section 5.1	Section 6.2.1
Groundwater impacts	Section 3.5	Section 5.2	Section 6.2.2
Long-term human health risk	Section 3.6	Section 5.3	Section 6.2.3
Intruder risk	Section 3.7	Section 5.4	Section 6.2.4
Regulatory compliance	Section 3.8	Section 5.5	Section 6.2.5

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

The specific values for residual waste volume and retrieval leakage volume utilized to develop the waste retrieval cases are not emphasized because the purpose of the analysis is not to select a case for implementation, but to provide a vehicle to evaluate how performance measures change as residual waste and leak loss volumes change. To provide results over a range of inputs, some of the cases include residual waste volumes and retrieval leakage volumes that would not meet the objectives of the retrieval technology demonstration.

This RPE report is not intended to set the minimum performance standard for the waste retrieval demonstration. The retrieval demonstration should 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. Consideration of tank and tank farm closure criteria (as they are understood today) should also be taken in an effort to remove enough waste with minimal leakage providing reasonable assurance that the tank and the tank farm can be moved toward closure without having to plan for multiple retrieval campaigns.

It is recognized that consideration of 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 consider the relationship between tank waste retrieval as it relates to tank farm closure before, during, and after tank waste retrieval.

The RPE methodology will be used to provide risk-based performance data to other elements of the tank C-104 waste retrieval project. The performance measures evaluated will be used to support identification of the requirements for the LDMM system in terms of required leak detection limits and response actions and the identification of requirements for the retrieval system in terms of the extent of waste retrieval necessary to meet risk and regulatory-based criteria. The Tri-Party Agreement F&R document will discuss how the results of this RPE are applied to the waste retrieval system. Another aspect of the retrieval demonstration involves showing the limit of the retrieval technology (i.e., operational conditions for demonstrating when the technology has reached the practical limit), which will be defined in the Tri-Party Agreement F&R document and not as part of this RPE report.

2.0 BACKGROUND

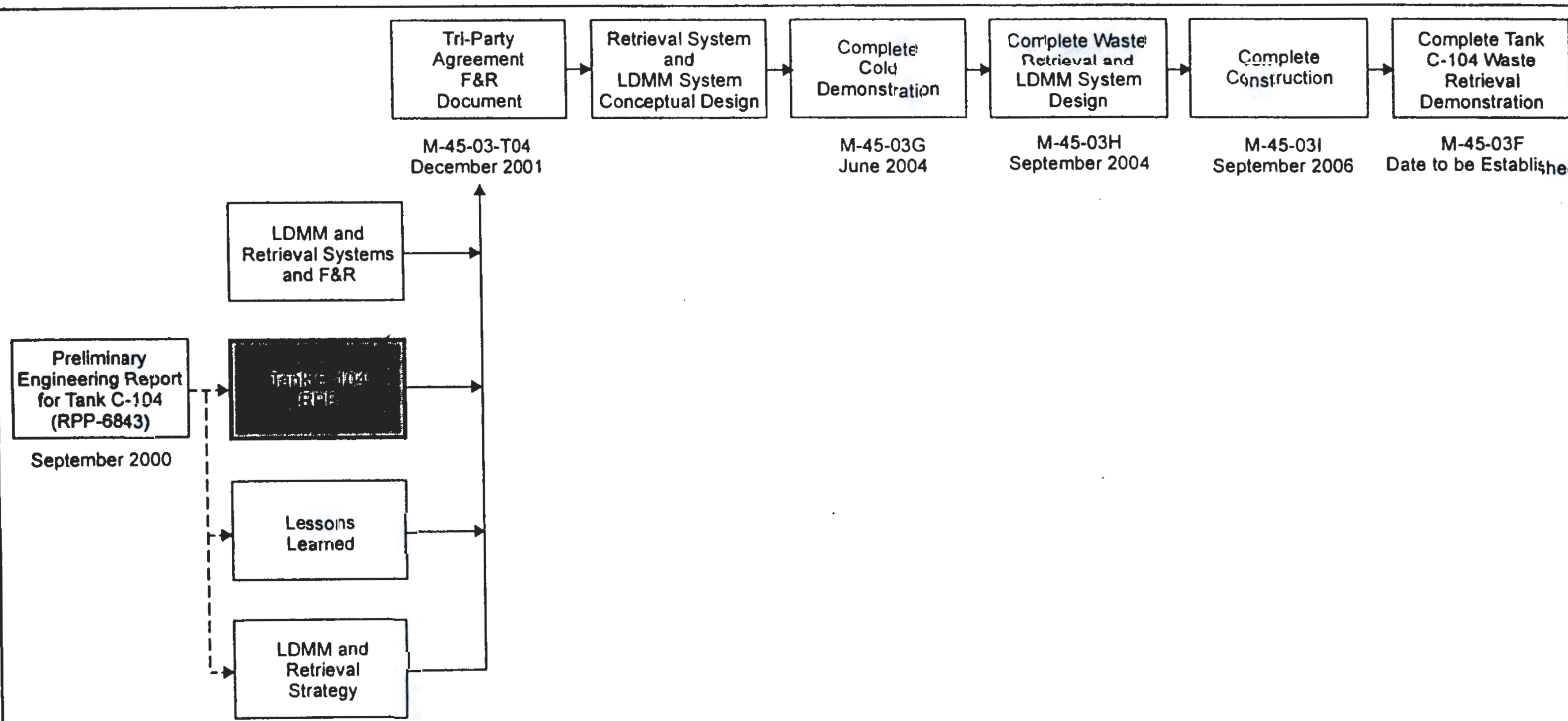
In 1999 the U.S. Department of Energy (DOE) completed the RPE methodology for the AX tank farm, documented in *Retrieval Performance Evaluation Methodology for the AX Tank Farm* (DOE/RL-98-72), as a demonstration of the methodologies, data, and analysis necessary to support making tank waste retrieval and tank farm closure decisions required under the Tri-Party Agreement. 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 utilizes 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 waste retrieval leak loss.

In August of 2000 the Tri-Party Agreement was modified to reflect a revised strategy for SST waste retrieval activities via Milestone Change Package M-45-00-01A. The revised strategy focuses on maximizing risk reduction by prioritizing the retrieval of waste from tanks with a high inventory of contaminants of concern (CoCs) 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 the overall F&R for the waste retrieval demonstration systems, the need for an overarching F&R document has been identified. That overarching document, referred to as the Tri-Party Agreement F&R document, will provide the framework within which the waste retrieval systems will be designed and operated. The major elements of the Tri-Party Agreement F&R document along with the Tri-Party Agreement milestones leading up to completion of the waste retrieval demonstration in tank C-104 are shown in Figure 2.1. Tri-Party Agreement Milestone M-45-03-T04 specifies how the F&R document for tank C-104 should include a scoping-level RPE that provides a human health risk evaluation associated with waste volumes to be retrieved and the maximum volume of waste that could leak during waste retrieval operations. Milestone M-45-03F specifies the tank C-104 waste retrieval goal as retrieval of 99% of the August 2000 best-basis inventory volume (BBI 2000), with at least 89 kg of plutonium retrieved to safe storage.

2.1 SETTING

The Hanford Site 200 East Area (Figure 2.2) is located on a plateau about 11 km (7 mi) south of the Columbia River. This area housed facilities called separations plants that received and dissolved irradiated fuel from the Site 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 those SSTs have since leaked into the soil, either directly from the tanks or from associated transfer piping.

Figure 2.1. Tank C-104 Waste Retrieval Demonstration Milestones



F&R = functions and requirements.
LDMM = leak detection, mitigation, and monitoring.
RPE = retrieval performance evaluation.

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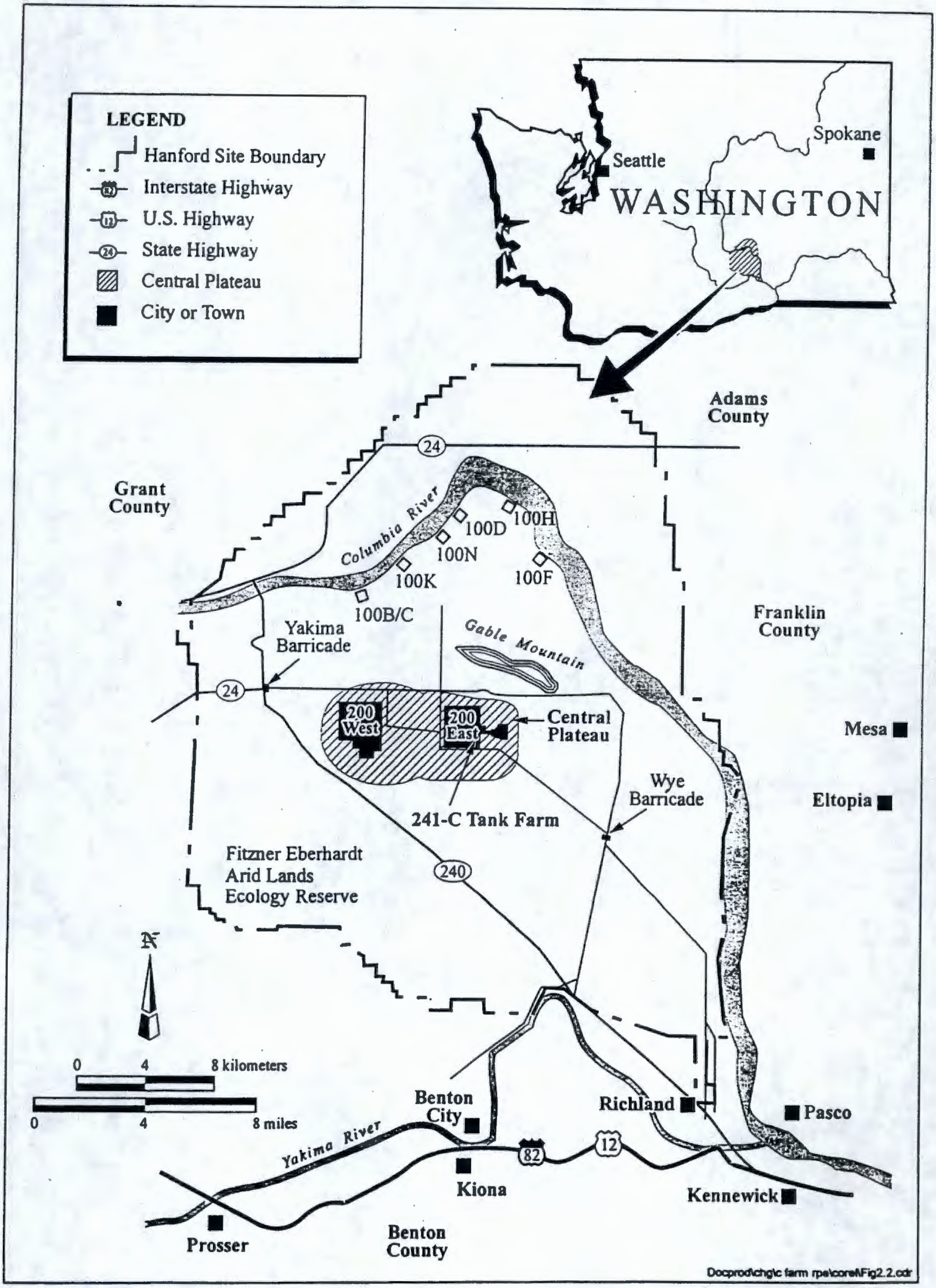
Figure 2.2. Hanford Site Map and Vicinity



2.2 FACILITIES DESCRIPTION

This section contains descriptions of the C tank farm and tank C-104. Definition and description of ancillary equipment are also provided.

2.2.1 C Tank Farm

The C tank farm is located along the eastern edge of the 200 East Area (Figure 2.3). The C tank farm contains 16 SSTs, 12 with 2,000,000-L (530,000-gal) capacity and 4 with 208,000-L (55,000-gal) capacity; waste transfer lines; leak detection systems; and tank ancillary equipment. The larger SSTs are 23 m (75 ft) in diameter while the smaller tanks are 6 m (20 ft) in diameter. The C farm SSTs are approximately 9.5 m (31 ft) tall from base to dome. Figure 2.4 provides drawings of the two types of C farm tanks. The sediment cover from the apex of the dome to ground surface is approximately 2 m (7 ft).

The C tank farm was constructed between 1943 and 1944 as one of the first-generation tank farms at the Hanford Site. The tanks were designed to receive non-boiling waste. Each C farm tank was designed with a primary steel tank liner, concrete shell and dome, and dish-shaped bottom. The C farm tanks are treatment, storage, and/or disposal (TSD) units operating under interim status pending closure. Following waste retrieval, the C 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 Tri-Party Agreement Milestone M-45-00. Under the *Washington Administrative Code* and Tri-Party Agreement requirements, individual tanks cannot be closed; an entire tank farm must be closed as a unit.

Information and data regarding the C tank farm facility description are taken from historical tank content estimates in *Historical Tank Content Estimate for the Northeast Quadrant of the Hanford 200 East Area* (WHC-SD-WM-ER-349). Additional historical data on the C tank farm including historical operating data such as waste level, temperature profiles, and sample analyses, are provided in *Supporting Document for the Northeast Quadrant of the Hanford 200 East Area* (WHC-SD-WM-ER-313).

Tanks C-101 through C-106 received metal waste, and tanks C-107 through C-112 received first-cycle and B Plant decontamination wastes. Tanks C-201 through C-204 were used to settle waste while the supernate was sent to a crib. The C tank farm also received Plutonium-Uranium Extraction Plant fission product waste, which led to the high-heat load in tank C-106. The high-heat load in tank C-106 resulted in the SST Program prioritizing that tank for early waste retrieval. The bulk of the waste in tank C-106 was removed (using past-practice retrieval methods) in a retrieval campaign that was completed in fiscal year 2000, and the tank was removed from the Watch List.

Figure 2.3. Location Map of C Tank Farm and Surrounding Facilities in the 200 East Area

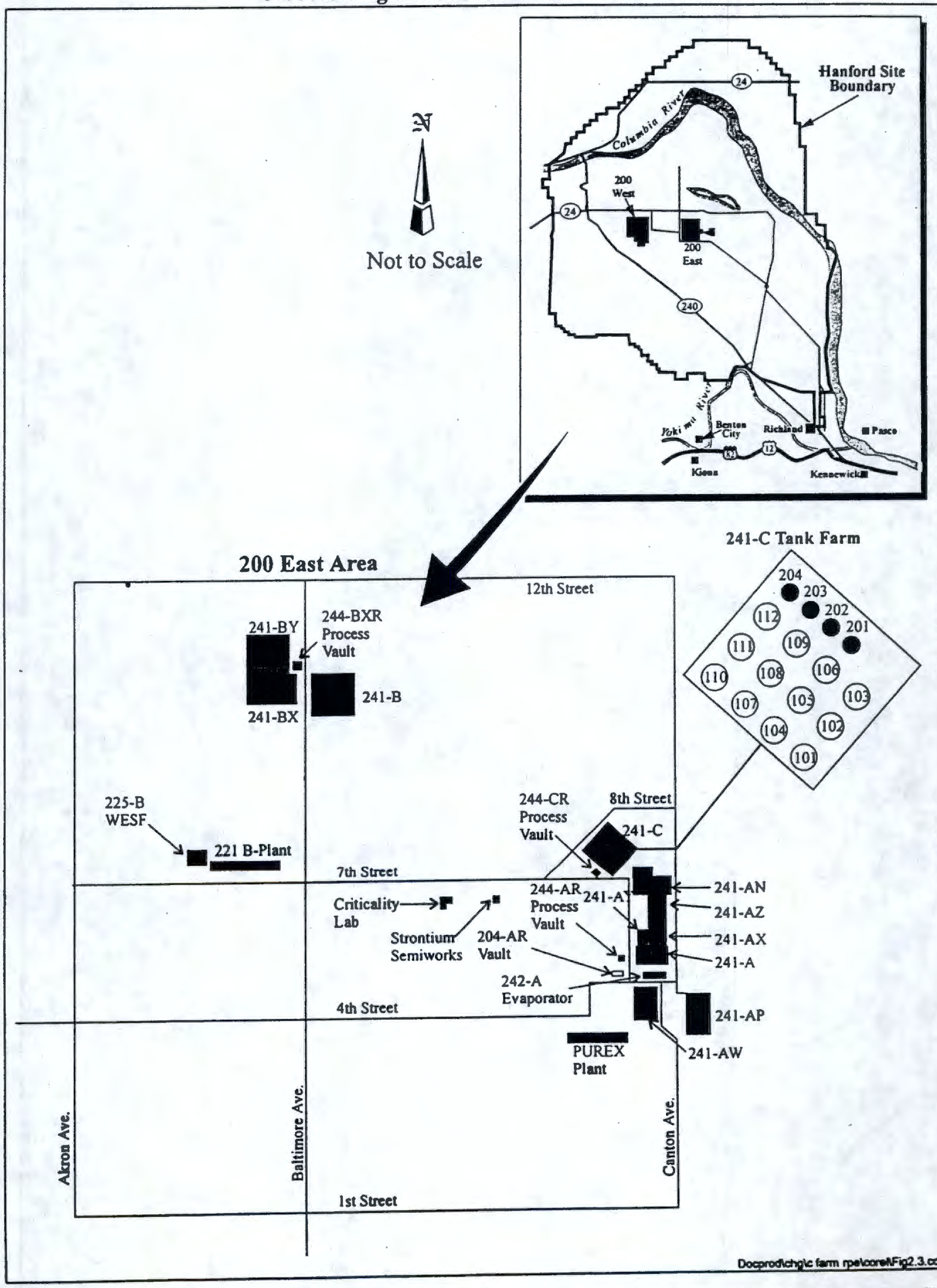
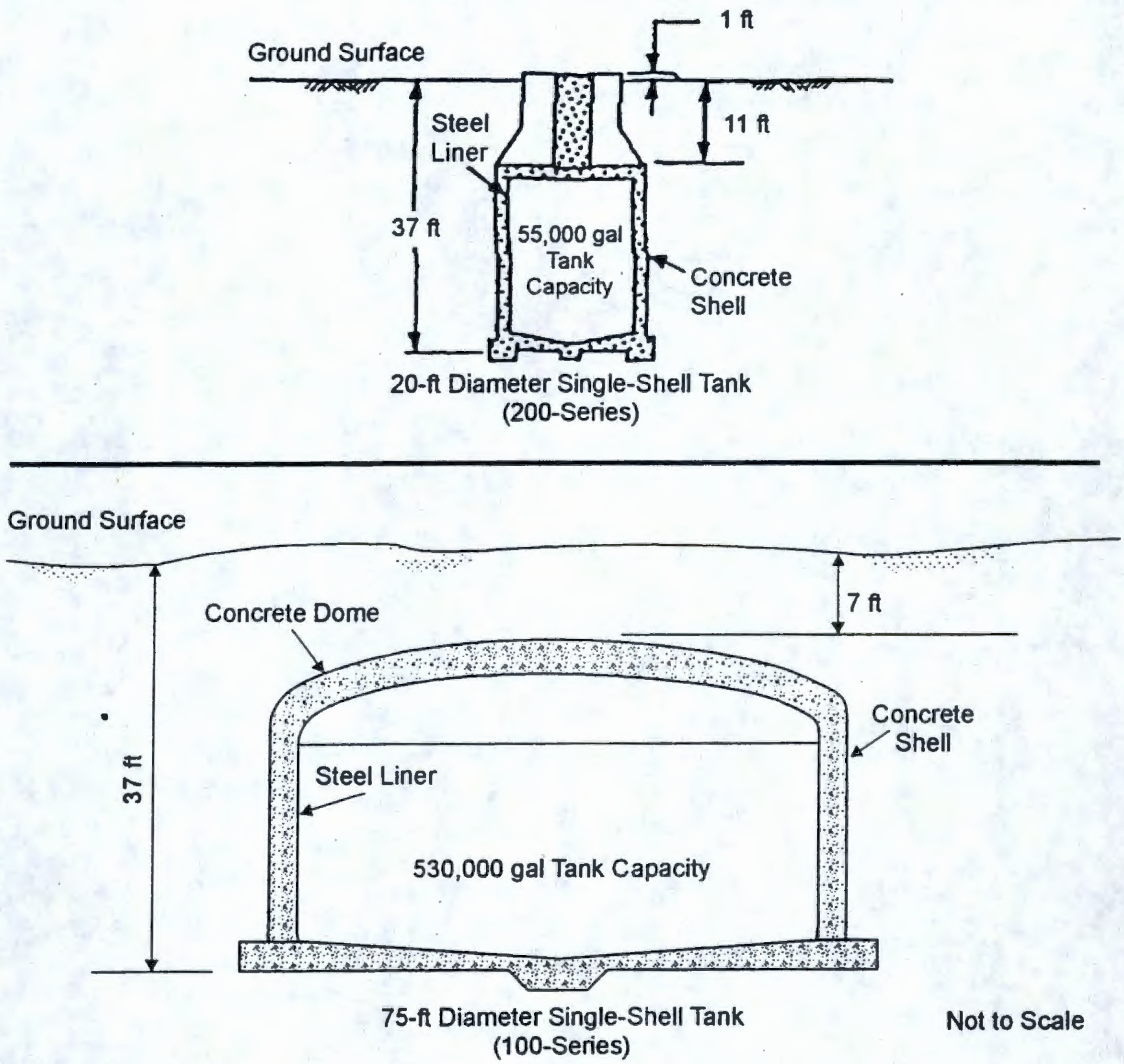


Figure 2.4. C Farm Tanks



(Adapted from HNF-EP-0182-150)

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2.2.2 Tank C-104

Tank C-104 was used to store metal waste beginning in October 1946. The tank was full in February 1947. The waste was sluiced from the tank in 1953 in an effort to recover the uranium. U Plant waste was introduced into the tank in 1955. The tank was subsequently emptied and then received various wastes until 1980 when the supernate was pumped out and the tank was declared inactive. Interim stabilization efforts were completed for tank C-104 in 1989. Tank C-104 is categorized as a sound tank and contains 995,000 L (263,000 gal) of waste (HNF-EP-0182-150). The presence of gamma contamination in the vadose zone around tank C-104 was evaluated during baseline spectral gamma logging of the C tank farm (GJO-HAN-18). The spectral gamma logging effort concluded that the soil contamination around tank C-104 is most likely from overfilling, surface spills, and subsurface pipeline leaks. Vadose zone inventory should be considered in future RPE updates and when evaluating tank farm closure options.

2.2.3 Ancillary Equipment

Ancillary equipment is defined as structures, piping, and equipment outside the waste tanks but associated with tank farm operations. Most of the ancillary equipment in the C tank farm was abandoned in place when the C 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 exposure (if the equipment is removed) or long-term human health risk (if the equipment is left in place). The ancillary equipment list for the C tank farm includes the following:

- Twelve surplus buildings and other surface facilities
- 70 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.

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3.0 TECHNICAL APPROACH

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 leakage volumes supports definition of the LDMM system requirements.

Section 3.1 provides a summary-level overview of the technical approach. Section 3.2 describes the approach used to identify specific waste retrieval cases for analysis. Section 3.3 describes the approach used to develop contaminant inventory estimates for past leaks, potential retrieval leaks, and tank waste residuals for each of the waste retrieval cases. Sections 3.4 through 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, contaminant transport and groundwater impacts, long-term human health risk, and inadvertent human intruder risk. The results of these calculations are presented in Section 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.

3.1 OVERVIEW OF THE TECHNICAL APPROACH

The RPE process was developed as a decision tool to support waste retrieval and closure decisions utilizing 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 waste retrieval to help develop criteria for the extent of retrieval and leak loss criteria and then after waste retrieval to evaluate performance measures using actual retrieval and leak loss data. The current application of this RPE focuses on developing waste retrieval and leak loss criteria for tank C-104 within the C tank farm.

The following performance measures are assessed.

- **Short-term human health risk** (Section 3.4) – Human 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 and injuries and fatalities resulting from industrial accidents.

- **Groundwater impacts** (Section 3.5) – Impacts resulting from releases to the environment from past waste tank leaks and spills, potential releases during waste retrieval, and from residual waste that remains in the tanks following closure. The assessment considers a 10,000-year period of interest beginning at present. The groundwater impact assessment relies on the results of the fate and transport analyses at the nearby AX tank farm. Those results are scaled, based on the inventory differences between the AX and C tank farm source terms, to estimate the groundwater concentration of CoCs at the C tank farm boundary. The estimated groundwater concentrations of the

CoCs for the C tank farm are provided as input to the assessment of long-term human health risk and are compared to regulatory standards.

- **Long-term human health risk** (Section 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 evaluating 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. Although this time period is longer than the 1,000 years required for DOE performance assessments, it was selected for the following reasons:

  - Classification of the residual waste will require a determination from the U.S. Nuclear Regulatory Commission (NRC) that will be based in part on demonstrating protection of human health and the environment over a 10,000-year period
  - Future NEPA requirements for assessing tank closure will consider the 10,000-year period
  - Based on previous analyses, impacts from tank residuals would not be expected to migrate to the receptor location during a 1,000-year period.

- **Inadvertent human intruder risk** (Section 3.7) – Human 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.

- **Regulatory compliance** (Section 3.8)– Applicable and appropriate regulatory requirements are identified including areas where waste retrieval issues and specific quantitative performance measures exist.

The best available data for each component of tank C-104 and the remaining tank farm system were used to provide calculations for each performance measure. Assumptions were developed to complete the analysis where data were unavailable or highly uncertain. 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 C-104 and the C tank farm includes the following:

- Development of a conceptual model of the tank and tank farm system (e.g., tank farm components, sources of contamination, engineered systems, and the natural environment) to analyze the potential impacts of SST waste retrieval

- Identification of waste retrieval cases that span a 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
- Development of factors to enable the scaling groundwater impact results from evaluations of the nearby AX tank farm to the C tank farm
- Performance of a risk assessment to assess short- and long-term human health risks
- Comparison of the performance of the total system to requirements established by federal and state regulations and the Tri-Party Agreement.

3.1.1 Conceptual Model of the C 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. Those decisions 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 C-104 within the context of the C tank farm. Focusing on tank C-104 against the backdrop of the C tank farm as a whole provides a means of evaluating performance measures in a single tank without losing sight of how that tank affects the tank farm as a whole. A conceptual model of the C tank farm for long-term human health risk and groundwater impact assessment is depicted in Figure 3.1 and represents the following.

- The C tank farm including all tanks and soils within the tank farm boundary and from the surface to the groundwater.
- All waste sources within the C tank farm boundary including:
  - Contamination in the vadose zone from past tank spills and releases
  - Potential releases to the environment during waste retrieval activities
  - Releases to the environment from residual waste 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.
- Human exposure under residential farmer and industrial scenarios and resulting human health impacts from contaminants that have migrated beyond the tank farm boundary.

Figure 3.2 depicts the waste sources, release mechanisms, exposure pathways, and receptors for all impacts analyzed in this RPE.

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

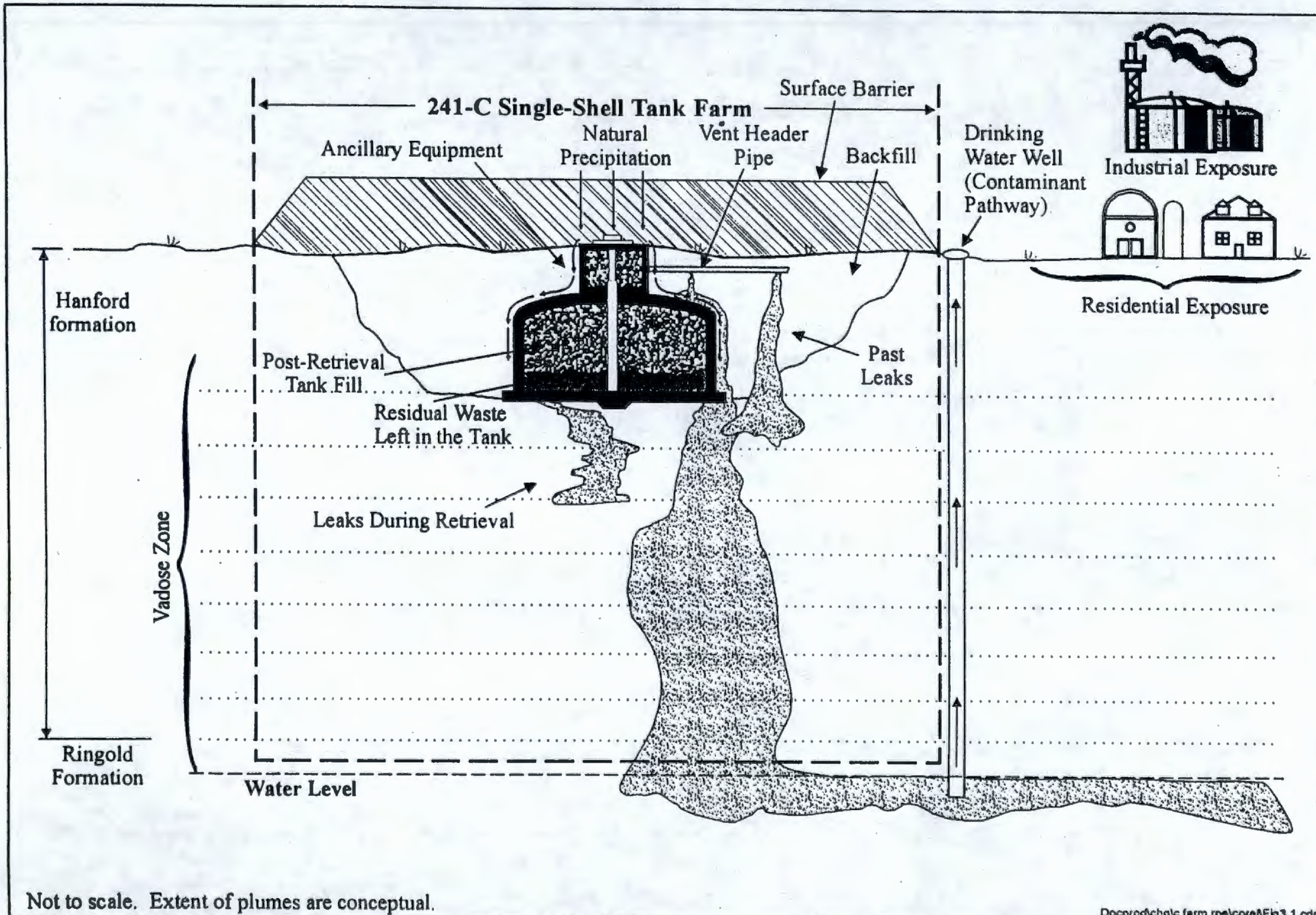
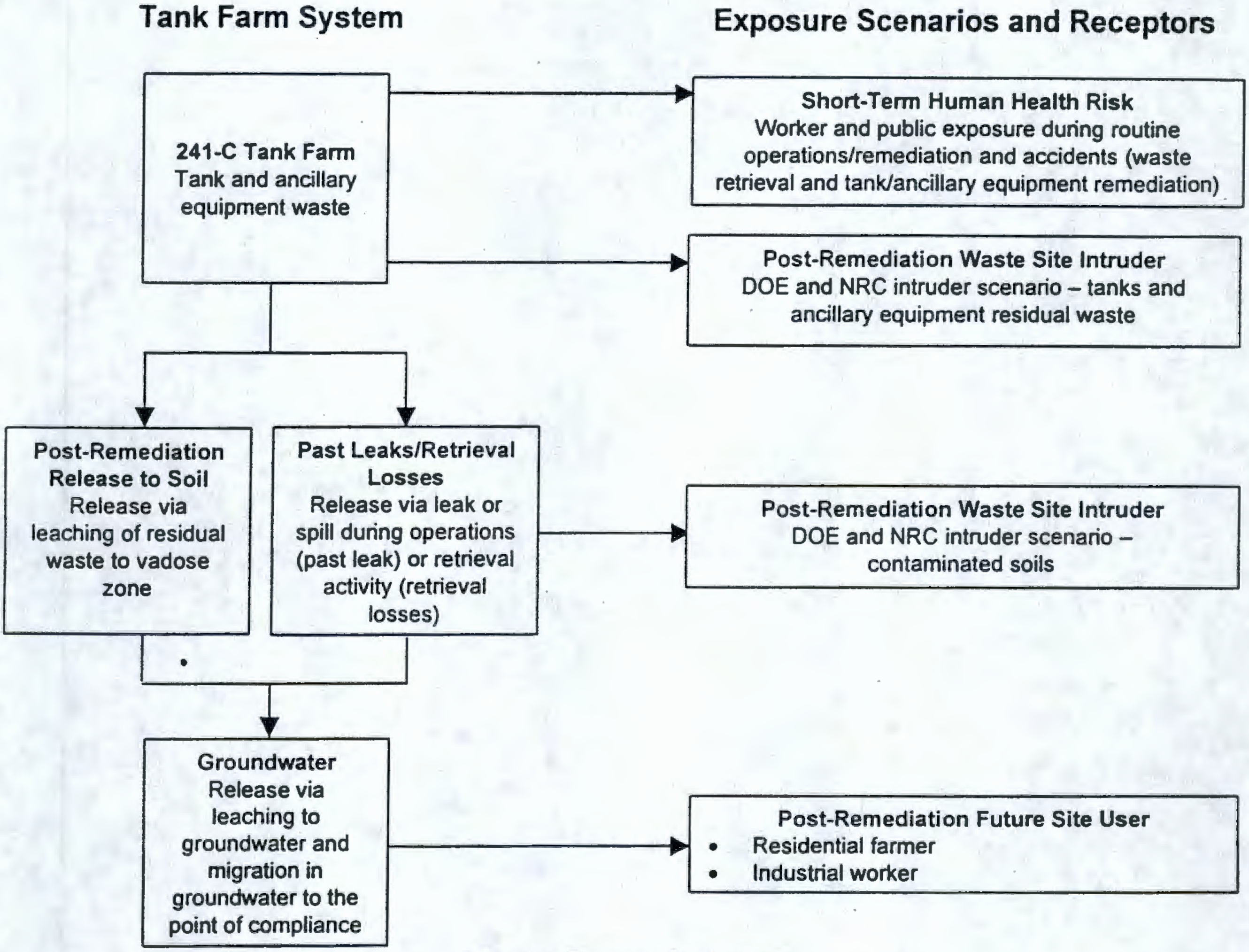


Figure 3.2. Evaluated Waste Sources, Release Mechanisms, Exposure Pathways, and Receptors



Receptor Exposure Pathways

Short-Term Human Health Risk				Long-Term Human Health Risk		Long-Term Human Health Risk Future Site User (Post-Remediation)	
				Waste Site Intruder			
Pathway	Involved Worker	Noninvolved Worker	Public	NRC	DOE	Residential Farmer	Industrial Worker
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, which is addressed in Section 3.7.2.

CoCs = contaminants of concern.
DOE = U.S. Department of Energy.
NA = not applicable.
NRC = U.S. Nuclear Regulatory Commission.

3.1.2 Use of Waste Retrieval Cases

The approach used to evaluate performance measures for tank C-104 and the C tank farm was to identify a number of specific waste retrieval cases that cover a range of retrieval leakage volumes and residual waste volumes for tank C-104 along with a baseline set of assumptions for the remaining C farm tanks. Performance measures for each of the cases have been calculated and these case-specific results used to develop risk versus volume relationships of interest.

Because of the proximity of the C tank farm to the AX tank farm and similarities in the vadose zone properties, a scaling approach was developed for this scoping-level RPE that utilizes contaminant transport modeling results from the AX tank farm to predict results for the C tank farm. This approach provides for evaluation of potential impacts without the commitment of resources required to develop and execute a numerical model for the C tank farm. The technical rationale for the scaling approach is provided in Section 3.5.

3.2 IDENTIFICATION OF WASTE RETRIEVAL CASES FOR ANALYSIS

Nine waste retrieval cases have been identified for this evaluation. Each case has specific values for retrieval leakage volume and residual waste volume for tank C-104 and the remaining C 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 the tank farm, each case involves identification of an assumed end state for tank C-104 and an assumed end state for the remaining C farm tanks. The specific values utilized to develop the cases are not important because the purpose of the analysis is not to select one of the cases for implementation but to evaluate how the performance measures change as the residual and leakage volumes change. It is also 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 retrieval technology demonstration or the Tri-Party Agreement.

The major components considered when identifying cases for evaluation included the extent of waste retrieval and the potential retrieval leak loss that could occur during waste retrieval operations. Because the purpose of this analysis is to focus on near-term retrieval decisions, a number of the tank and tank farm closure elements that were considered in DOE/RL-98-72 were not evaluated in this analysis. A single baseline closure scenario is assumed for each of the waste retrieval cases.

The approach used to develop waste retrieval strategies resulting in volume retrieved and retrieval leak loss assumptions is based on the fiscal year 2000 *Preliminary Engineering Report for the 241-C-104 Retrieval System* (RPP-6843), and the experience gained in retrieving waste from tank C-106 in fiscal year 2000. A process was used to narrow the number of combinations to retrieval cases that accomplish the following:

- Represent a range of potential residual waste volumes and retrieval leakage volumes
- Be responsive to current waste retrieval goals
- Support analysis required to evaluate case-specific performance measures with applicable laws and regulations.

Nine waste retrieval cases have been defined, as shown in Table 3.1. The principle variables are volume of waste retrieved (presented as residual waste volume) and retrieval leak loss. One case also includes construction of an interim barrier to evaluate how retrieval leakage impacts are affected by an interim barrier during waste retrieval operations.

Table 3.1. Summary of Waste Retrieval Cases

Case Number	Residual Waste Volume Remaining Following Retrieval[a]			Retrieval Leak Loss			Interim Barrier
	Tank 241-C-104 (gal)	Remaining 100-Series Tanks[b] (gal)	200-Series Tanks[c] (gal)	Tank 241-C-104[c] (gal)	Remaining 100-Series Tanks (gal)	200-Series Tanks (gal)	
1	2,700	2,700	220	8,000	8,000	800	N
2	6,000	6,000	600	8,000	8,000	800	N
3	2,700	2,700	220	0	0	0	N
4	2,700	2,700	220	0	8,000	800	N
5	2,700	2,700	220	40,000	8,000	800	N
6	2,700	2,700	220	80,000	8,000	800	N
7	27,000	2,700	220	8,000	8,000	800	N
8	50,000	2,700	220	8,000	8,000	800	N
9	2,700	2,700	220	8,000	8,000	800	Y

[a]2,700 gal represents the Tri-Party Agreement interim retrieval goal of 360 ft^3 for the 100-series single-shell tanks.

[b]Except tank C-106 (to provide a conservative estimate of long-term human health risk for the tank farm it is assumed that no additional retrieval from tank C-106 will be conducted; therefore, no retrieval leak loss from tank C-106).

[c]220 gal represents the Tri-Party Agreement interim retrieval goal of 30 ft^3 for the 200-series single-shell tanks.

To obtain liters multiply gallons by 3.785.

Tri-Party Agreement = *Hanford Federal Facility Agreement and Consent Order.*

The waste retrieval demonstration for tank C-104 is intended to demonstrate the capability of a retrieval technology to remove waste from the tank. It is anticipated that the effectiveness or efficiency of the retrieval system will drop off as the amount of waste remaining in the tanks decreases. The practical limit for when the retrieval system has reached the limit of the technology will be defined in the Tri-Party Agreement F&R document. Tri-Party Agreement Milestone M-45-03F establishes a waste retrieval goal of 89 kg of total plutonium and 99% by tank content volume.

A number of conservative assumptions were made in developing the nine waste retrieval cases. This conservative approach results in providing a reasonable upper bound tank on the potential impacts. For example the smallest residual waste volume assumed for tank C-104 is based on the Tri-Party Agreement interim retrieval goal of 360 ft^3 (10,000 L [2,700 gal]). Cases with smaller residual volumes for tank C-104 are not evaluated because for long-term human health risk analysis there is a small span between the Tri-Party Agreement interim retrieval goal and no residual waste representative of 100% retrieval relative to the other residual waste volumes evaluated. For short-term human health risk analysis there is considerable uncertainty in estimating the operations time required to demonstrate the limit of retrieval technology.

Conservative assumptions (i.e., assumptions that result in higher risks or impacts) were also made for the remaining tank farm elements so as not to underestimate the long-term human health risk contribution from the remaining C farm tanks. The assumptions made for the remaining C 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 tank farm. It was assumed that no additional waste would be retrieved from tank C-106. The long-term performance of tank C-106 and the tradeoffs associated with additional waste retrieval from that tank will be evaluated separately. For all but one of the cases it is conservatively assumed that each of the tanks would leak during waste retrieval. No retrieval leakage would be expected from a sound tank.

3.3 SOURCE TERM INVENTORY ESTIMATES

Three discrete source terms are addressed in this evaluation: past leaks, retrieval leakage, and residual waste. The nine waste retrieval cases evaluated are similar to those evaluated in DOE/RL-98-72 and include a single best-basis past leak release case and multiple retrieval leakage and residual waste release cases. A common closure end state is assumed for all cases (i.e., tank stabilization and enhanced *Resource Conservation and Recovery Act of 1976* [RCRA] Subtitle C cap). Multiple release cases are not of interest for the past leak source term because the long-term human health risk from the C tank farm past leaks will not be affected by the tank C-104 waste retrieval system performance. In contrast, multiple release cases are of interest for the retrieval leakage and residual waste source terms because these 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 a tank farm and not an individual tank, tank C-104 impacts need to be understood within the context of the C tank farm. Source inventories are therefore developed for all tanks in the C tank 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.

Evaluation of waste retrieval cases for the C tank farm requires the development of case-specific source terms. Source terms address different methods of release of contaminants from the engineered system (e.g., tanks) to the accessible environment. Developing source terms involves defining the contaminant inventory and evaluating potential release mechanisms. Identification and quantification of source terms are necessary to evaluate the short-term impacts to human health during routine remediation activities and accidents and the long-term impacts resulting from releases during and after remediation.

Potential inventory release mechanisms from underground storage tanks are identified in DOE/RL-98-72. The release mechanisms identified constitute the three source terms also used in this document. This section focuses on developing the C tank farm inventory data used to evaluate waste retrieval operations and their effects on short- and long-term human health risks. Inventory estimates were developed for each of the major long-term human health risk source term components. Source terms for short-term human health risk and accident analysis are strategy-specific and are based on the chemical and radiological inventory present in the tanks and equipment being analyzed. The waste retrieval technology evaluated in support of this RPE includes routine air emissions estimates that were used as short-term human health risk source terms.

Source terms of concern for assessing long-term human health risk include past leaks, residual waste remaining after retrieval, and potential waste retrieval leakage. Strategy-specific source term inventory estimates have been developed for these three components and are discussed in the following sections. These three source terms are evaluated in the analysis because they have the potential to impact the groundwater and reach potential receptors within the 10,000-year period of interest. Both residual waste and retrieval leak loss inventories are developed based on assumed events and future conditions during and after waste retrieval operations.

The source terms associated with each component of the waste retrieval cases include the following.

- **Past leaks** – All cases consider vadose zone contamination from past leaks. Past leaks are included in the analysis to allow for the potential contribution of past leak impacts to the impacts from retrieval leakage.

- **Retrieval leakage** – Potential retrieval leakage volumes evaluated include 0; 30,000; 150,000; and 300,000 L (0; 8,000; 40,000; and 80,000 gal) for tank C-104 to cover a range of potential retrieval leakage. Because the long-term impacts from retrieval leakage will also be evaluated within the context of the tank farm, retrieval leakage volumes of 0 and 30,000 L (0 and 8,000 gal) were identified for the remaining 100-series tanks. Retrieval leakage volumes for the 200-series SSTs were scaled based on tank size.

- **Residual waste** – Post-retrieval residual waste volumes of 10,000; 23,000; 100,000; and 190,000 L (2,700; 6,000; 27,000; and 50,000 gal) were identified for tank C-104 to represent retrieval performance that was equal to and less than the Tri-Party Agreement interim retrieval goal of 360 ft^3. Because the long-term impacts from tank residuals are evaluated within the context of the tank farm residual waste volumes of 10,000 L (2,700 gal) were assumed for the remaining 100-series tanks in all cases except one where a residual volume of 23,000 L (6,000 gal) was assumed to represent less-than-optimum retrieval across the tank farm.

3.3.1 Past Tank Leak Estimates

Seven of the C farm tanks (C-101, C-110, C-111, C-201, C-202, C-203, and C-204) are classified as assumed leakers (HNF-EP-0182-150). Best-estimate radiological and chemical inventories were developed for past tank leaks based on available process information regarding the type of waste that was stored in the tank or that was transferred at the time the leaks were believed to have occurred (LA-UR-00-4050). The tank waste releases were estimated based on location, timing, and leak volume information from HNF-EP-0182-150. The leak compositions were defined using Hanford defined waste model waste streams (LA-UR-96-3860) and the supernate mixing model subroutine as a function of time (LA-UR-00-4050). The past leak source term inventory estimates are provided in the Appendix of this document.

3.3.2 Retrieval Leak Loss Estimates

It is assumed that the C farm tanks will be retrieved using supernate from a number of double-shell tanks (DSTs) (Appendix). Because there are presently no specific plans for which DSTs will be used to provide supernate for waste retrieval from a given C farm tank, the available supernate was modeled as a composite of supernate from potential DSTs. This composite supernate is then assumed to have the same wash factor properties as water (for conservatism) and final chemical concentrations are calculated for retrieval liquid in each C farm tank. These final chemical concentrations are used to estimate chemical constituent releases due to retrieval leaks. Inventory estimates associated with a retrieval leakage volume of 30,000 L (8,000 gal) are developed for the 100-series tanks (except tank C-106). For tank C-104, retrieval leak loss inventory estimates using volumes of 150,000 L (40,000 gal) and 300,000 L (80,000 gal) also are developed. To account for the significantly smaller tank volume of the 200-series tanks, the 30,000-L (8,000-gal) leak loss volume used for the 100-series tanks is scaled by the ratio of the 200-series tank volume to the 100-series tank volume, or one-tenth. Therefore, the 200-series tanks are analyzed using a leak loss volume of 3,000 L (800 gal).

The assumption that all of the C farm tanks will be retrieved using DST supernate is bounding in that it provides for a higher retrieval leakage source-term even though it is unlikely that DST supernate would be used on any of the seven tanks that are assumed leakers. A sensitivity case is evaluated to determine how retrieval source terms vary if the tanks designated as leakers are retrieved using water. The liquid used for waste retrieval will be evaluated on a tank-by-tank basis.

The estimated retrieval leakage volumes are based on meeting limiting conditions for waste retrieval. The limiting conditions considered are a maximum supernate concentration of 5 molar sodium and a maximum value of 10 wt% solids in the retrieved waste. These limits are established to minimize the possible crystallization of sodium-rich salts in the waste transfer lines and to minimize problems transferring slurries. Further discussion of how retrieval liquid concentrations are estimated and how the retrieval leakage source term inventory estimates are used is provided in the Appendix of this document.

3.3.3 Residual Tank Waste Estimates

The chemical and radiological inventories associated with various residual waste volumes have been evaluated for the C farm tanks. Residual tank waste solids volumes evaluated range from 10,000 to 100,000 L (2,700 to 27,000 gal) for the 100-series tanks and 830 L (220 gal) to 2,300 L (600 gal) for the 200-series tanks. These tank residual waste volumes are selected to represent retrieval performances equal to or worse relative to the Tri-Party Agreement interim retrieval goal of 360 ft^3 (10,000 L [2,700 gal]) for 100-series tanks and 30 ft^3 (830 L [220 gal]) for 200-series tanks. An optimal retrieval case was not evaluated because DOE/RL-98-72 shows that residual waste volumes of less than 360 ft^3 correspond to a large uncertainty in measuring such a small volume of waste and results in only a small reduction in long-term human health risk.

The starting point for calculating the residual waste inventory in the C farm tanks is the best-basis inventory estimates developed for each tank (BBI 2000). Some of these estimates are derived from tank waste samples while others depend on tank composition models as described in LA-UR-96-3860. Modeling data, through the use of standard templates, are used to describe the composition of waste types in tanks where samples have not been taken. The Hanford defined waste model (LA-UR-96-3860) is used to supply missing analytical values or to define the expected composition of missing analytes in these templates.

The best-basis inventory is normally defined in total kilograms for chemicals and total curies for radionuclides. To calculate the residual waste inventories in the C farm tanks (except tank C-106) it is assumed that the tank waste will be retrieved using DST supernate as the retrieval medium with, in the case of a 360-ft^3 retrieval heel, a final water rinse. The final water rinse would transport any soluble species in the waste to the DST receiver tank, leaving water-washed solids to comprise the residual waste in each tank. This method for determining residual waste inventories is chosen because it relies on the same data currently being used in the Hanford Tank Waste Operation Simulator model to simulate all of the tank farm waste retrieval operations from waste retrieval to previtrification separations to glass production.

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 retrieval cases for the C tank farms. 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 retrieval activities.

All waste retrieval cases assume a common closure configuration for the tank farm. Because the short-term human health risk associated with closure activities would be common to all the retrieval cases it would not be a good differentiator and is therefore not included in this evaluation.

Retrieval losses are assumed to occur at or near the base of the tank. It is not anticipated that the subsurface leaks at the base of the tank would result in an atmospheric release (in the short-term) nor would the ionizing radiation have an appreciable health risk to workers. For this reason the short-term human health risk from various retrieval loss scenarios is not included in this evaluation.

3.4.1 Occupational Injuries, Illnesses, and Fatalities

The number of injuries, illnesses, and fatalities resulting from retrieval activities is calculated based on the most currently available incidence rates that would be applicable to the 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.

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 the accident occurring also is evaluated. The methodology used to identify and quantify the radiological risk from accidents involves the following steps.

Step 1. Accident identification. Potential hazards associated with retrieval activities are identified from existing preliminary hazards analyses and other safety documents. The hazards are 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 is 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 include damage ratios, airborne release fractions, airborne release rates, leak path factors, and respirable fractions. Use of the reduction factors is dependent on 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. 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 meteorology tower in the 200 West Area. 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 is included for the general public receptor dose, as indicated in Figure 3.2.

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 in the workplace 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 material has spread instantaneously and uniformly. A crew of 10 people is assumed exposed. 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 that have been designated as part of the Hanford Reach National Monument (65 FR 7319). These 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 along with the appropriate atmospheric dispersion coefficient and the source term to determine the radiological dose to the 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 in *1990 Recommendation of the International Commission on Radiological Protection* (ICRP 1991).

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 (Dentler 1995). The emergency response planning guidelines, 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. Cumulative hazards or the acute hazard index for toxic and corrosive/irritant chemical classes are evaluated.

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

3.4.4 Radiological Latent Cancer Fatality 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 various tasks. Noninvolved worker and general public exposures are estimated by determining the expected routine radiological releases during retrieval and closure. Noninvolved worker exposure is assumed to be from inhalation and external radiation from the plume continuously throughout a 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 receptors are in the same location and the same population size as defined for radiological accidents in Section 3.4.3.

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

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.

3.5 GROUNDWATER IMPACTS

Groundwater impacts estimated for the C tank farm are scaled from the DOE/RL-98-72 analyses in which a large number of waste retrieval and residual waste scenarios are considered. A subset of those scenarios is used for this evaluation. Key to this approach is the enabling assumption that vadose zone conditions at the AX tank farm are sufficiently similar to those at the C tank farm to allow for scaling of the AX tank farm groundwater impact assessment results to the C tank farm. A comparison of the vadose conditions at the AX and C tank farms is provided in *Enabling Assumptions and Calculations to Support the Tank C-104 Retrieval Performance Evaluation* (HNF-7989).

It is recognized that this scaling approach introduces an added degree of uncertainty; however, this added uncertainty is acceptable for this scoping-level RPE because additional analysis will be performed in the future following tank waste retrieval and prior to tank farm closure.

Scaling groundwater concentrations from the DOE/RL-98-72 analysis to the C tank farm is expected to be conservative (i.e., over-predict contaminant concentrations at the C tank farm). The AX tank farm comprises 4 tanks while the C tank farm comprises 12 large tanks and 4 small tanks. The two-dimensional contaminant transport model developed for the AX tank farm vadose zone comprises two half tanks and the residual waste inventory is aggregated into these two half tanks. Because of the areal differences, scaling from the AX tank farm analysis to the C tank farm produces conservative contaminant concentrations in the groundwater. Additionally, because of the size of the C tank farm, one would not expect a receptor located at any point along the tank farm boundary to be in a position to intercept contaminant plumes from all tanks at the same time. See HNF-7989 for details related to the scaling approach used for estimating groundwater impacts.

As described in Section 3.5 of DOE/RL-98-72, the approach to assessing the groundwater impacts for releases from the AX tank farm began with developing vadose zone and saturated zone conceptual models and associated assumptions based on best available data and analysis. The next step, using these conceptual models as a basis, was to determine uncertainty and most sensitive parameters for the complete pathway beginning with the source and ending with the calculated risk. This focused near-term data collection efforts and numeric model development. Based on the best available data, information learned from model application in the SX tank farm and screening-level analysis numeric models for the AX tank farm, vadose zone and groundwater models were developed. After this step, the migration of contaminants through the vadose zone and groundwater were calculated for the various strategies and options. This approach was intended to be iterative such that analysis would be updated when additional data become available, and these in turn would be used to focus the subsequent data collection efforts on the most important data.

Individual calculations (i.e., numerical model simulations) were performed for the following contaminant source terms:

- Contamination already released to the vadose zone from past tank leaks and spills
- Future waste retrieval leakage releases
- Tank and ancillary equipment waste residual releases.

The calculated contaminant flux through the vadose zone from each of these sources was used as input to a sitewide two-dimensional groundwater flow model that calculated the contaminant concentrations in the unconfined aquifer at selected time periods over a 10,000-year period. The fact that the groundwater impacts from each of the three AX tank farm source terms were calculated separately enables the re-postprocessing of the AX tank farm results for the specific contaminant inventory scenarios associated with the C tank farm.

The PORFLOW numerical model (NUREG/CR-5991) was used to implement the calculation of flow and transport in the vadose zone and saturated zone (i.e., the unconfined aquifer or groundwater). PORFLOW numerically solves a variable set of equations for general transport, multi-phase pressure, and one or more chemical species. The governing equations are supplemented by constitutive equations, phase-change relations, equations of state, and initial and boundary conditions. Numerical implementation of the vadose zone flow and transport portion of the problem was based on the vadose zone conceptual model specifically developed for conditions known or assumed for the AX tank farm.

The saturated zone (groundwater) conceptual model is a working model describing the horizontal flow and transport of contaminants from the point where they reach the unconfined aquifer immediately below the AX tank farm to where they reach a receptor or are discharged to the Columbia River. The conceptual groundwater model used for the AX tank farm impact assessment was modified from *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (PNNL-11800). PNNL-11800 uses a three-dimensional transient flow and transient transport model for groundwater flow and transport (PNL-10886, PNNL-11665, PNNL-11801). In general, the hydraulic and transport parameters adopted for the AX tank farm groundwater model can be traced back to the site groundwater model used in PNNL-11800, although implementation is significantly different. The large number of strategies that required analyses coupled with a long-term period of interest (10,000 years) necessitated an approach that was computationally efficient yet provided the appropriate level of detail.

Numerical implementation and testing of both the AX tank farm vadose zone and groundwater model are provided in Appendix B of DOE/RL-98-72.

3.6 LONG-TERM HUMAN HEALTH RISK

The intent of the long-term human health risk analysis is to estimate the potential 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. The analysis identifies the peak risks at the tank farm boundary under residential farmer and industrial worker scenarios. Peak risks at the tank farm boundary from hazardous chemicals are also evaluated using the state of Washington "Model Toxics Control Act" (MTCA) Method B and C scenarios. The approach for this risk assessment is consistent with the overall RPE approach established in DOE/RL-98-72.

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.

The DOE/RL-98-72 analysis uses a contaminant transport analysis to predict the distribution of tank waste contaminants in time and space over the post-remediation period of interest. For this evaluation, groundwater contaminant concentrations are estimated by scaling from the results of the DOE/RL-98-72 analysis. It is recognized that long-term human health risk values calculated based on scaled groundwater concentrations contain an added level of uncertainty. Despite this uncertainty, a scaling approach is considered appropriate for this evaluation given that there are no new vadose zone characterization data available to support detailed contaminant transport modeling and the waste retrieval performance of the remaining C farm tanks is uncertain. The approach presented in this section is intended only to support decisions related to waste retrieval from tank C-104. It is anticipated that final closure decisions for tank C-104 and the C tank farm as a whole will require more rigorous evaluation, including numerical modeling of contaminant fate and transport.

3.6.1 Contaminants of Concern

The CoCs considered in this evaluation are largely consistent with those used in DOE/RL-98-72. Those CoCs are as follows.

- **Radionuclides**: carbon-14, selenium-79, technetium-99, iodine-129, and uranium isotopes -233, -234, -235, -236, and -238.

- **Chemicals**: nitrite, nitrate, chromium, and total 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. Inventory estimates could not be developed for cyanide and ethylenediaminetetraacetic acid

(EDTA) because cyanide and EDTA are not routinely analyzed for and are not part of the best-basis inventory standard list of constituents (BBI 2000). EDTA is present in the estimated past leak inventory for several C farm tanks; however, no scaling factor could be developed for EDTA in the past leak source term because EDTA was not present in the past leak inventory for AX tank farm. Additionally, chromium has been identified as a CoC in the RCRA facility investigation/corrective measures study process and is included as a CoC in this analysis. The chemical CoCs for this evaluation therefore consist of nitrite, nitrate, and chromium.

3.6.2 Scaling Factors

Scaling factors for this RPE are calculated as the ratio of contaminant-specific groundwater concentration to initial source inventory.

$$K^i_{S(x,y,t)} = \frac{C^i_{S(x,y,t)}}{I^i_{S(AX)}} \qquad \text{Eq. 1}$$

Where:

$K^i_{S(x,y,t)}$ = scaling factor for contaminant *i* released from source term *S*

$C^i_{S(x,y,t)}$ = groundwater concentration of contaminant *i* from source term *S* (DOE/RL-98-72 model output)

$I^i_{S(AX)}$ = initial source inventory of contaminant *i* released from source term *S* (DOE/RL-98-72 model input).

Receptor groundwater concentrations for this RPE are calculated as the product of the contaminant-specific scaling factors and the C tank farm source inventories. The DOE/RL-98-72 groundwater concentrations used to derive the scaling factors are taken at the AX tank farm boundary at the time of peak human health risk over the 10,000-year analysis period. Risks calculated with these scaling factors are therefore assumed to provide peak risks at the C tank farm boundary.

The DOE/RL-98-72 analysis evaluates one release scenario for past leaks and multiple release scenarios (i.e., variations in release volume) for retrieval leakage and residual waste. The latter scenarios comprise retrieval leakage volumes of 30,000 L (8,000 gal) and 150,000 L (40,000 gal) per tank; and residual waste volumes of 1,020; 10,200; and 102,000 L (270; 2,700; and 27,000 gal) per tank. Each DOE/RL-98-72 release scenario provides the basis for generating a set of contaminant-specific scaling factors (six sets in all) for use in this evaluation.

To support the development of tank C-104 risk-based retrieval performance criteria, this evaluation considers nine retrieval leakage and residual waste release cases. Cases equivalent to those scenarios analyzed in DOE/RL-98-72 are evaluated, plus additional release cases as needed to bracket the risk-based regulatory action thresholds (e.g., the 1×10^{-4} federal and 1×10^{-5} state criteria for excess lifetime cancer risk). The corresponding scaling factor from DOE/RL-98-72 is used for C tank farm retrieval leakage volumes of 30,000 L (8,000 gal) and 150,000 L

(40,000 gal) per tank; and for residual waste volumes of 830; 10,000; and 100,000 L (220; 2,700; and 27,000 gal) per tank. For C tank farm waste retrieval leakage and residual waste volumes lying between the volumes evaluated in DOE/RL-98-72, the scaling factor values are approximated using a linear approximation (i.e., by assuming scaling factors vary linearly with volume).

For retrieval leakage and residual waste volumes that are outside of the range evaluated in DOE/RL-98-72, scaling factors are approximated by assuming that the linear relationship between scaling factor and volume (i.e., line slope) remains the same outside the range as inside. Discussion of the calculations used for scaling factors and tables showing scaling factors for past leak, retrieval leak loss, and residual waste source terms are provided in HNF-7989.

3.6.3 Exposure

The principal long-term human health risk receptor scenarios used for this evaluation are taken from the 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.

3.6.3.1 Residential Farmer Scenario. 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 animals, vegetables, 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.

3.6.3.2 Industrial Worker Scenario. 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 8 hours). The scenario is intended to represent nonremediation workers assumed to wear no protective clothing.

Analysis of MTCA Method B and Method C exposure scenarios (WAC 173-340-720) is also included to allow for comparison to risks being assessed for past tank leaks and releases at SST

waste management areas under the RCRA corrective action process (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 C tank farm boundary and used as a water supply for the receptors.

3.6.4 Risk

Long-term human health risk is calculated for this evaluation using a unit risk factor (URF) approach consistent with the approach used for the *Tank Waste Remediation System Hanford Site, Richland, Washington, Final Environmental Impact Statement* (DOE/EIS-0189) and DOE/RL-98-72 analyses. An 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. As previously discussed, the exposure medium of interest for this evaluation is groundwater and the contaminant concentration values used are scaled from the results of the DOE/RL-98-72 analysis. The URF values used for this analysis are contaminant- and scenario-specific groundwater URFs taken from Appendix D of DOE/EIS-0189. The human health impact measures given by the URFs are incremental lifetime cancer risk (ILCR) for radionuclides and carcinogenic chemicals, and hazard index for noncarcinogenic chemicals.

Calculation detail for long-term human health risk is in HNF-7989. The long-term human health risk calculation results are used to develop risk-versus-volume relationships. Risk-based retrieval performance criteria (i.e., retrieval leakage limits and extent of retrieval requirements) are developed by plotting the human health risk values calculated for the retrieval cases 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 for tank C-104 are of interest because they provide the primary basis for determining retrieval performance criteria for tank C-104. Plots using risk and volume data for the entire C tank farm are also of interest because they provide a sense of how quickly the C 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 C-104 composite risk to maintain compliance with certain risk-based regulatory standards.

3.7 INTRUDER RISK

The intent of the inadvertent human intrusion analysis is to estimate the potential health effects to a hypothetical future site user from exposure to tank waste contaminants remaining onsite following waste retrieval and tank farm closure actions. The inadvertent human intruder is assumed to excavate into or drill through the contamination within the tank farm.
The methodology used for assessing intruder impacts is consistent with the approach used in

DOE/RL-98-72. Because a well is only a few inches in diameter and can only penetrate one tank at a time, the intruder analysis addresses tank C-104 impacts only. The purpose of the intruder assessment is to support an analysis of compliance requirements and waste classification issues related to tank C-104 waste retrieval and closure. Intruder impacts 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.

3.7.1 U.S. Department of Energy Intruder Scenario

The DOE demonstrates protection of the inadvertent human intruder through site-specific performance assessments using a 100-mrem/yr chronic dose standard and a 500-mrem acute dose standard. 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). The scenarios used are the well driller scenario and the post-drilling resident scenario. These scenarios were selected based on their applicability to the deep contamination sources (i.e., tank residual waste and soil contaminated by retrieval leak loss) involved in this analysis.

Table 3.2 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.

Table 3.2. Intruder Scenario Unit Dose Factors at 100 Years from 1998

Radionuclide	Dose Factor (mrem per curies exhumed)	
	Well Driller	Post-Drilling Resident
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

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 intruders receive radiation exposures because of their proximity to and use of these contaminated surface areas. The analysis considers radionuclide contaminants only. 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.

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 C-104 and into the underlying soil column down to the aquifer. The source is calculated based on the residual waste in tank C-104 and the contaminated soil from retrieval leakage. The source (Ci_{exh}) from tank C-104 is calculated using the following equation:

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

Where:

Ci_{tnk} = total activity of each radionuclide of concern in tank C-104
r_{well} = radius of the well or 0.15 m (0.5 ft)
r_{tnk} = radius of tank C-104 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 postdrilling 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 the 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 different 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 and the total ingestion is 445 mg/yr (0.02 oz/yr). The post-drilling resident inhales radionuclides suspended in the air by gardening activity and wind for 4,380 hours a year and is exposed externally to the contaminated soil while working in the garden or residing in the house built on top of the disposal site for 3,260 hours a year.

3.7.2 U.S. Nuclear Regulatory Commission Intruder Scenario

The NRC intruder scenario is considered in this analysis because of its implications to tank farm closure; closure options may be bounded by concentration of radionuclides in residual waste volumes remaining after retrieval. The NRC intruder scenario is described in "Licensing Requirements for Land Disposal of Radioactive Waste" (10 CFR 61). It is applied in this analysis not in terms of determining risk to the intruder but because it led to the derivation of a classification system for waste based on maximum concentration levels of radionuclides. Meeting Class C limits is a criterion in determination of incidental waste, which can be handled as LLW as described in Section 3.8.1.1. Therefore, in this RPE the concentration of radionuclides in the tank C-104 residual waste will be compared to the Class C limits derived through the NRC intruder scenario shown in Table 3.3.

Table 3.3. 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.

Class C waste concentration limits were derived based on calculated doses to inadvertent intruders, assuming intrusion occurred at 500 years after waste disposal. The intruder is assumed to contact the disposed waste while performing typical excavation work such as installing utilities, putting in basements, etc. Two scenarios were considered in developing the Class C limits: intruder-construction scenario and intruder-agriculture scenario. Class C limits are the waste concentrations that would deliver either a 500-mrem dose to the whole body or bone, or a 1,500-mrem dose to other organs under an intruder-construction or intruder-agriculture scenario (HNF-3428).

The Savannah River Site recently closed two tanks that had been used to store mixed HLW. As part of the closure process, the unretrievable waste was stabilized in grout through a process described in *Summary of Communication with DOE Tank Sites on Tank Closure Issues* (Shyr and Bustard 1997) in accordance with *Branch Technical Position on Concentration Averaging and Encapsulation* (NRC 1995). In a December 1999 draft letter response from NRC to DOE Savannah River Site, the following statements were made with respect to conformance with criterion two of the incidental waste criteria (Paperiello 1999):

> Staff believes that concentration averaging in accordance with the Branch Technical Position on Concentration Averaging, is generally acceptable in this context to meet Class C concentration limits, and recognizes that the alternative provisions for waste classification proposed by DOE are generally similar to those in 10 CFR 61.58. The NRC proposes that the alternative provision for waste reclassification meet the following concentration limits. No radionuclide concentration shall exceed ten times the value specified in Table 1 of 10 CFR 61.55, at 500 years following the

proposed Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) 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 the fractions for all Table 1 radionuclides shall not exceed ten, and the sum of the fractions for all Table 2 radionuclides shall not exceed one.

The formulae for uniformly mixing grout with residual waste to yield concentrations that do not exceed Class C limits developed at the Savannah River Site may be applied to the residual waste in tank C-104, based on the results of other analyses in this evaluation.

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. Ecology is authorized to implement HWMA requirements in lieu of federal program requirements pursuant to RCRA. EPA retains the federal 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, analysis, 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, and tanks and ancillary equipment are described in Section 3.8.1. Regulatory compliance of the tank C-104 waste retrieval approach is addressed in Section 3.8.2.

3.8.1 Relevant Regulations and Requirements

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

3.8.1.1 Federal Statutes and Regulations. Table 3.4 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.

Table 3.4. 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*.

The following paragraphs summarize the federal statutes and regulations that affect tank waste retrieval and closure and are largely excerpted from HNF-3428. Three federal entities have the majority of regulatory authority for the disposal of radioactive waste: EPA, DOE, and NRC. Each of these entities 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 of or the waste has already been released to the environment, (e.g., a spill or leak). EPA has the lead role for writing regulations, and DOE and NRC regulations and orders cannot be inconsistent 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 *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.

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 the authority to implement the release standards. Later, Congress granted EPA authority to address the 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 transuranic (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* establishes 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 10 CFR 61 for Class C LLW (i.e., Greater Than Class C [GTCC] LLW). These amendments require the NRC to license the DOE facility for disposal of commercially-generated GTCC LLW.

The 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 (10 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 *Radioactive Waste Management* (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 high-level, 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 those 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 Plant 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 shall be documented to support the determinations. 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 comparable 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 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 the *Hazardous and Solid Waste Amendments of 1984,* the *Federal Facility Compliance Act of 1992*, and the *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 that perform regulated activities. EPA regulations implementing RCRA are found at 40 CFR 260 through 40 CFR 280.

Most, but not all, of the EPA hazardous waste program at the Hanford Site is delegated to the Washington State Department of Ecology (Rosenthal 1997). EPA delegated the RCRA-based program to Ecology in 1986 through the Tri-Party Agreement, with DOE as the third party.

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

3.8.1.2.1 Hazardous Waste Management Act. The HWMA and its implementing regulations in "Dangerous Waste Regulations" (WAC 173-303), implement RCRA in Washington State. The Tri-Party Agreement 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 HWMA Subtitle C TSD units. Because the SSTs were in operation on the effective date of the RCRA regulations, they could continue operations without a final status permit. The SSTs 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). However, because the SSTs will not be used for continued dangerous waste management, the SSTs must undergo closure in lieu of final status permitting (Ecology et al. 1989).

3.8.1.2.2 Tri-Party Agreement Requirements. The Tri-Party Agreement establishes an action plan for cleanup that addresses priority actions, methods for resolving problems, and milestones. The Tri-Party Agreement 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 Tri-Party Agreement establishes the applicability of RCRA and CERCLA and their amendments to the Hanford Site. In 2000 the Tri-Party Agreement was amended to adjust near-term milestones, target dates, and associated language governing SST waste retrieval and 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 Tri-Party Agreement related to managing tank waste and tank farm closure at the Hanford Site.

As described in the Tri-Party Agreement, 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 Hanford Facility RCRA Permit will be amended to indicate that the applicable unit has been closed (DOE/RL-89-16).

Tri-Party Agreement Milestone M-45-00 declares the SSTs unfit-for-use. According to WAC-173-303-604, the SSTs are deemed unfit-for-use tanks based on secondary containment and or inability for tank integrity assessment and 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 close 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 either to obtain from Ecology (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 to be 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 Tri-Party Agreement 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.

Tri-Party Agreement 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 Tri-Party Agreement 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, on updating tank farm closure/post-closure work plans, and maximizing waste storage space in DSTs from waste retrievals in SSTs.

Appendix H of the Tri-Party Agreement 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. The appendix provides for SST demonstration of achievability of waste retrieval goal during tank C-104 tank retrieval demonstrations. 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.

3.8.2 Regulatory Compliance of Waste Retrieval Approach

Tri-Party Agreement Milestone M-45-03F calls for 99% retrieval of tank C-104 contents and retrieval to safe storage of at least 89 kg of plutonium. For the tank C-104 waste retrieval demonstration, the goal will be assessed against two major areas. The first is the achievability of the goal during tank C-104 waste retrieval demonstrations. This will demonstrate retrieval of sludge/hard heel wastes in a tank in the 200 East 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 include 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.

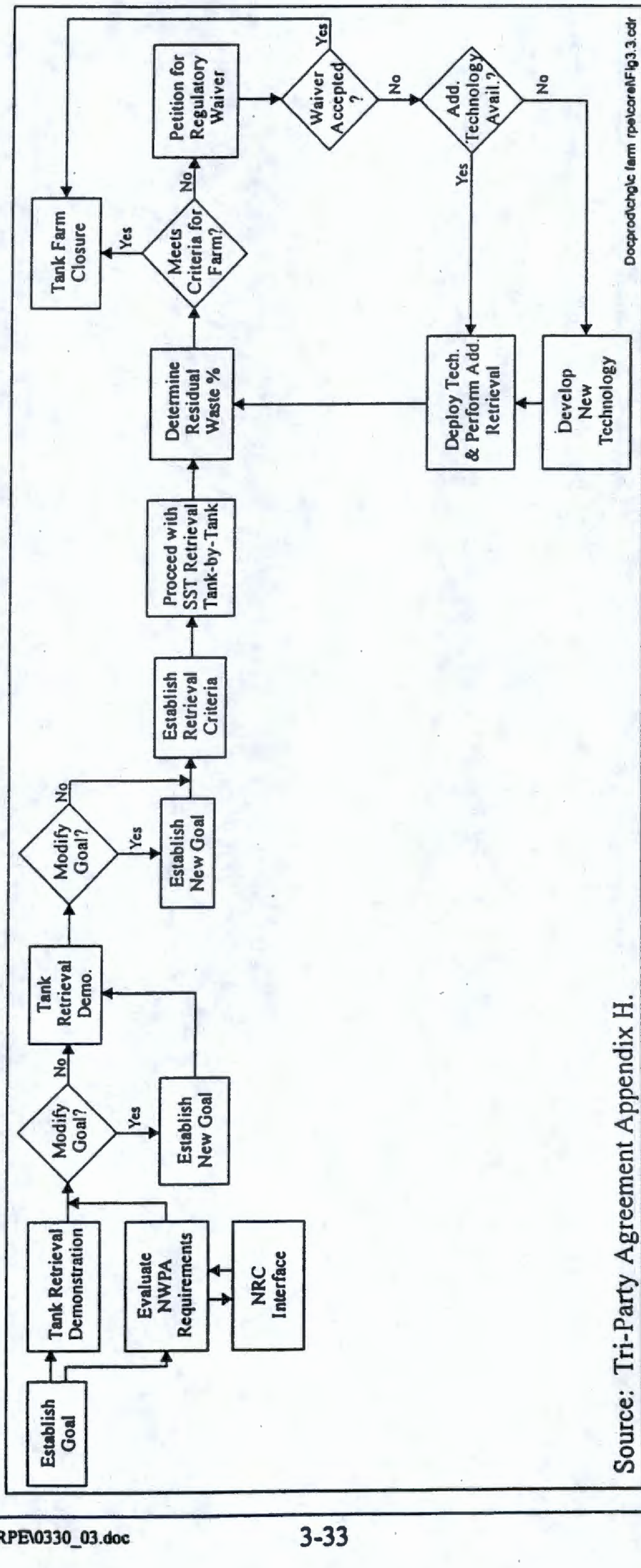
DOE and Ecology will assess the waste retrieval goal and modify the waste retrieval goal to match the most restrictive case (i.e., the highest retrieval percentage requirement).
The tank C-104 waste retrieval demonstration will be performed, and the residual waste inventory will be calculated. DOE and Ecology will then perform an assessment of the waste retrieval goal. Based on the demonstration results the goal may be modified to match the best available technology. The agencies will notify NRC as required for compliance with the *Nuclear Waste Policy Act*. Formal criteria for retrieval of waste from the remaining SSTs will be

established, and closure plans for the C tank farm will be finalized with concurrence from regulatory agencies. Waste will be retrieved from the remaining C farm SSTs. Retrieval activities may occur on a tank-by-tank basis to allow flexibility to retrieve tanks from various 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 Tri-Party Agreement Appendix H, waste residuals will be calculated for each tank following retrieval. Notification to appropriate regulatory authorities will document compliance with criteria. If residuals comply with criteria, final closure operations will proceed. If residuals 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 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. The tank farm will be held in interim status pending completion of the additional 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 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 3.3 provides a generic logic diagram of this process.

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



Source: Tri-Party Agreement Appendix H.

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4.0 DESCRIPTION OF WASTE RETRIEVAL CASES

This section summarizes the intent of the nine waste retrieval cases defined to determine the impacts of different performance levels of waste retrieval operations as they relate to short-term human health risk, impacts to groundwater, long-term human health risk, and inadvertent human intrusion. Section 4.1 outlines the major enabling assumptions associated with creating and evaluating the cases. Section 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 demonstration requirements, but to provide adequate risk-based analysis to support the Tri-Party Agreement requirements for retrieval.

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 C-104, this evaluation need not include a no-action case where the current waste inventory would be left in place. A baseline level of waste retrieval is assumed for all remaining tanks in the C tank farm (i.e., all tanks except tank C-106). This assumption supports an evaluation of the long-term performance of tank C-104 cases combined with the long-term performance of the other C farm tanks.

4.1.1 Waste Retrieval Technology Assumptions

Preliminary engineering for the tank C-104 waste retrieval system was completed in fiscal year 2000 to develop the technical concepts and support the planning basis for Project W-523, as documented in RPP-6843. Three alternative retrieval system configurations were evaluated:

- Sluicing
- Mining with a remotely operated crawler
- Combined sluicing and crawler method.

RPP-6843 provides sufficient detail to move the tank C-104 waste retrieval project into the conceptual design phase. One of the three retrieval system alternatives is assumed to be selected for conceptual design.

RPP-6843 indicates that the projected performance of all three retrieval systems is similar with respect to the estimated residual waste volume remaining following retrieval. All three of the waste retrieval systems evaluated (when properly configured) have the potential to retrieve sufficient waste from tank C-104 to leave a heel of approximately 2,550 L (670 gal). Given this, any of the three systems evaluated could be deployed to meet the residual waste volumes of the waste retrieval cases identified.

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 paragraphs is taken from *Leak Detection, Monitoring, and Mitigation Design Concepts Evaluation Report for Crawler Based Retrieval Technologies* (RPP-7628). 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 the tank C-104 LDMM system including the following.

- Leak detection in-tank methods:
  - Mass balance
  - Volumetric inventory balance (catastrophic leak detection)
  - Volumetric precision (precision 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 resistively, and time domain reflectrometry).

In recent years the ex-tank methods identified have improved and could be used to both detect a leak and quantify the volume of liquid released from a tank. Preliminary testing indicates that those methods are very promising; however, those technologies are not sufficiently mature to deploy in support of tank C-104 waste retrieval on the schedule outlined in the Tri-Party Agreement. The current drywell leak detection system should be used throughout the tank C-104 waste retrieval process as secondary indication capability to the leak detection system chosen for LDMM.

The same technologies used to perform leak detection can 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 waste mining strategy. The criteria used to evaluate which LDMM technology would best work for tank C-104 include 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-7628 the LDMM concept recommended for tank C-104 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.

4.1.3 Tank Stabilization Assumptions

Following waste retrieval, tank C-104 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 as the initial step in stabilizing the tanks in an attempt to encapsulate the tank residuals. 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 the NRC classification of the tank residuals 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, meets NRC Class C LLW criteria.

4.1.4 Ancillary Equipment Assumptions

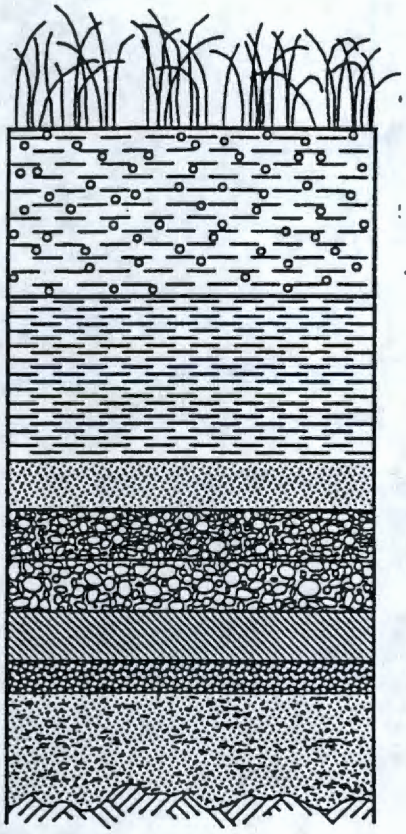
Stabilization of ancillary equipment is assumed to include (1) demolishing and removing all surface buildings and equipment that would interfere with constructing the surface barrier and (2) stabilizing the subsurface equipment with grout to prevent long-term subsidence. Concepts for stabilization of 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 C 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.

4.1.5 Surface Barrier Assumptions

An enhanced RCRA Subtitle C barrier is assumed to be constructed over the C 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). This 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 4.1.

Figure 4.1. Enhanced RCRA Subtitle C Barrier Cross-Section



Adapted from DOE/RL-93-33

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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 nine waste retrieval cases has not been developed because (1) the analysis is focused on retrieval decisions for tank C-104 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 C-104. The presence or absence of a retrieval leak does not affect the project cost. However, a leak may result in a stop to 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.

Incremental cost differences associated with different LDMM systems and the temporary barrier associated with one of the waste retrieval cases will be evaluated to the extent possible. For example, the reduction in long-term human health risk from waste retrieval leakage can be evaluated against the incremental cost of installing a temporary barrier over the C tank farm prior to waste retrieval.

4.2 SUMMARY OF WASTE RETRIEVAL CASE DESCRIPTIONS

All nine waste retrieval cases assume a common endpoint that includes the following parameters.

- Vadose zone contamination from past leaks is not remediated.
- Residual tank waste, ancillary equipment, and vadose zone characterization is conducted to support tank farm closure.
- 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 4.1) is constructed over the tank farm.

The waste retrieval cases are designed to illustrate the effect of different waste retrieval performance levels in tank C-104 as well as for the entire C tank farm. The following summarize the intent of the different cases.

- Case 1 is designed as the baseline waste retrieval case and assumes retrieval from all C farm tanks to the Tri-Party Agreement interim retrieval goal of 360 ft^3, with minimal leak loss from each tank.
- Case 2 is designed to demonstrate the risks associated with retrieving waste from tank C-104 to the same extent as was achieved in the tank C-106 waste retrieval operations.

- Cases 3, 4, 5, and 6 are designed to evaluate the effects of varying amounts of retrieval leak loss from tank C-104.
- Cases 7 and 8 are designed to evaluate the effects of varying the volume of the residual waste heel left in tank C-104 after retrieval.
- Case 9 is designed to illustrate the effects of an interim surface barrier on retrieval leakage.

Table 3.1 provides a summary of the principle variables associated with each case. Specifics of the variables associated with each case are delineated in HNF-7989.

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5.0 ANALYSIS RESULTS

This section describes the results of the impact assessment for the nine waste retrieval cases. The human health risk assessment is presented in Sections 5.1 to 5.4. How well each case complies with applicable federal and state regulations is analyzed in Section 5.5. Two significant number figures are used for presentation of results to show relative differences between the retrieval cases. This is not intended to imply a level of confidence in the results, which are generally order-of-magnitude projections.

5.1 SHORT-TERM HUMAN HEALTH RISK RESULTS

The short-term human health risk analysis supports a comparison of the short-term human health risks associated with variations in waste retrieval and the use of an interim barrier as defined by the nine waste retrieval cases. 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 the waste from tank C-104 using the crawler system (e.g., installation of the crawler system and the support systems) would be the same for all the tank C-104 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 the construction of an interim barrier are calculated for comparison in this analysis. Retrieval leak losses are also excluded from this short-term human health risk analysis because they would 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 Sections 5.2 and 5.3.

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 and construction of an interim barrier. 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 analysis methodology is discussed in Section 3.4.

5.1.1 Occupational Risk Results

The occupational risk in this analysis is 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 occupational risk to the involved workers for each case are presented in Table 5.1. Details of the enabling assumptions, data for analysis, and the analysis calculations are provided in HNF-7989.

Table 5.1. Occupational Risk to Involved Workers

Incident	Labor Requirements (labor-hr)	Incident rate (incident/ labor-hr)	Risk (incident)
Cases 1, 3, 4, 5, and 6			
TRC	6.6E+03	1.9E-05	1.3E-01
LWC	6.6E+03	8.0E-06	5.3E-02
Fatality	6.6E+03	1.4E-08	9.0E-05
Cases 2			
TRC	6.5E+03	1.9E-05	1.3E-01
LWC	6.5E+03	8.0E-06	5.3E-02
Fatality	6.5E+03	1.4E-08	8.9E-05
Case 7			
TRC	6.0E+03	1.9E-05	1.2E-01
LWC	6.0E+03	8.0E-06	4.8E-02
Fatality	6.0E+03	1.4E-08	8.2E-05
Case 8			
TRC	5.4E+03	1.9E-05	1.1E-01
LWC	5.4E+03	8.0E-06	4.4E-02
Fatality	5.4E+03	1.4E-08	7.4E-05
Case 9			
TRC	1.2E+04	1.9E-05	2.3E-01
LWC	1.2E+04	8.0E-06	9.4E-02
Fatality	1.2E+04	1.4E-08	1.6E-04

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

5.1.2 Routine Radiological Risk Results

The unit of measure for routine radiological risk in this analysis is the number of LCFs resulting from radiological exposures from routine daily operations. Exposure to the involved worker would be from ionizing radiation fields in radiation zones. Exposure to the noninvolved worker and general public would be from abated air emissions during routine operations. 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 for each case are presented in Table 5.2. Details of the enabling assumptions, data for analysis, and analysis calculations are provided in HNF-7989.

5.1.3 Routine Chemical Risk Results

The routine chemical risk from waste retrieval operations is toxic health effect measured in exceedance of a 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 parameters of the calculation and the routine ILCR to the involved worker MEI, noninvolved worker MEI, and general public MEI for each case are presented in Table 5.3. The enabling assumptions, data for analysis, and analysis calculations are provided in HNF-7989. The chemical concentrations in the residual waste would be the same for all cases; therefore, the hazard index for all cases would be the same.

5.1.4 Radiological Accident Risk Results

Only operational accidents are evaluated in this RPE. Additional accidents will be evaluated as part of conceptual design. All nine waste retrieval cases assume the same crawler technology for retrieval; therefore, each case is subject to the same type of accidents. Crawler-based retrieval accidents are evaluated in 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 the authorization basis (HNF-SD-WM-SAR-067). The severity of a given accident and the frequency of the accident is common to all nine cases evaluated; 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-7989.

5.1.5 Chemical Accident Risk Results

The same conclusions reached in Section 5.1.4 for radiological accidents also apply to potential chemical accidents. Because all nine waste retrieval cases assume the same crawler 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 are the same for all nine 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.

Table 5.2. Routine Radiological Risk (2 Sheets)

Receptor	Dose (rem)*	Dose-to-Risk Conversion Factor (LCF/rem)*	Risk (LCF)
Cases 1, 3, 4, 5, and 6			
Involved worker MEI	5.0E-01	4.0E-04	2.8E-03
Involved worker population	2.3E+00	4.0E-04	9.2E-04
Noninvolved worker MEI	4.6E-08	4.0E-04	1.8E-11
Noninvolved worker population	2.0E-06	4.0E-04	8.2E-10
General public MEI	1.2E-11	5.0E-04	5.8E-15
General public population	3.3E-07	5.0E-04	1.6E-10
Cases 2			
Involved worker MEI	5.0E-01	4.0E-04	2.8E-03
Involved worker population	2.3E+00	4.0E-04	9.1E-04
Noninvolved worker MEI	4.5E-08	4.0E-04	1.8E-11
Noninvolved worker population	2.0E-06	4.0E-04	8.1E-10
General public MEI	1.2E-11	5.0E-04	5.8E-15
General public population	3.3E-07	5.0E-04	1.6E-10
Case 7			
Involved worker MEI	5.0E-01	4.0E-04	2.8E-03
Involved worker population	2.1E+00	4.0E-04	8.3E-04
Noninvolved worker MEI	4.1E-08	4.0E-04	1.7E-11
Noninvolved worker population	1.9E-06	4.0E-04	7.4E-10
General public MEI	1.1E-11	5.0E-04	5.3E-15
General public population	3.0E-07	5.0E-04	1.5E-10
Case 8			
Involved worker MEI	5.0E-01	4.0E-04	2.8E-03
Involved worker population	1.9E+00	4.0E-04	7.5E-04
Noninvolved worker MEI	3.7E-08	4.0E-04	1.5E-11
Noninvolved worker population	1.7E-06	4.0E-04	6.7E-10
General public MEI	9.6E-12	5.0E-04	4.8E-15
General public population	2.7E-07	5.0E-04	1.4E-10

Table 5.2. Routine Radiological Risk (2 Sheets)

Receptor	Dose (rem)*	Dose-to-Risk Conversion Factor (LCF/rem)*	Risk (LCF)
Case 9			
Involved worker MEI	5.0E-01	4.0E-04	2.8E-03
Involved worker population	6.9E+00	4.0E-04	2.8E-03
Noninvolved worker MEI	4.6E-08	4.0E-04	1.8E-11
Noninvolved worker population	2.0E-06	4.0E-04	8.2E-10
General public MEI	1.2E-11	5.0E-04	5.8E-15
General public population	3.3E-07	5.0E-04	1.6E-10

*Person-rem for population receptors

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

Table 5.3. Routine Chemical Risk to Maximally Exposed Individuals

Receptor	ILCR	Hazard Index
Cases 1, 3, 4, 5, 6, and 9		
Involved worker MEI	5.1E-09	2.3E-01
Noninvolved worker MEI	2.2E-09	1.0E-07
General public MEI	6.6E-13	5.3E-05
Cases 2		
Involved worker MEI	5.1E-09	2.3E-01
Noninvolved worker MEI	2.2E-09	1.0E-07
General public MEI	6.5E-13	5.3E-05
Case 7		
Involved worker MEI	4.7E-09	2.3E-01
Noninvolved worker MEI	2.0E-09	1.0E-07
General public MEI	6.0E-13	5.3E-05
Case 8		
Involved worker MEI	4.2E-09	2.3E-01
Noninvolved worker MEI	1.8E-09	1.0E-07
General public MEI	5.4E-13	5.3E-05

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

5.2 GROUNDWATER IMPACT RESULTS

The deterministic approach taken in DOE/RL-98-72, from which the scaled groundwater impacts have been obtained for this evaluation, is based on reasonably conservative best-estimate parameter values. The data on which the deterministic calculations are based are summarized in Appendix B of DOE/RL-98-72. The enabling assumptions used for this analysis are provided in HNF-7989. The means by which contaminants are transported in the vadose zone and groundwater are the same for all of the waste retrieval cases. The analysis methodology is discussed in Section 3.5.

The estimated impacts to the groundwater system are provided in terms of contaminant concentrations of selected contaminants in each of three mobility groups. Those groups are based on assumed distribution coefficient values developed for DOE/RL-98-72. Group 0 contains the most mobile contaminants, those with an assumed distribution coefficient of zero. Group 1 contains contaminants that are mobile in the near-field (i.e., are assumed to have a distribution coefficient of zero from ground surface to a depth of approximately 36.5 m [120 ft] bgs) and slightly retarded below 36.5 m (120 ft) bgs where the distribution coefficient is assumed to be 0.6 mL/g. Group 2 contains contaminants that are slightly retarded (i.e., the distribution coefficient is assumed to be 0.6 mL/g in all parts of the vadose zone and groundwater system). The selected contaminants are technetium-99 and nitrate for Group 0, iodine-129 for Group 1, and uranium-238 for Group 2. The groundwater impacts from the past leak source term are constant for Cases 1 through 8 because those cases all assume the same recharge history. Case 9 assumes the application of a temporary barrier, resulting in a different recharge history and different maximum contaminant concentrations in groundwater. These impacts are summarized in Table 5.4.

Table 5.4. Maximum Contaminant Concentrations in Groundwater for the Past Leak Source Term at 2,600 Years for the C Tank Farm

Case	Technetium-99[a] (pCi/L)	Nitrate[b] (mg/L)	Iodine-129[c] (pCi/L)	Uranium-238[d] (pCi/L)
1-8	22	1.9E-03	6.4E-04	4.4E-03
9	2	2.4E-03	8.8E-04	4.2E-04

[a]The drinking water standard (40 CFR 141) for technetium-99 is 900 pCi/L.
[b]The drinking water standard (40 CFR 141) for nitrate is 45 mg/L.
[c]The drinking water standard (40 CFR 141) for iodine-129 is 1 pCi/L.
[d]The drinking water standard (40 CFR 141) for uranium-238 is approximately 6.7 pCi/L based on the drinking water standard of 0.02 mg/L for total uranium.

The groundwater impacts resulting from retrieval leakage, residual volume, and the composite of the three source terms (i.e., past leaks, retrieval leakage, and residual volume) for the C tank farm are summarized in Table 5.5 for technetium-99, nitrate, iodine-129, and uranium-238.

5.3 LONG-TERM HUMAN HEALTH RISK RESULTS

This section presents the results of the long-term human health risk assessment. The results are generated using the methodology described in Section 3.6 and the source term inventories discussed in Section 3.3. Tables 5.6 and 5.7 summarize the long-term human health risk analysis results. The tables show results for both tank C-104 and the C tank farm as a whole for each of the nine waste retrieval cases by source term (i.e., past leaks, retrieval leak loss, residual waste, and composite). The results shown are the ILCR and the hazard index calculated for the industrial worker and residential farmer scenarios.

The long-term human health risk can be converted to dose 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. The Washington State Department of Health has issued guidance that the dose limit for release of a site is 15 mrem/year total effective dose equivalent (WDOH/320-015). Using the conversion factor this 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.

Table 5.5. Maximum Contaminant Concentrations in Groundwater for the Retrieval, Residual, and Composite Source Terms for the Nine Cases Considered for the C Tank Farm

Case	Maximum Contaminant Concentration in Groundwater Resulting from Retrieval Leakage at 2,600 years				Maximum Contaminant Concentration in Groundwater Resulting from Residual Waste Remaining in Tanks at 2,600 years				Maximum Contaminant Concentration in Groundwater as a Composite of Past Leaks, Retrieval Leakage, and Residual Volume at 2,600 years			
	Tc^{99} [a] (pCi/L)	Nitrate[b] (mg/L)	I^{129} [c] (pCi/L)	U^{238} [d] (pCi/L)	Tc^{99} [a] (pCi/L)	Nitrate[b] (mg/L)	I^{129} [c] (pCi/L)	U^{238} [d] (pCi/L)	Tc^{99} [a] (pCi/L)	Nitrate[b] (mg/L)	I^{129} [c] (pCi/L)	U^{238} [d] (pCi/L)
1	81	0.11	5.5E-02	1.1E-04	170	20	3.5E-02	9.7E-03	260	20	9.3E-02	1.1E-02
2	81	0.11	5.5E-02	1.1E-04	250	100	0.27	2.1E-02	340	100	0.33	2.2E-02
3	0	0	0	0	170	20	3.5E-02	9.7E-03	180	20	3.8E-02	1.1E-02
4	80	0.11	5.5E-02	1.1E-04	170	20	3.5E-02	9.7E-03	260	20	9.3E-02	1.1E-02
5	84	0.11	5.5E-02	1.2E-04	170	20	3.5E-02	9.7E-03	260	20	9.3E-02	1.1E-02
6	86	0.11	5.5E-02	1.4E-04	170	20	3.5E-02	9.7E-03	260	20	9.3E-02	1.1E-02
7	81	0.11	5.5E-02	1.1E-04	180	23	3.5E-02	2.5E-02	260	23	9.3E-02	2.6E-02
8	81	0.11	5.5E-02	1.1E-04	180	26	3.5E-02	3.9E-02	270	26	9.3E-02	4.0E-02
9	110	0.14	7.3E-02	7.1E-05	2	20	1.3E-03	9.6E-03	130	20	7.7E-02	1.0E-02

[a]The drinking water standard (40 CFR 141) for technetium-99 is 900 pCi/L.
[b]The drinking water standard (40 CFR 141) for nitrate is 45 mg/L.
[c]The drinking water standard (40 CFR 141) for iodine-129 is 1 pCi/L.
[d]The drinking water standard (40 CFR 141) for uranium-238 is approximately 6.7 pCi/L based on the drinking water standard of 0.02 mg/L for total uranium.

Table 5.6. Industrial Worker Long-Term Human Health Risks by Source Term and Case*

Case		Past Leaks (Farm)	Waste Retrieval Leak Loss		Residual Waste		Composite Source Term	
			Tank C-104	C Tank Farm	Tank C-104	C Tank Farm	Tank C-104	C Tank Farm
1	ILCR	2.0E-08	2.5E-08	6.8E-07	4.7E-09	1.7E-06	2.9E-08	2.4E-06
	HI	5.2E-05	4.3E-05	3.1E-03	4.0E-03	4.9E-01	4.0E-03	5.0E-01
2	ILCR	2.0E-08	2.5E-08	6.8E-07	2.2E-08	2.6E-06	4.7E-08	3.3E-06
	HI	5.2E-05	4.3E-05	3.1E-03	1.8E-02	2.6E+00	1.8E-02	2.6E+00
3	ILCR	2.0E-08	0.0E+00	0.0E+00	4.7E-09	1.7E-06	4.7E-09	1.7E-06
	HI	5.2E-05	0.0E+00	0.0E+00	4.0E-03	4.9E-01	4.0E-03	4.9E-01
4	ILCR	2.0E-08	0.0E+00	6.6E-07	4.7E-09	1.7E-06	4.7E-09	2.4E-06
	HI	5.2E-05	0.0E+00	3.1E-03	4.0E-03	4.9E-01	4.0E-03	5.0E-01
5	ILCR	2.0E-08	9.3E-08	7.5E-07	4.7E-09	1.7E-06	9.8E-08	2.5E-06
	HI	5.2E-05	1.9E-04	3.3E-03	4.0E-03	4.9E-01	4.2E-03	5.0E-01
6	ILCR	2.0E-08	1.1E-07	7.7E-07	4.7E-09	1.7E-06	1.2E-07	2.5E-06
	HI	5.2E-05	3.2E-04	3.4E-03	4.0E-03	4.9E-01	4.3E-03	5.0E-01
7	ILCR	2.0E-08	2.5E-08	6.8E-07	1.0E-07	1.8E-06	1.3E-07	2.5E-06
	HI	5.2E-05	4.3E-05	3.1E-03	7.3E-02	5.6E-01	7.3E-02	5.7E-01
8	ILCR	2.0E-08	2.5E-08	6.8E-07	1.9E-07	1.9E-06	2.1E-07	2.6E-06
	HI	5.2E-05	4.3E-05	3.1E-03	1.3E-01	6.2E-01	1.3E-01	6.3E-01
9	ILCR	2.0E-08	3.3E-08	9.1E-07	2.6E-09	4.7E-07	3.6E-08	1.4E-06
	HI	5.2E-05	5.7E-05	4.2E-03	3.9E-03	4.8E-01	4.0E-03	4.9E-01

*Values shown are the source term specific risk contributions at the time of peak long-term human health risk over a 10,000-year post-remediation period.

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

Table 5.7. Residential Farmer Long-Term Human Health Risks by Source Term and Case*

Case		Past Leaks (Farm)	Waste Retrieval Leak Loss		Residual Waste		Composite Source Term	
			Tank C-104	C Tank Farm	Tank C-104	C Tank Farm	Tank C-104	C Tank Farm
1	ILCR	6.8E-07	4.4E-07	2.2E-05	9.7E-08	5.0E-05	5.4E-07	7.2E-05
	HI	5.7E-03	7.3E-03	8.3E-01	6.8E-01	1.5E+02	6.8E-01	1.5E+02
2	ILCR	6.8E-07	4.4E-07	2.2E-05	4.3E-07	7.4E-05	8.7E-07	9.6E-05
	HI	5.7E-03	7.3E-03	8.3E-01	5.1E+00	8.0E+02	5.1E+00	8.0E+02
3	ILCR	6.8E-07	0.0E+00	0.0E+00	9.7E-08	5.0E-05	9.7E-08	5.0E-05
	HI	5.7E-03	0.0E+00	0.0E+00	6.8E-01	1.5E+02	6.8E-01	1.5E+02
4	ILCR	6.8E-07	0.0E+00	2.2E-05	9.7E-08	5.0E-05	9.7E-08	7.2E-05
	HI	5.7E-03	0.0E+00	8.3E-01	6.8E-01	1.5E+02	6.8E-01	1.5E+02
5	ILCR	6.8E-07	1.7E-06	2.3E-05	9.7E-08	5.0E-05	1.8E-06	7.4E-05
	HI	5.7E-03	3.7E-02	8.6E-01	6.8E-01	1.5E+02	7.1E-01	1.5E+02
6	ILCR	6.8E-07	2.1E-06	2.4E-05	9.7E-08	5.0E-05	2.2E-06	7.4E-05
	HI	5.7E-03	7.3E-02	9.0E-01	6.8E-01	1.5E+02	7.5E-01	1.5E+02
7	ILCR	6.8E-07	4.4E-07	2.2E-05	1.9E-06	5.1E-05	2.4E-06	7.4E-05
	HI	5.7E-03	7.3E-03	8.3E-01	2.3E+01	1.8E+02	2.3E+01	1.8E+02
8	ILCR	6.8E-07	4.4E-07	2.2E-05	3.6E-06	5.3E-05	4.0E-06	7.6E-05
	HI	5.7E-03	7.3E-03	8.3E-01	4.2E+01	2.0E+02	4.3E+01	2.0E+02
9	ILCR	6.8E-07	5.9E-07	2.9E-05	1.9E-08	4.7E-06	6.0E-07	3.5E-05
	HI	5.7E-03	9.7E-03	1.1E+00	6.7E-01	1.5E+02	6.7E-01	1.5E+02

*Values shown are the source term specific risk contributions at the time of peak long-term human health risk over a 10,000-year post-remediation period.

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

Section 5.3.1 provides the tank-specific results by source term for tank C-104. Section 5.3.2 provides the results by source term for the C tank farm. Section 5.3.3 compares the results for the receptor scenarios based on DOE/RL-91-45 formulas with those based on the MTCA formulas.

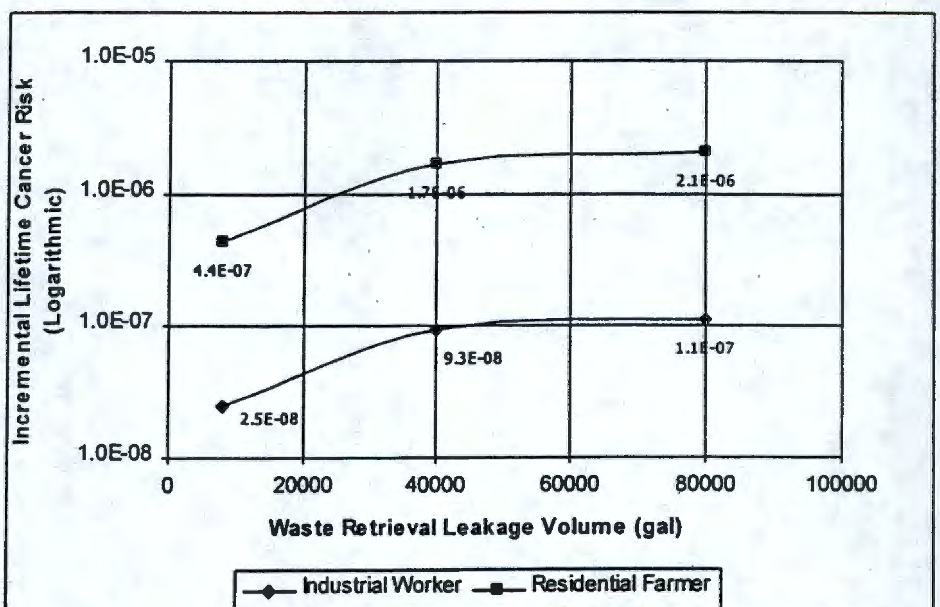
5.3.1 Tank C-104 Long-Term Human Health Risk Assessment Results

This section presents the tank-specific long-term human health risk results for tank C-104 by source term.

5.3.1.1 Tank C-104 Past Leaks. Tank C-104 is currently classified as sound and does not have a past leak source term. There would be no long-term human health risks from tank C-104 past leaks.

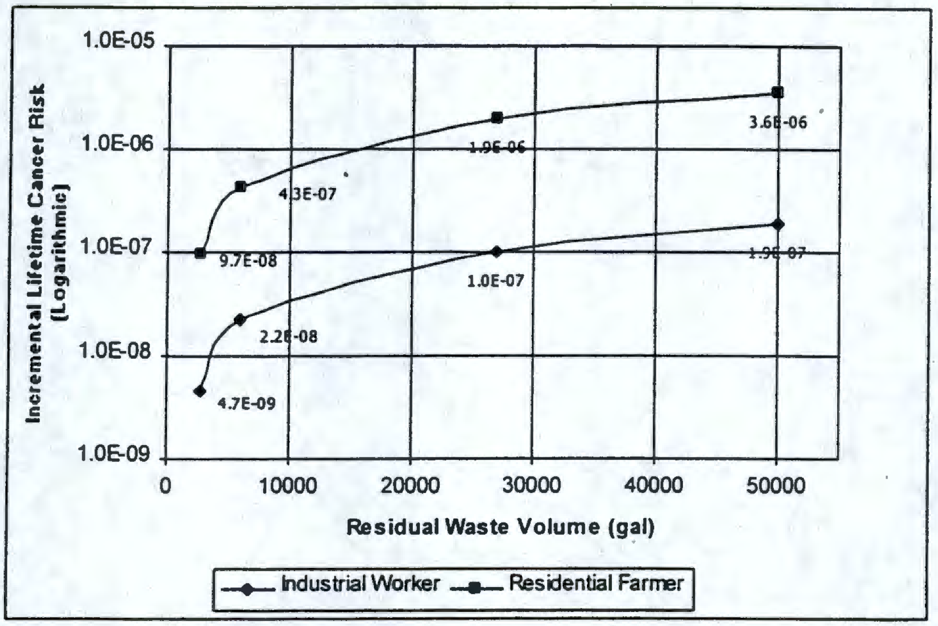
5.3.1.2 Tank C-104 Waste Retrieval Leak Loss. For the industrial worker, the ILCR from tank C-104 waste retrieval leak losses vary between 2.5×10^{-8} and 1.1×10^{-7} and for the hazard index vary between 2.3×10^{-5} and 2.3×10^{-4}. For the residential farmer, the ILCR varies between 4.4×10^{-7} and 2.1×10^{-6} and the hazard index varies between 7.6×10^{-3} and 7.6×10^{-2}. The low and high ILCR and hazard index values result from tank C-104 waste retrieval leak losses of 30,000 L (8,000 gal) and 300,000 L (80,000 gal), respectively. Figure 5.1 shows the risk-to-volume relationship between ILCR and tank C-104 waste retrieval leak losses based on the nine waste retrieval cases analyzed. The peak risk of 1.1×10^{-7} ILCR to the industrial worker is equivalent to 1.8×10^{-4} rem (0.18 mrem).

Figure 5.1. Relationship of Tank C-104 Retrieval Leakage Risk Versus Volume



5.3.1.3 Tank C-104 Residual Waste. For the industrial worker, the ILCR from tank C-104 residual waste varies between 2.6×10^{-9} and 1.9×10^{-7} and the hazard index varies between 2.1×10^{-3} and 1.3×10^{-1}. For the residential farmer, the ILCR varies between 1.9×10^{-8} and 3.6×10^{-6} and the hazard index varies between 6.9×10^{-1} and 4.4×10^{1}. The low and high ILCR and hazard index values result from tank C-104 residual waste volumes of 10,000 L (2,700 gal) (with interim barrier use) and 190,000 L (50,000 gal), respectively. Figure 5.2 shows the risk-to-volume relationship between ILCR and tank C-104 residual waste based on the nine waste retrieval cases analyzed. The peak risk of 1.9×10^{-7} ILCR to the industrial worker is equivalent to 3.2×10^{-4} rem, or an average annual dose of 0.016 mrem/yr.

Figure 5.2. Relationship of Tank C-104 Residual Waste Risk Versus Volume



5.3.1.4 Tank C-104 Composite Source Term. For the industrial worker, the ILCR from the tank C-104 composite source term varies between 4.7×10^{-9} and 2.1×10^{-7} and the hazard index varies between 2.1×10^{-3} and 1.3×10^{-1}. For the residential farmer, the ILCR varies between 9.7×10^{-8} and 4.0×10^{-6} and the hazard index varies between 7.0×10^{-1} and 4.4×10^{1}. The low ILCR and hazard index values would result from the composite of no waste retrieval leak losses and 10,000 L (2,700 gal) of residual waste. The high ILCR and hazard index values result from the composite of 30,000 L (8,000 gal) of waste retrieval leak losses and 190,000 L (50,000 gal) of residual waste. Figures 5.3 and 5.4 show the risk-to-volume relationships between the composite ILCR and, respectively, tank C-104 waste retrieval leak losses (for 10,000 L [2,700 gal] of residual waste) and tank C-104 residual waste (for 30,000 L [8,000 gal] of waste retrieval leak losses) based on the nine waste retrieval cases analyzed.

Figure 5.3. Tank C-104 Composite Risk Versus Retrieval Leakage Volume (Assuming 10,000 L [2,700 gal] of Residual Waste)

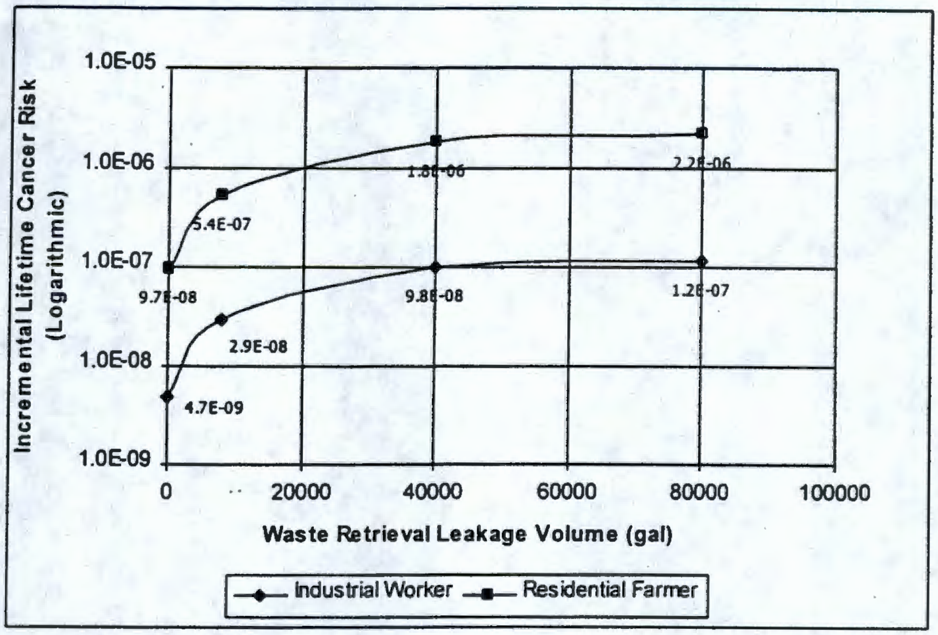
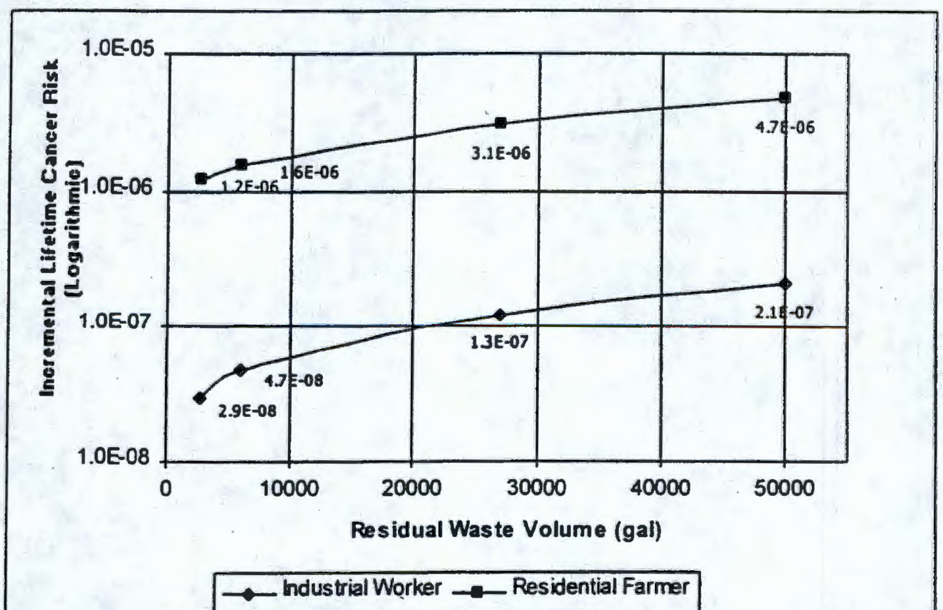


Figure 5.4. Tank C-104 Composite Risk Versus Residual Waste Volume (Assuming 30,000 L [8,000 gal] of Retrieval Leakage)



5.3.2 C Tank Farm Long-Term Human Health Risk Assessment Results

This section presents the long-term human health risk results for the C tank farm as a whole by source term.

5.3.2.1 C Tank Farm Past Leaks. A total of seven tanks in the C tank farm are documented as having leaked (tanks C-101, C-110, C-111, C-201, C-202, C-203, and C-204) (HNF-EP-0182-150). The past leak source term for these tanks is the same for all nine waste retrieval cases and, as a result, the long-term human health risk is identical for each case (Tables 5.6 and 5.7). For the industrial worker, the ILCR at the time of peak composite risk is 2.0×10^{-8} and the hazard index is 1.4×10^{-5}. For the residential farmer, the ILCR at the time of peak composite risk is 6.8×10^{-7} and the hazard index is 5.6×10^{-3} (Tables 5.6 and 5.7). Of the 7 C farm tanks classified as leakers, tank C-101 has by far the largest estimated past leak volume (76,000 L [20,000 gal]) and inventory and dominates the C tank farm long-term human health risk from past leaks.

5.3.2.2 C Tank Farm Waste Retrieval Leak Losses. For the industrial worker, the ILCR from C tank farm waste retrieval leak losses varies between 6.6×10^{-7} and 9.1×10^{-7} and the hazard index varies between 9.4×10^{-4} and 1.3×10^{-3}. For the residential farmer, the ILCR varies between 2.2×10^{-5} and 2.9×10^{-5} and the hazard index varies between 8.6×10^{-1} and 1.1×10^{0}. The low ILCR and hazard index values result from no waste retrieval leak losses from tank C-104.and waste retrieval leak losses of 30,000 L (8,000 gal) from the other 100-series tanks and 3,000 L (800 gal) from the 200-series tanks. The high ILCR and hazard index values result from interim barrier use with waste retrieval leak losses of 30,000 L (8,000 gal) from tank C-104 and the other 100-series tanks and 3,000 L (800 gal) from the 200-series tanks.

To reflect current near-term plans for waste retrieval from sound tanks, long-term human health risk calculations assume DST supernate will be used as the retrieval fluid. This also provides conservative leak loss inventory estimates. Recognizing that tanks classified as leakers will probably be retrieved using water, a sensitivity case assumes water is used to retrieve waste from leaking tanks. The risks are 15% to 20% lower on a tank basis. A more complete presentation is provided in HNF-7989.

5.3.2.3 C Tank Farm Residual Waste. For the industrial worker, the ILCR from C tank farm residual waste varies between 4.7×10^{-7} and 2.6×10^{-6} and the hazard index varies between 2.3×10^{-1} and 9.4×10^{-1}. For the residential farmer, the ILCR varies between 4.7×10^{-6} and 7.4×10^{-5} and the hazard index varies between 1.6×10^{2} and 8.3×10^{2}. The low ILCR and hazard index values result from interim barrier use with residual waste volumes of 10,000 L (2,700 gal) in tank C-104 and the other 100-series tanks and 830 L (220 gal) in the 200-series tanks. The high ILCR and hazard index values result from residual waste volumes of 23,000 L (6,000 gal) in tank C-104 and the other 100-series tanks and 1,500 L (400 gal) in the 200-series tanks.

5.3.2.4 C Tank Farm Composite Source Term. For the industrial worker, the ILCR from the C tank farm composite source term varies between 1.4×10^{-6} and 3.3×10^{-6} and the hazard index varies between 2.3×10^{-1} and 9.4×10^{-1}. For the residential farmer, the ILCR varies between 3.5×10^{-5} and 9.6×10^{-5} and the hazard index varies between 1.6×10^{2} and 8.2×10^{2}. The low ILCR and hazard index values result from the composite of interim barrier use with past leaks; waste retrieval leak losses of 30,000 L (8,000 gal) for tank C-104 and the other 100-series tanks and 3,000 L (800 gal) for the 200-series tanks; and residual waste volumes of 10,000 L (2,700 gal) in the 100-series tanks and 830 L (220 gal) in the 200-series tanks. The high ILCR and hazard index values result from the composite of past leaks; waste retrieval leak losses of 30,000 L (8,000 gal) in tank C-104 and the other 100-series tanks and 3,000 L (800 gal) in the 200-series tanks; and residual waste volumes of 23,000 L (6,000 gal) in tank C-104 and the other 100-series tanks and 1,500 L (400 gal) in the 200-series tanks.

5.3.3 Receptor Scenario Results Comparison

Table 5.8 compares the long-term human health risk results for the DOE/RL-91-45 scenarios based on DOE/RL-91-45 (industrial worker and residential farmer) with the results for the scenarios based on MTCA (Method B and Method C). Because the risk criteria set forth in "The Model Toxics Control Act Cleanup Regulation" (WAC 173-340) are applicable only to nonradioactive contaminants, Table 5.8 compares only hazard index values. Table 5.8 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 consistently the least conservative (i.e., produces the lowest hazard index values) of the four scenarios.

5.4 INTRUDER RISK RESULTS

This section presents the results of the risk analyses for the inadvertent human intruder based on the DOE and NRC methodologies described in Section 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 the inadvertent human intruder at 500 years.

5.4.1 U.S. Department of Energy Intruder Scenario

The doses to the well driller and post-driller resident for each of the nine waste retrieval cases are presented in Table 5.9. 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 C-104 and soil contaminated by tank C-104 waste retrieval leak losses. The radiological activity in the residual waste and retrieval leak losses is obtained from calculations presented in the Appendix of this document.

Table 5.8. Comparison of Peak Hazard Index for Different Receptor Scenarios by Case[a]

Case[b, c]	Tank C-104				C Tank Farm			
	Residential Farmer	Industrial Worker	MTCA Method B	MTCA Method C	Residential Farmer	Industrial Worker	MTCA Method B	MTCA Method C
1	7.1E-01	2.1E-03	1.5E-01	7.0E-02	1.6E+02	2.3E-01	1.9E+01	8.9E+00
2	5.3E+00	1.6E-02	1.2E+00	5.3E-01	8.3E+02	9.4E-01	8.4E+01	3.8E+01
3	7.0E-01	2.1E-03	1.5E-01	7.0E-02	1.6E+02	2.3E-01	1.9E+01	8.8E+00
4	7.0E-01	2.1E-03	1.5E-01	7.0E-02	1.6E+02	2.3E-01	1.9E+01	8.9E+00
5	7.4E-01	2.2E-03	1.6E-01	7.3E-02	1.6E+02	2.3E-01	1.9E+01	8.9E+00
6	7.8E-01	2.3E-03	1.7E-01	7.7E-02	1.6E+02	2.3E-01	1.9E+01	8.9E+00
7	2.4E+01	7.2E-02	5.2E+00	2.4E+00	1.8E+02	3.0E-01	2.4E+01	1.1E+01
8	4.4E+01	1.3E-01	9.6E+00	4.4E+00	2.0E+02	3.6E-01	2.9E+01	1.3E+01
9	7.0E-01	2.1E-03	1.5E-01	6.9E-02	1.6E+02	2.3E-01	1.9E+01	8.7E+00

[a]Values shown are the peak hazard index over a 10,000-year post-remediation period.
[b]Cases 1, 3, 4, 5, and 6 compare risks that vary with increasing retrieval leak loss (in order: Cases 3, 4, 1, 5, and 7).
[c]Cases 1, 2, 7 and 8 (in order) compare risks that vary with increasing residual heel volume.

MTCA = Model Toxics Control Act.

Table 5.9. Well Driller and Post-Driller Resident Dose in 2100

Case	Well Driller (mrem/incident)	Post-Driller Resident (mrem/yr)
1	2.2E+01	6.7E+01
2	4.5E+01	1.3E+02
3	1.9E+01	5.1E+01
4	1.9E+01	5.1E+01
5	3.1E+01	1.3E+02
6	4.4E+01	2.1E+02
7	8.8E+01	5.2E+02
8	3.6E+02	1.0E+03
9	2.2E+01	6.7E+01

5.4.2 U.S. Nuclear Regulatory Commission Requirements

A comparison of the radionuclide concentrations (before stabilization) in the residual waste in tank C-104 to the Class C upper limit concentration values is presented in Table 5.10. The tank C-104 residual concentrations are discussed in more detail in the Appendix of this document. The comparison shows the long-lived radionuclides (specifically, alpha emitting TRU with $t_{1/2} > 5$ yr and plutonium-241) can greatly exceed the Class C upper limits. Table 5.10 also shows the long-lived radionuclide sum-of-fractions is greater than 1, or an exceedance of 117 times.

Table 5.10. Tank C-104 Residual Waste Concentrations Compared to the Class C Upper Limits

Long-Lived Radionuclides	Class C Upper Limits	Tank C-104 Residual Concentrations
Carbon-14	8 Ci/m^3	0.0001 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	0.01 Ci/m^3
Iodine-129	0.08 Ci/m^3	0.0001 Ci/m^3
Alpha emitting transuranic with $t_{1/2} > 5$ yr	100 nCi/g	5,900 nCi/g
Plutonium-241	3,500 nCi/g	14,000 nCi/g
Curium-242	20,000 nCi/g	4.9 nCi/g
Short-Lived Radionuclides		
Nickel-63	700 Ci/m^3	3.7 Ci/m^3
Nickel-63 in activated metal	7,000 Ci/m^3	0 Ci/m^3
Strontium-90	7,000 Ci/m^3	1,300 Ci/m^3
Cesium-137	4,600 Ci/m^3	170 Ci/m^3
Sum-of-fractions for long-lived radionuclides	1.0	120
Sum-of-fractions for short-lived radionuclides	1.0	0.23

The residual waste inventory estimates in tank C-104 were further evaluated for each of the cases (HNF-7989) using the Shyr and Bustard (1997) methodology to determine the minimum volume of grout that would be required to stabilize the residual waste and at the same time reduce the radiological constituent concentrations to a level that would not exceed Class C upper limits. This evaluation was performed to determine the feasibility of attaining Class C concentrations through stabilization of the residuals. The minimum depth of grout that would be required for each case is summarized in Table 5.11.

Table 5.11. Minimum Level of Grout Required to Reduce Concentrations to Class C Upper Limits

Case	Residual Waste Volume (gal)	Minimum Level of Grout (in.)
1, 3, 4, 5, 6, 9	2,700	89
2	6,000	200
7	27,000	890
8	50,000	1,600

To obtain liters multiply gallons by 3.785.
To obtain centimeters multiply inches by 2.54.

5.5 REGULATORY COMPLIANCE RESULTS

This section describes the regulatory compliance for the results presented in Sections 5.1 to 5.4 for Cases 1 through 9. The methodology used for regulatory compliance analysis is presented in Section 3.8. The following items are 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 period of 2,600 years (over a 10,000-year period)
- Risk to DOE and NRC inadvertent human intruder
- Tri-Party Agreement milestones.

5.5.1 Short-Term Human Health Risk Compliance

Short-term human health risks were evaluated based on operating the waste retrieval system to different end points 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. Case 9, which assumes construction of an interim barrier, was considered separately because there is additional risk to workers resulting from constructing the barrier.

5.5.1.1 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 C-104 can be retrieved with appropriate time, distance, and shielding provisions in a manner that maintains worker doses within acceptable limits. The noninvolved worker and general public radiological LCF risk from normal operations do not exceed the regulatory requirement standard of 100 mrem/yr for all cases analyzed based on the assumptions and data in this report. Based on the results, no LCFs were reported for the general public or offsite receptor.

5.5.1.2 Routine Chemical Exposure During Retrieval Operations. Short-term chemical health impacts from normal operations would be below the regulatory standard for noncarcinogenics for all 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).

5.5.2 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 are the EPA MCLs and are the only requirements discussed.

The CoC with the highest concentration level for the radionuclides in the groundwater is technetium-99. The highest chemical concentration is nitrate.

Technetium-99 is used as an indicator constituent as a result of its mobility in the environment (distribution coefficient of 0) and its long half-life. Technetium-99 will not exceed the EPA regulatory MCL (900 pCi/L) for any of the cases for the radionuclides. Nitrate exceeds the regulatory standard of 45 mg/L in Case 2. All other CoCs are below EPA MCLs, the DOE derived concentration guides, and state concentration limits.

5.5.3 Long-Term Human Health Risk Compliance

Long-term human health risks were evaluated based on the maximum groundwater concentration and the level of risk (i.e., ILCR and hazard index) as expressed in human health exposure to nine radiological constituents (technetium-99; selenium-79; iodine-129; carbon-14; and uranium-233, -234, -235, -236, and -238) and four chemical constituents (total uranium, chromate, nitrate, and nitrite). These constituents were chosen to evaluate long-term human health risks.

For carcinogenic risk, the level of protection provided under the regulations ranges from 1 in 10,000 (1.0×10^{-4}) to 1 in 1,000,000 (1.0×10^{-6}). For hazardous chemicals under residential or industrial scenarios Washington State requires ILCR not to be higher than 1.0×10^{-6} for individual contaminants and 1.0×10^{-5} for cumulative contaminants (WAC 173-340), while the

EPA requires the ILCR not to be higher than 1.0×10^{-4} (55 FR 8666). For noncarcinogenic risk a hazard index equal to or greater than one exceeds state and federal standards.

Regulatory standards may be exceeded for long-term human health risk and not for drinking water standards (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 human health standard; while the DWS only assumes consumption. For example, the DWS for technetium-99 is 900 pCi/L and exposure to groundwater concentrations at this level would result in an ILCR of 2.3×10^{-4} for a residential farmer.

Based on available data and assumptions documented in this report, no exceedance of long-term human health risk standards occur for tank C-104 and the C tank farm for the industrial worker scenario. Exceedance of the hazard index standard does occur for tank C-104 in the residential farmer scenario in Cases 2, 7, and 8. Exceedances of ILCR and hazard index standards also occur for the C tank farm in all nine cases for the residential farmer scenario.

5.5.4 Inadvertent Human Intruder 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 5.9) indicate that tank C-104 would meet the 500 mrem dose limit under all nine waste retrieval cases but would exceed the 100 mrem/yr chronic dose limit under Cases 2, 5, 6, 7, and 8.

According to the results presented in Section 5.4, the NRC standard for upper concentration limits for Class C LLW disposal would be exceeded for tank C-104 in all nine waste retrieval cases if no additional actions were implemented. However, for all but Cases 7 and 8 the Class C limits could theoretically be met with stabilization of the residual waste with grout, assuming uniform mixing of the grout and the residual waste. The technological feasibility of uniformly mixing the required amount of grout with the residual waste is uncertain. Section 6.0 addresses this uncertainty with respect to current NRC determinations at the DOE Savannah River Site.

5.5.5 Tri-Party Agreement Milestone Compliance

The Tri-Party Agreement Milestone M-45-03F states:

> Goals of this demonstration shall include the retrieval to safe storage of approximately 89 kg of plutonium (which represents approximately 17% of the total plutonium inventory within the SST system), and 99% of tank contents by volume (per DOE's Best-Basis Inventory data of 8/01/2000).

These 89 kg of plutonium criteria translates to retrieving 950,000 L (250,000 gal) of waste from tank C-104 (HNF-7989). The 99% of tank content by volume represent 9,960 L (2,630 gal) compared to 10,220 L (2,700 gal), which represents the Tri-Party Agreement Milestone M-45-00 interim retrieval goal of 360 ft^3. This 260-L (70-gal) difference is minor in comparison to the uncertainty associated with measuring residual waste volumes.

Cases 1, 2, 3, 4, 5, 6, and 9 meet the Milestone M-45-03F demonstration goal of retrieving approximately 89 kg (196 lb) of plutonium from tank C-104.

6.0 CONCLUSIONS

This section provides the conclusions and recommendations relative to tank waste retrieval for tank C-104 based on the analysis of results presented in Section 5.0. Section 6.1 provides a summary of the conclusions as they relate to near-term waste retrieval efforts. Section 6.2 provides a summary of the conclusions specific to the different areas of analysis.

6.1 SUMMARY CONCLUSIONS

The summary conclusions in the following sections are identified RPE findings that would influence waste retrieval and LDMM system criteria.

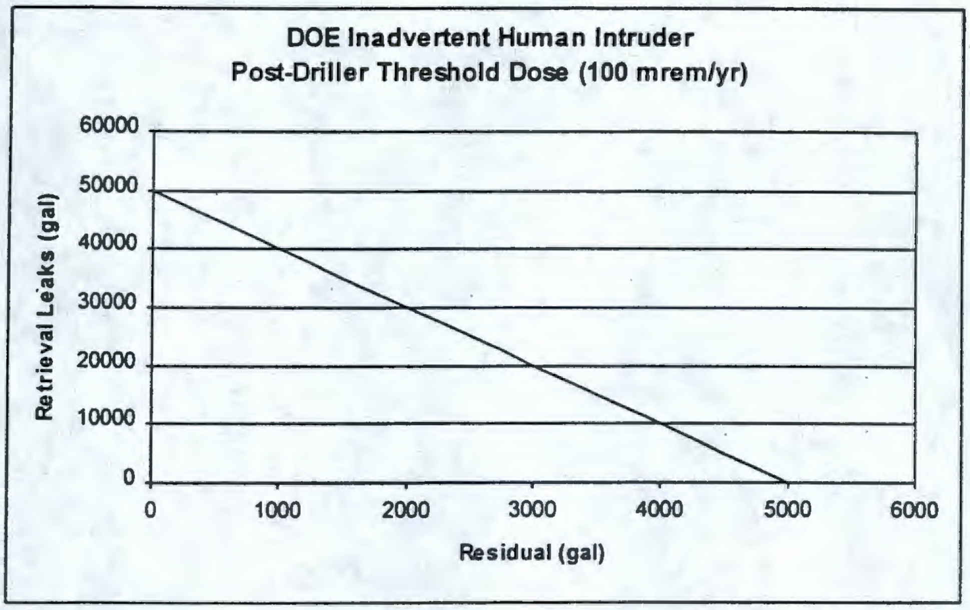
6.1.1 Tank C-104 Conclusions

The goal of the technology demonstration in tank C-104 is to demonstrate the limits of technology for the waste retrieval system and application and demonstration of the LDMM to waste retrieval. The Tri-Party Agreement F&R document will identify the proposed methodology for demonstrating the limit of the technology. Because of the potential for leakage to occur during retrieval and the interrelationship between retrieval leakage and residual waste from a closure standpoint it is important to understand how the variation in residual waste volume and retrieval leakage volume influence the risk- and regulatory-based performance measures.

The final extent of retrieval is a tank farm closure issue; however, if the goal of the retrieval function is to enter the tank one time then the extent of 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 retrieval criteria. This approach does not preclude the retrieval of additional waste from the tank in the future as additional information is gathered during and after waste retrieval activities in the remaining C farm tanks and as closure criteria are established.

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 C-104 are driven by the inadvertent human intruder and regulatory waste classification performance measures.
The inadvertent human intruder analysis indicates that with no retrieval leakage a residual waste volume less than or equal to 19,000 L (5,000 gal) would be required to meet the post-drilling resident DOE inadvertent human intruder dose of 100 mrem/yr. If leakage were to occur during retrieval then the combination of residual waste and retrieval leakage could contribute to the intruder impacts. Figure 6.1 shows the relationship between residual waste volume and retrieval leakage volume for the post-drilling resident waste site intruder at the performance standard of 100 mrem/yr. For additional discussion of the inadvertent human intruder see Section 5.4.

Figure 6.1. Intruder Risk Versus Retrieval Leakage and Residual Volume



The intruder analysis also includes an evaluation of the various residual waste volumes against the NRC waste classification criteria in 10 CFR 61. The baseline closure strategy for the SST is landfill closure with the residual waste disposed of in place. This strategy requires DOE to petition NRC for an incidental waste determination for the tank residuals. The waste in tank C-104 exceeds Class C limits because the Class C limits are concentration based. Thus, any amount of residual waste would exceed the limits without pursuing a strategy to incorporate the residuals into a stabilized solid form (i.e., grout) at a concentration that does not exceed Class C limits. While there is considerable uncertainty about the ability to mix or incorporate the residuals into a stabilized waste form, it is not necessary to resolve this issue prior to retrieving the waste. The relationship between residual waste volume and the Class C limits when the residuals are incorporated into a solid waste form should be considered. The analysis results indicate that a residual waste volume of 10,000 L (2,700 gal) would need to be incorporated into a solid waste form of approximately 230 cm (90 in.) to meet Class C limits. There would be considerable technical uncertainty in trying to mix residual waste with this volume of grout or other stabilizing material. This indicates that from the standpoint of reclassifying the residual waste as incidental waste using Class C limits and concentration averaging, the retrieval criteria measured as residual waste volume should be less than 10,000 L (2,700 gal). This may not be technically or economically feasible. Therefore, for tank C-104 it is likely that the DOE petition to NRC for reclassification of the residuals that regulatory options for site-specific Class C limits will have to be established.

The long-term human health risk analysis results show that this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104. If a uniform risk allocation process were used to apportion a risk level for the tank farm and a total ILCR of 1×10^{-5} were uniformly allocated among the 16 C farm tanks then the allowable risk per tank would be 6×10^{-7}. Under this risk allocation methodology the long-term human health risk is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104 under the industrial worker scenario. Risk allocation, coupled with the residential farmer exposure scenario, would restrict the retrieval leakage volume. However, the residential farmer scenario is considered to be overly conservative for the purposes of making tank farm waste retrieval decisions.

Likewise, long-term groundwater impacts as a performance measure would not be a driver for establishing LDMM system criteria for tank C-104. The maximum contaminant concentrations in groundwater resulting from retrieval losses for tank C-104 up to 300,000 L (80,000 gal) (Case 6) would not be expected to exceed DWSs.

6.1.2 C Tank Farm Conclusions

The DOE waste site intruder and the NRC waste classification issues discussed for tank C-104 are tank-specific and are not cumulative for the tank farm. The long-term human health risk performance measure and groundwater impacts are cumulative for the tank farm and thus need to be evaluated for the tank of interest and for the entire tank farm.

The groundwater impact and long-term human health risk analyses indicate that tank C-104 does not proportionally contribute to the C tank farm groundwater impacts and long-term human health risk under similar retrieval leakage and residual waste conditions. This indicates that the groundwater impacts and long-term human health risk on a tank farm level are not sensitive to changes in the performance of the waste retrieval system for tank C-104 from a residual waste volume or retrieval leakage perspective. Only under the larger residual volume cases does tank C-104 begin to proportionally contribute to the C tank farm groundwater impacts and human health risk.

Tank C-104 does not contribute proportionally to groundwater impacts and long-term human health risk because its effect is masked by effects from tank C-106. The chemical and radiological species that groundwater impacts and drive long-term human health risk to receptors located outside the tank farm boundary are water soluble and highly mobile through the soil.

6.2 CONCLUSIONS BY AREA OF ANALYSIS

Conclusions specfic to the areas of short-term human health risk, groundwater impacts, long-term human health risk, intruder risk, and regulatory compliance are provided in the following sections.

6.2.1 Short-Term Human Health Risk Conclusions

This section provides the conclusions reached in the short-term human health risk analysis for occupational risk, routine radiological risk, routine chemical risk, radiological accident risk, and chemical accident risk. Short-term human health risk analysis results are presented in Section 5.1. Only the human health risk associated with retrieval operations and the construction of an interim barrier are calculated for comparison. The results of the analysis indicate that, overall, short-term human health risk is not a driver for establishing tank C-104 waste retrieval and LDMM system criteria.

6.2.1.1 Occupational Risk Conclusions. A comparison of the occupational risks (i.e., TRCs, LWCs, and fatalities) associated with the nine waste retrieval cases and the additional health risk resulting from constructing an interim barrier 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 C-104.
- As less sludge is retrieved from tank C-104 in comparison to the cases with 10,000 L (2,700 gal) residual waste (Cases 1, 3, 4, 5, 6, 9) the occupational risk from retrieval operations is reduced by 1% for Case 2, 10% for Case 7, and 20% for Case 8.
- Adding the occupational risk from constructing an interim barrier for Case 9 increases the TRC, LWC, and fatality incidences by 75% as compared to the cases that assume 10,000 L (2,700 gal) residual waste without an interim barrier (Cases 1, 3, 4, 5, 6).

6.2.1.2 Routine Radiological Risk Conclusions. A comparison of the routine radiological risks (LCF) to the involved worker, noninvolved worker, and general public associated with the nine waste retrieval cases and the additional health risk resulting from constructing an interim barrier results in the following conclusions.

- There is no LCF among the worker population, noninvolved worker population, or general public population resulting from waste retrieval operations. The LCF risk to the involved worker MEI, noninvolved worker MEI, and general public MEI is very small (2.0×10^{-4}, 1.8×10^{-11}, 5.8×10^{-15}, respectively). Therefore, the analysis results indicate that this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104.
- As less sludge is retrieved from tank C-104 in comparison to that assumed in the cases with 10,000 L (2,700 gal) residual waste (Cases 1, 3, 4, 5, 6, 9) the LCF risk from waste retrieval operations is reduced by 1% for Case 2, 10% for Case 7, and 20% for Case 8.
- Adding the LCF risk from constructing an interim barrier for Case 9 increases the LCF risk to the involved workers by 2% as compared to the cases that assume 10,000 L (2,700 gal) residual waste without an interim barrier (Cases 1, 3, 4, 5, 6).

6.2.1.3 Routine Chemical Risk Conclusions. A comparison of the routine carcinogenic health risks (ILCR) to the involved worker MEI, noninvolved worker MEI, and general public MEI during retrieval operations associated with the nine waste retrieval cases results in the following conclusions.

- The ILCR for all the cases is small (i.e., less than 1.0×10^{-8}). Therefore, the analysis results indicate that this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104.

- As less sludge is retrieved from tank C-104 in comparison to that assumed in the cases with 10,000 L (2,700 gal) residual waste (Cases 1, 3, 4, 5, 6, 9) the ILCR risk from waste retrieval operations is reduced by 1% for Case 2, 10% for Case 7, and 20% for Case 8.

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 VOC and/or ammonia emissions to within the prescribed limits. Such safeguards would help prevent a potential release that occurred with tank C-106 when the air permit limit was immediately exceeded when waste retrieval began (RPP-5687).

6.2.1.4 Radiological Accident Risk Conclusions. The severity of a given accident and the frequency of the accident are common to all nine 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. Therefore, this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104.

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 nine 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 C-104.

6.2.2 Groundwater Impact Conclusions

This section provides conclusions regarding the results of the groundwater impact analysis of the waste retrieval cases. Groundwater impact analysis results are presented in Section 5.2. Conclusions are provided first for tank C-104 and then on a tank farm basis.

6.2.2.1 Tank C-104 Groundwater Impact Conclusions. The compliance status of tank C-104 relative to groundwater drinking water standard (DWS)-based regulations will be based on the combined groundwater contaminant concentration contributions from past tank releases, waste retrieval leak losses, and residual waste. The groundwater impacts from technetium-99, nitrate, iodine-129, and uranium-238 were estimated for all of the waste retrieval cases and it was found that the impacts associated with tank C-104 would all be below DWSs for these constituents for all cases. Of all the cases considered, Case 2 would come the closest to reaching or exceeding a DWS. The estimated groundwater impacts and associated DWSs (based on 40 CFR 141) for the composite of the three source terms (i.e., past tank releases, waste retrieval leak loss, and residual waste) for tank C-104 for Case 2 are as follows:

- Technetium-99 4.5 pCi/L (DWS 900 pCi/L)
- Nitrate 0.7 mg/L (DWS 45 mg/L)
- Iodine-129 2.4×10^{-3} pCi/L (DWS 1 pCi/L)
- Uranium-238 4.6×10^{-3} pCi/L (DWS 6.7 pCi/L)

These estimated groundwater impacts associated with tank C-104 for Case 2 are below the DWS. The risk impacts, discussed in the next section, would be more restrictive because the estimated risk is the sum of the risk from each contaminant. Thus, it would be possible to be below a DWS on a contaminant-by-contaminant basis but exceed a risk-based regulatory standard.

The results of the analysis indicate that this performance measure (i.e., drinking water standards) is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104.

6.2.2.2 C Tank Farm Groundwater Impact Conclusions. The groundwater impact analysis results indicate that the composite groundwater impacts for the C tank farm are not sensitive to changes in the performance of the waste retrieval system for tank C-104 from a residual waste volume or retrieval leakage perspective. For instance, a 30,000-L (8,000-gal) retrieval leak from tank C-104 would have virtually no effect on the composite peak groundwater contaminant concentrations for the C tank farm (Case 1 compared to Case 4). The same is true for retrieval leaks of 150,000 L (40,000 gal) and 300,000 L (80,000 gal) from tank C-104 (Case 1 compared to Cases 5 and 6) in which there would be virtually no effect on the composite peak groundwater contaminant concentrations for the C tank farm. Leaving residual waste volumes of 100,000 L (27,000 gal) and 190,000 L (50,000 gal) in tank C-104 causes only very small increases in the composite peak groundwater contaminant concentration for the C tank farm compared to leaving only 10,200 L (2,700 gal) in tank C-104 (Case 1 compared to Cases 7 and 8).

From a tank farm perspective, several additional general conclusions can be drawn. The composite peak groundwater contaminant concentrations for the C tank farm are more sensitive to changes in residual waste volume than to changes in retrieval leakage volume (Case 1 compared to Case 2 versus Case 1 compared to Case 3). The use of an interim barrier has a small overall effect on the composite peak groundwater contaminant concentrations for the C tank farm (Case 1 compared to Case 9). Lastly, under 40 CFR 141, only Case 2 exceeds the standard and only for nitrate. The estimated composite peak groundwater concentration for nitrate for Case 2 was 100 mg/L and the DWS is 45 mg/L. Over 99% of the nitrate in the composite concentration results from the residual assumed for this case.

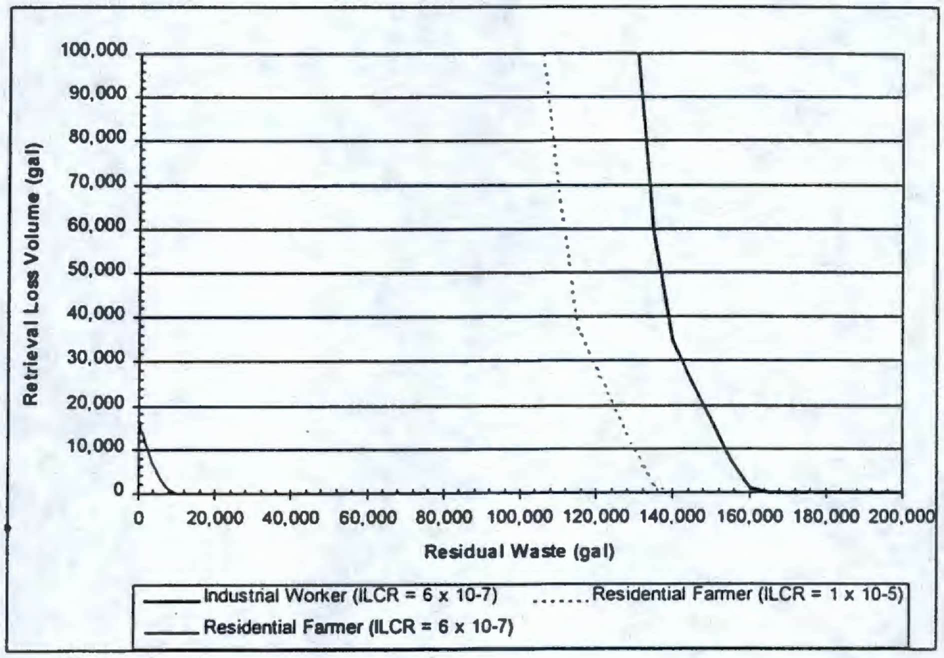
6.2.3 Long-Term Human Health Risk Conclusions

This section provides the conclusions based on the results of long-term human health risk analysis. Long-term human health risk analysis results are presented in Section 5.3.

6.2.3.1 Tank C-104 Long-Term Human Health Risk Conclusions. The compliance status of tank C-104 relative to risk-based regulatory standards will be based on the combined risk contributions from waste retrieval leak losses and residual waste remaining in the tank. Maintaining compliance with a given risk standard requires consideration of the contribution from residual waste and retrieval leakage. For a given risk level the amount of residual waste decreases if the retrieval leakage volume increases. Conversely, the amount of leakage during retrieval has to be decreased as the amount of residual waste left in the tank is increased. Figure 6.2 shows the relationship between tank C-104 retrieval leakage volume and residual waste volume for the industrial worker and residential farmer scenarios at several ILCR levels based on the analysis results for the nine waste retrieval cases. Figure 6.2 is truncated at

400,000 L (100,000 gal) of retrieval leak loss because of the scaling approach and the limited number of modeled leak loss volume cases from the AX tank farm. Also, the 1×10^{-6} worker line falls outside (greater leak loss volume and greater residual volume) the region shown on the graph.

Figure 6.2. Industrial Worker and Residential Farmer ILCR Levels for Tank C-104 Retrieval Leakage Volume and Residual Waste Volume



The analysis results indicate that under the industrial worker scenario, tank C-104 does not exceed the Washington State human health risk standards (i.e., ILCR of 1×10^{-5} and hazard index of 1.0) even if very large (300,000 L [80,000 gal]) retrieval leak losses occur or the amount of residual waste left in the tank is very large (190,000 L [50,000 gal]). If a uniform risk allocation process is used and a total ILCR of 1×10^{-5} is uniformly allocated among the 16 C farm tanks then the allowable risk per tank is be 6×10^{-7}. The analysis indicates that with no retrieval leak loss tank C-104 would meet an ILCR threshold of 6×10^{-7} under the industrial worker scenario provided the residual waste volume does not exceed 621,000 L (164,000 gal). From a long-term human health risk perspective, the limiting factor is the residual waste volume and not the retrieval leakage volume. Even with a catastrophic retrieval leak loss of 400,000 L (100,000 gal), a residual waste volume of 500,000 L (132,000 gal) could still be left in tank C-104 without exceeding the ILCR threshold of 6×10^{-7} for the industrial worker scenario (Figure 6.2).

Under the residential farmer scenario, tank C-104 meets the Washington State human health risk standards except in the waste retrieval cases where residual waste volumes are 22,700 L (6,000 gal) (Cases 2, 7, and 8). Assuming no retrieval leakage occurs, tank C-104 meets the state ILCR standard of 1×10^{-5} under the residential farmer scenario provided residual waste volumes do not exceed 530,000 L (140,000 gal). As for the industrial worker scenario, the limiting factor is the residual waste volume and not the retrieval leakage volume. Even with a catastrophic retrieval leak loss of 400,000 L (100,000 gal) and a residual waste volume of 397,000 L (105,000 gal), tank C-104 does not exceed an ILCR of 1×10^{-5} for the residential farmer scenario. However, if a uniform risk allocation process as described above is used, the risk-based retrieval criteria envelope for tank C-104 is significantly more restrictive. Tank C-104 is able to meet an ILCR threshold of 6×10^{-7} under the residential farmer scenario but the retrieval leak losses are limited to 61,000 L (16,000 gal) and the residual waste volume is limited to 38,000 L (10,000 gal).

The results of the analysis indicate that this performance measure is not a driver for establishing waste retrieval and LDMM system criteria for tank C-104 under the industrial worker or residential farmer scenarios. However, under the residential farmer scenario this performance measure could be a driver if a uniform risk allocation process is used and consideration is given to the risk allowance for tank C-104 relative to the total risk limit for the C tank farm as a whole. The extent to which the residential farmer scenario drives the retrieval criteria development process depends on the assumptions used to allocate risk across all tanks in the C tank farm. The risk allocation approach presented here (i.e., uniformly allocating the threshold ILCR value of 1×10^{-5} across all 16 tanks) is intended to serve only as an example. Alternative approaches involving different assumptions on the performance of the other C farm tanks (e.g., allocating risk nonuniformly between 100-series and 200-series tanks) could alter the importance of the residential farmer scenario.

6.2.3.2 C Tank Farm Long-Term Human Health Risk Conclusions. The analysis results indicate that the long-term human health risk for the C tank farm as a whole is not sensitive to changes in the performance of the waste retrieval system for tank C-104 from a residual waste volume or retrieval leakage perspective. A 30,000-L (8,000-gal) retrieval leak from tank C-104 would have virtually no effect on the peak risk for the C tank farm (Case 1 compared to Case 4) and retrieval leaks of 150,000 L (40,000 gal) and 300,000 L (80,000 gal) from tank C-104 would have only minimal effects (Case 1 compared to Cases 5 and 6). Leaving residual waste volumes of 100,000 L (27,000 gal) and 190,000 L (50,000 gal) in tank C-104 causes only small increases in the peak risk for the C tank farm compared to leaving only 10,200 L (2,700 gal) in tank C-104 (Case 1 compared to Cases 7 and 8).

From a tank farm perspective, several additional general conclusions can be drawn. The peak risk for the C tank farm as a whole is more sensitive to changes in residual waste volume than to changes in retrieval leakage volume (Case 1 compared to Cases 2 and 3). The use of an interim barrier has a small overall effect on the peak risk for the C tank farm (Case 1 compared to Case 9). Lastly, under the industrial worker scenario the peak risk for the C tank farm does not exceed the Washington State human health risk standards for any of the cases analyzed; under the residential farmer scenario all nine waste retrieval cases exceed the standards.

6.2.4 Intruder Risk Conclusions

This section provides the conclusions based on the inadvertent human intruder analysis for the DOE intruder scenario and the NRC requirements. Intruder risk analysis results are presented in Section 5.4.

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 in a year from chronic exposure (post-driller resident) (DOE O 435.1). A comparison of the well driller and post-driller resident doses to the DOE regulations for the various 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. Case 8 has the greatest radiological impact (360 mrem) to the well driller.
- Cases 2, 5, 6, 7, and 8 exceed the 100 mrem chronic dose limit set in DOE O 435.1 for the post-driller resident; Cases 1, 3, 4, and 9 do not.
- Tank C-104 exceeds the 100 mrem/yr chronic dose limit except for cases where the Tri-Party Agreement-compliant residual waste volume of 10,000 L (2,700 gal) is coupled with the assumed baseline retrieval leakage volume of 30,000 L (8,000 gal) (Cases 1, 3, 4, 9).

6.2.4.2 U.S. Nuclear Regulatory Commission Requirement Conclusions. The analysis results indicate that this performance measure is a significant driver for establishing tank C-104 waste retrieval and LDMM system criteria. The NRC analysis results in the following conclusions.

- Mixing the residual waste with grout to achieve NRC Class C concentrations is not feasible for any of the nine waste retrieval cases.
- Residual volumes approximately 1 order of magnitude smaller than the Tri-Party Agreement interim retrieval goal of 360 ft^3 (Case 1) would be required to reach a point where stabilization of the residuals with approximately 25 cm (10 in.) of grout would meet NRC Class C limits.

6.2.5 Regulatory Compliance Conclusions

This section addresses conclusions based on the results of regulatory compliance analysis. Regulatory compliance analysis results are presented in Section 5.5. The regulatory compliance analysis involves the four performance measure areas of short-term human health risk, groundwater quality, long-term human health risk, and inadvertent human intrusion as well as other regulatory issues. Such issues include hazardous or dangerous waste management and disposal, radioactive waste management and disposal, and potential retrieval leak loss. Each issue is discussed regarding its ability to comply with applicable and relevant regulations.

This section also addresses retrieval leak loss thresholds and residual waste thresholds based on compliance with the regulations using available data and assumptions.

The tank C-104 retrieval demonstration goals as specified in Tri-Party Agreement Milestone M-45-03F are to remove to safe storage approximately 89 kg of plutonium and 99% of the tank C-104 contents by volume. The more restrictive of these two goals from a retrieval performance perspective is the removal of 99% of the tank contents by volume. Removing 89 kg of plutonium would require retrieving at least 950,000 L (250,000 gal) of waste from tank C-104, equating to a maximum residual waste volume of 49,000 L (13,000 gal). Removing 99% of the tank contents by volume would require retrieving at least 985,300 L (260,370 gal) of waste from tank C-104, equating to a maximum residual waste volume of 9,950 L (2,630 gal). A residual waste volume of 9,950 L (2,630 gal) would be slightly more restrictive (i.e., require more 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, the two goals for all practical purposes are the same.

6.2.5.1 Short-Term Human Health Risk Compliance Conclusions. The short-term human health risks associated with routine retrieval operations assumed in each of the nine waste retrieval cases do not exceed standards for the general public MEI. The incremental dose for the MEI at the Site boundary from tank C-104 retrieval operations (duration 30 days) is 1.2×10^{-11} rem/yr; therefore, the total is below the International Commission on Radiological Protection standard of 0.1 rem/yr (ICRP 1991).

6.2.5.2 Groundwater Protection Compliance Conclusions. Analysis results of the maximum groundwater concentration value for each CoC were compared to the EPA MCLs, DOE derived concentration guide, and 4 mrem effective dose equivalent concentrations for drinking water. Typically the EPA MCLs are the lowest regulatory standard. Nitrate is the only constituent to exceed the EPA MCLs in any of the nine waste retrieval cases. The constituent with the highest groundwater concentration is nitrate at 100 mg/L in Case 2; the EPA MCL for nitrate is 45 mg/L (EPA/822-B-96-002).

6.2.5.3 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). No exceedance of long-term human health risk occurs for tank C-104 and the C tank farm in the industrial worker scenario. The long-term human health risks associated with the residential farmer scenario exceed the Washington State standard of 1.0×10^{-5} ILCR and hazard index standard of 1.0 in all nine waste retrieval cases, but are below the EPA standard of 1.0×10^{-4} ILCR. Hazard index exceedance of 1.0 occurs for the residential farmer scenario for tank C-104 for Cases 2, 7, and 8.

6.2.5.4 Inadvertent Human Intrusion Compliance Conclusions. The analysis results indicate that Cases 2, 5, 6, 7, and 8 exceed the exposure performance objective for the post-driller resident (100 mrem/yr). Only cases with the minimal amount of residual waste (10,000 L [2,700 gal]) and no more than 30,000 L (8,000 gal) of waste retrieval leak losses do not exceed the chronic dose limit of 100 mrem/yr. The performance objective for the well driller indicates the performance objective for the acute dose (500 mrem/yr) is not exceeded for any case.

Under the NRC intruder scenario, used to establish Class C concentration limits for CoCs, none of the waste retrieval cases achieve satisfaction of the criteria. This issue becomes extremely important in determining waste retrieval goals in terms of closure decisions. Even if long-term human health risk is adequately addressed with most of the cases, none of the cases can meet the Class C LLW standard based on the criteria for incidental waste established by the NRC staff for the Savannah River Site tank closure (Travers 1999). The most significant regulatory issue relates to the LLW Class C standards for waste retrieval from tank C-104. The plutonium concentrations established under 10 CFR 61 for class C limits exceed the criteria. Discussion in Section 6.2.5.5 addresses this regulatory issue.

6.2.5.5 Additional Regulatory Issues. Conclusions related to regulatory issues beyond the four performance measure drivers are addressed in the following sections.

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. Mechanical removal technologies remove bulk quantities of waste, but do not preferentially remove key radionuclides. Therefore, reduction of volume by waste removal may not change concentrations. Chemical treatment which removes key radionuclides may be added to the retrieval technology employed for tank C-104.

6.2.5.5.2 Inadvertent Human Intruder Scenario Issues. The NRC regulatory requirements for the classification of Class C LLW is analyzed for tank C-104. The analysis reveals that 10 m^3 (360 ft^3) of residual waste will only meet Class C standards when the residual waste is mixed with 230 cm (89 in.) of grout per the methodology established for the Savannah River Site. The NRC incidental waste Criterion 2 states that:

> ...wastes will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR 61.

Using grout will ensure the waste will be in a solid physical form but uniformly mixing the residual with 230 cm (89 in.) of grout may not be technically feasible. NRC staff recommends 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 ten 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 the fractions for all Table 1 radionuclides shall not exceed 10, and the sum of the fractions for all Table 2 radionuclides shall not exceed 1. This standard is not attainable with tank C-104 because of the concentration of plutonium in the residual.

If DOE is not able to demonstrate that the residual waste meets less than Class C limits, DOE may need to consider different regulatory options to have NRC determine that the residual is incidental waste. Other than the baseline approach, other options potentially available to DOE are as follows:

- **Disposal as incidental waste, site-specific Class C limits** – If the residual waste does not meet NRC Class C LLW limits and as a result of the residual waste being located 16.2 m (55 ft) belowground surface in the tanks, Hanford Site-specific Class C limits can be established to meet the NRC scenario for intruder construction. The NRC has authority to develop a Site-specific Class C limit under 10 CFR 61.

  Implementation of this approach is uncertain because there is only regulatory precedent for NRC establishing site-specific Class C limits is the recent action at the Savannah River Site. Tank C-104 will not meet the Savannah River Site-specific limits. However, preliminary analysis in HNF-3428 indicates that Hanford Site-specific values can be developed and even the most problematic radionuclides in the Hanford Site SSTs are likely to meet the Class C performance objectives (i.e., dose limits) for the protection of inadvertent intruders.

- **Dispose as GTCC equivalent LLW** – The NRC does not rule out near-surface disposal of GTCC wastes. The NRC has, however, established the default option for GTCC as disposal in a geologic repository. The NRC states that (HNF-3428):

  > Disposal methods for GTCC waste must generally be more stringent than near-surface disposal. The proposed amendments to Part 61 specified that one "more stringent method would be geologic repository disposal. Other methods are not specified but are also left open to DOE, subject to Commission approval.

  This regulatory option is untested. The NRC has not established how it would determine if waste processing or facility design would be protective of intruders or the public and it is uncertain if the NRC or DOE would regulate onsite disposal. The NRC does not have authority to regulate the disposal of DOE LLW. However *Low-Level Radioactive Waste Policy Amendments of 1985* grants the NRC legislative authority to license the DOE disposal of commercially generated GTCC LLW, and this situation could be viewed as an extension of that existing authority (HNF-3428). In this case, because the SST residual waste is GTCC LLW, the NRC could become the regulator for onsite disposal based on 10 CFR 61. A major strength of this option is the recognition that the waste does not meet the characteristics of LLW (i.e., it exceeds Class C limits), and yet the waste does not need to be disposed of in a deep geologic repository (i.e., it is not HLW).

6.3 UNCERTAINTIES

The long-term human health risk analysis presented in this RPE is based on inventory projections for what would remain in the C farm tanks following waste retrieval and leak losses that could occur during waste retrieval from all C farm tanks. The inventory estimates were developed using wash factors; there is some uncertainty with the tank-specific wash factors, as the basis for the wash factors is approximate at best. Tank-specific chemical modeling could provide a better basis for calculating residual waste inventories and potential retrieval leakage should be considered in future RPE analyses.

Future updates of this RPE should consider specific contaminant transport simulations to reduce the uncertainties associated with scaling the results from DOE/RL-98-72. However, because the findings of this RPE indicate that the waste site intruder is the constraining performance measure and the RPE is a scoping-level evaluation, the uncertainty associated with scaling the contaminant transport is considered acceptable for making retrieval decisions.

DOE/RL-98-72 evaluates tank closure options that include demolition and removal of the tanks and contaminated soils from the tank farm. That study concludes the presence of retrieval leakage beneath the base of a tank would significantly add to worker doses from tank and soil excavation. The engineering approach developed for tank and soil excavation involves radiation workers operating shielded equipment. Remote operations are evaluated but would require substantial research and development efforts prior to deployment. Based on the AX tank farm analysis in DOE/RL-98-72 it can be concluded that large retrieval leak loss volumes could preclude clean closure due to the increased risk to workers.

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 (BBI 2000) and a methodology designed to provide a best estimate for retrieval leakage concentrations and residual waste concentrations that considers tank-specific wash factors. Several different approaches were identified for estimating the post-retrieval residual waste inventory. The variation in results obtained using different methods is an uncertainty that warrants further evaluation. Source terms or release rates from the tank residuals are conservative in that no credit is taken for stabilization of the tank residuals (e.g., grouting the residuals). Additionally the tanks are assumed to completely degrade at the same time providing a conservative estimate of residual waste impacts across the tank farm. The contaminant transport methodology and results for the AX tank farm RPE (DOE/RL-98-72), which were used as the basis for scaling tank C-104 and C tank farm impacts, was reviewed by a number of individuals. The risk factors used in this tank C-104 RPE for the industrial worker and residential farmer exposure scenarios were taken from DOE/RL-98-72 and DOE/EIS-0189. Both of these documents underwent 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. 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 DOE/RL-98-72 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 in overall uncertainty. The results of the DOE/RL-98-72 uncertainty analysis are generally applicable to this tank C-104 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 C 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 magnitude of the uncertainty should not be used to delay interim decisions to move forward with waste retrieval.

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APPENDIX

RETRIEVAL AND RESIDUAL INVENTORY CALCULATIONS

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CONTENTS

ATTACHMENTS

TABLES

LIST OF TERMS

BBI	best-basis inventory
DST	double-shell tank
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*

A.1.0 INTRODUCTION

The composition of the waste in each C farm tank was estimated for during and after waste retrieval. These waste composition estimates provide the estimated source terms for leaks that might occur during waste retrieval and for the residual waste that might be released from the tanks in the future. The principal sources of information for the estimates are the best-basis inventory (BBI) data (BBI 2000) and *Waste Tank Summary Report for Month Ending September 30, 2000* (HNF-EP-0182-150). The composition of all waste in each tank was estimated for during waste retrieval and for several potential compositions of waste residuals after retrieval according to the waste retrieval cases evaluated in the main text.

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. An average double-shell tank (DST) supernate is used as the waste retrieval-sluicing medium for retrieval operations at all C farm tanks except tank C-104 (i.e., DST AY-101 supernate is assumed to be used).

3. The baseline retrieval end point is as defined in the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989), commonly referred to as the Tri-Party Agreement; specifically, a wet sludge heel of 360 ft^3 (10,000 L [2,700 gal]) is assumed for 100-series tanks and 30 ft^3 (830 L [220 gal]) for 200-series tanks.

4. The initial conditions in the tanks are as defined in the BBI (BBI 2000).

5. Each component in the waste solids currently in the tanks will be dissolved according to the BBI wash factors upon addition of the waste retrieval liquid.

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 C tank 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-0182-150):

> 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.

The conventional units used in current Hanford Site documentation for tank compositions are used in the discussions and tables of this appendix. The units are as follows:

- Volumes – gallons
- Mass – kilograms
- Radionuclides – curies.

The values for volume had to be converted to liters to complete the inventory calculations reported in this appendix and then converted back to gallons when reported as calculation results.

A.2.0 PAST TANK LEAKS

Seven of the C farm tanks (C-101, C-110, C-111, C-201, C-202, C-203, and C-204) are classified as assumed leakers (HNF-EP-0182-150). Best-estimate radiological and chemical inventories were developed for past tank leaks based on available process information regarding the type of waste that was stored in the tank or that was transferred at the time the leaks were believed to have occurred (LA-UR-00-4050). The tank waste releases were estimated based on location, timing, and leak volume information from HNF-EP-0182-150. The leak compositions were defined using Hanford defined waste model waste streams (LA-UR-96-3860) and the supernate mixing model subroutine as a function of time (LA-UR-00-4050). Table A.1 summarizes the past leak source term inventory estimates.

Table A.1. Estimated Inventories for C Farm Tanks Past Leaks

CoCs	Units	Tank						
		241-C-101	241-C-110	241-C-111	241-C-201	241-C-202	241-C-203	241-C-204
Cr	Kg	1.96E+02	8.10E+00	6.05E+00	9.27E-01	7.09E-01	7.61E-01	6.02E-01
NO_2	kg	5.37E+03	1.55E+02	4.66E+02	8.84E+00	6.69E+00	7.22E+00	5.73E+00
NO_3	kg	6.29E+03	4.77E+02	1.36E+03	1.38E+02	1.05E+02	1.14E+02	9.01E+01
$U_{(TOTAL)}$	Kg	1.41E+02	6.90E+00	1.13E+01	8.92E-03	6.77E-03	7.30E-03	5.77E-03
^{14}C	Ci	5.52E+00	7.27E-02	6.64E-03	8.04E-04	6.13E-04	6.62E-04	5.24E-04
^{79}Se	Ci	7.68E-01	4.94E-03	1.67E-02	3.53E-03	2.68E-03	2.90E-03	2.30E-03
^{99}Tc	Ci	3.86E+01	5.12E-01	4.66E-02	5.69E-03	4.30E-03	4.65E-03	3.69E-03
^{129}I	Ci	7.45E-02	9.92E-04	8.95E-05	1.10E-05	8.35E-06	9.01E-06	7.14E-06
^{233}U	Ci	7.18E-03	1.59E-02	6.31E-09	5.48E-12	4.16E-12	4.49E-12	3.57E-12
^{234}U	Ci	4.66E-02	2.73E-03	3.67E-03	2.98E-06	2.27E-06	2.45E-06	1.94E-06
^{235}U	Ci	1.98E-03	1.06E-04	1.58E-04	1.26E-07	9.55E-08	1.03E-07	8.19E-08
^{236}U	Ci	9.10E-04	1.22E-04	6.21E-05	6.96E-08	5.28E-08	5.70E-08	4.53E-08
^{238}U	Ci	4.72E-02	2.30E-03	3.76E-02	2.96E-06	2.25E-06	2.44E-06	1.93E-06

CoCs = contaminants of concern.

A.3.0 RETRIEVAL AND RESIDUAL INVENTORY CALCULATIONS FOR RETRIEVAL OF TANK C-104 WASTE USING TANK AY-101 SUPERNATE

The current plan is to retrieve waste from tank C-104 using supernate from tank AY-101. This retrieval is planned as a confined sluicing and robotic technologies waste retrieval demonstration (RPP-6843). Retrieval of tank C-104 is scheduled to occur in fiscal year 2008 (RPP-7087). Tank C-104 currently contains approximately 263,000 gal of sludge and no supernate (HNF-EP-0182-150). Tank AY-101 currently contains about 94,000 gal of sludge (including interstitial liquid) and about 46,000 gal of supernate (HNF-EP-0182-150). The current compositions of the sludge in tank C-104 and the supernate in tank AY-101 from the BBI data (BBI 2000) are shown in Tables A.2 through A.5.

The BBI is the best inventory available but there is still considerable uncertainty in tank specific values. This is primarily due to the impossibility of getting representative samples. Representative sampling requires essentially free access to the sampled body, in this case the tanks. Single-shell tanks have such restricted access, and contain such heterogeneous waste that representative sampling is not possible. The BBI was established to make the best of this difficult circumstance and provide the best possible inventory estimates based on sample data, historical performance, and an evaluative process. The process used to evaluate tank data screens out some samples of other information as being unusable. One example of that is the tank C-104 sampling that is reported in *Inorganic and Radiochemical Analysis of 241-C-104 Tank Waste* (PNNL-13364). At the time of this report, the BBI is being re-baselined for all tanks.

A portion of the waste solids in tank C-104 will be dissolved in the retrieval liquid and transferred to tank AY-101, some will be retrieved as undissolved solids and transferred to tank AY-101 and a portion will remain in tank C-104 as a residual heel. Applying the BBI wash factors to the components in tank C-104 provides an estimate of each component that will remain undissolved and how much will dissolve in the retrieval liquid. About 64% of the BBI inventory will remain as undissolved solids, so about 678,000 kg of solids will remain in tank C-104 or will be retrieved to tank AY-101. The amount of solids in the residual heels was calculated using a porosity of 58.5%. Therefore, the estimated amount of residual solids in the 2,700 gal of residual sludge in tank C-104 will be 12,723 kg and about 665,300 kg of solids will be removed as a slurry in the retrieval liquid and transferred to tank AY-101.

The Tri-Party Agreement sets a goal of retrieving 89 kg (240 lb) of plutonium and 99% of the tank contents by volume. Removal of 99% of the original volume would leave a heel of 352 ft^3 (2,630 gal). This is basically the same as the common definition of 99% removal which leaves a heel of 360 ft^3 (2,700 gal), which would meet the goal of retrieving 89 kg (240 lb) of plutonium.

Table A.2. Current Chemical Inventory in Tank C-104

Analyte	Inventory (kg)	Analyte	Inventory (kg)
Al	9.15E+04	NO_2	3.70E+04
Bi	2.51E-00	NO_3	1.98E+04
Ca	3.03E+03	OH	4.44E+05
Cl	8.12E+02	Pb	8.49E+02
Cr	1.48E+03	PO_4	5.26E+03
F	3.51E+04	Si	1.04E+04
Fe	2.81E+04	SO_4	4.56E+03
Hg	3.53E-00	Sr	8.88E+01
K	1.35E+03	TIC as CO_3	4.93E+04
La	4.94E+01	TOC	1.44E+04
Mn	7.13E+03	U_{TOTAL}	5.45E+04
Na	1.82E+05	Zr	6.59E+04
Ni	2.67E+03	TOTAL	1.06E+06

Source: BBI 2000.

Table A.3. Current Radionuclide Inventory in Tank C-104

Analyte	Inventory (Ci)	Analyte	Inventory (Ci)
^{106}Ru	1.01E-01	^{236}U	9.47E-01
^{113}mCd	1.33E+02	^{237}Np	2.48E-02
^{125}Sb	8.19E-00	^{238}Pu	2.44E+02
^{126}Sn	2.15E+01	^{238}U	1.82E+01
^{129}I	1.39E-02	^{239}Pu	5.56E+03
^{134}Cs	6.54E-01	^{240}Pu	1.10E+03
^{137}Cs	1.14E+05	^{241}Am	6.37E+03
^{137}mBa	1.07E+05	^{241}Pu	1.66E+04
^{14}C	9.37E-01	^{242}Cm	5.87E-00
^{151}Sm	5.01E+04	^{242}Pu	9.65E-02
^{152}Eu	1.33E+01	^{243}Am	3.29E-01
^{154}Eu	1.93E+03	^{243}Cm	5.39E-01
^{155}Eu	8.24E+02	^{244}Cm	2.07E+01
^{226}Ra	4.34E-03	^{3}H	9.06E-00
^{227}Ac	6.19E+01	^{59}Ni	2.34E+01
^{228}Ra	1.98E+01	^{60}Co	6.78E+02
^{229}Th	4.39E-01	^{63}Ni	2.31E+03
^{231}Pa	1.11E+02	^{79}Se	1.34E+01
^{232}Th	1.10E-00	^{90}Sr	5.79E+05
^{232}U	2.32E+01	^{90}Y	5.79E+05
^{233}U	8.88E+01	^{93}mNb	4.95E+01
^{234}U	2.15E+01	^{93}Zr	5.83E+01
^{235}U	8.46E-01	^{99}Tc	2.52E+01

Source: BBI 2000.

Table A.4. Current Chemical Inventory in Tank AY-101 Supernate

Analyte	Inventory (kg)	Analyte	Inventory (kg)
Al	2.11E-00	NO_2	6.14E+03
Bi	4.70E-00	NO_3	4.52E+03
Ca	3.43E+01	OH	4.06E+03
Cl	1.11E+02	Pb	4.55E-00
Cr	1.83E+01	PO_4	2.00E+02
F	3.03E+01	Si	2.09E-00
Fe	2.09E-00	SO_4	1.02E+03
Hg	0.00E+01	Sr	8.04E-03
K	7.43E+01	TIC as CO_3	5.99E+03
La	1.17E-01	TOC	8.32E+02
Mn	4.14E-01	U_{TOTAL}	5.29E+01
Na	9.03E+03	Zr	2.83E-01
Ni	1.03E+01	TOTAL	3.21E+04

Source: BBI 2000.

Table A.5. Current Radionuclide Inventory in Tank AY-101 Supernate

Analyte	Inventory (Ci)	Analyte	Inventory (Ci)
^{106}Ru	3.54E-04	^{236}U	6.65E-04
^{113}mCd	4.29E-00	^{237}Np	2.00E-01
^{125}Sb	9.74E-00	^{238}Pu	2.12E-01
^{126}Sn	2.22E-01	^{238}U	1.77E-02
^{129}I	8.84E-04	^{239}Pu	1.90E-00
^{134}Cs	2.37E+01	^{240}Pu	5.75E-01
^{137}Cs	1.71E+04	^{241}Am	4.85E-00
^{137}mBa	1.62E+04	^{241}Pu	1.47E+01
^{14}C	5.22E-02	^{242}Cm	6.76E-03
^{151}Sm	5.18E+02	^{242}Pu	1.04E-04
^{152}Eu	2.76E-01	^{243}Am	4.95E-04
^{154}Eu	6.59E-00	^{243}Cm	7.90E-04
^{155}Eu	4.16E+01	^{244}Cm	2.99E-02
^{226}Ra	4.97E-06	^{3}H	1.94E-00
^{227}Ac	2.98E-05	^{59}Ni	7.80E-02
^{228}Ra	4.33E-03	^{60}Co	7.78E-00
^{229}Th	1.01E-04	^{63}Ni	7.71E-00
^{231}Pa	1.56E-04	^{79}Se	6.40E-02
^{232}Th	4.38E-04	^{90}Sr	3.29E+02
^{232}U	1.14E-02	^{90}Y	3.29E+02
^{233}U	4.36E-02	^{93}mNb	5.19E-01
^{234}U	1.94E-02	^{93}Zr	7.36E-01
^{235}U	7.86E-04	^{99}Tc	5.69E-00

Source: BBI 2000.

The amount of liquid that would be required for retrieval of 665,300 kg solids from tank C-104 would be greater than 1,000,000 gal based on the limitation of no greater than 10 wt% solids in solution transfers. This means that water will have to be added to tank AY-101 or tank C-104 in addition to the tank AY-101 supernate for retrieval of solids from tank C-104. However, a volume of more than 1,000,000 gal is not practical because that volume would exceed the capacity of tank AY-101. In actual practice, solids transferred out of tank C-104 will settle in tank AY-101 and the liquid will be recycled to tank C-104 to remove additional solids. Using this method, a smaller amount of liquid can be used without exceeding the 10 wt% limit in solution transferred between the tanks. Therefore, the maximum total amount of retrieval liquid would be the available 840,000-gal capacity of tank AY-101 (HNF-EP-0182-150) plus the 46,000 gal of supernate now in tank AY-101 (HNF-EP-0182-150) minus the solids removed from tank C-104 (58,700 gal). This equates to a maximum total retrieval liquid volume of 735,300 gal. A value of 700,000 gal was used to calculate the concentrations of components in the retrieval liquid. The concentrations in the retrieval liquid is then the sum of the contributions from both tanks C-104 and AY-101 divided by the volume of approximately 700,000 gal.

Because retrieval will be a dynamic operation with several liquid additions and slurry transfers, it is difficult to predict a tank C-104 tank composition at the time of a potential leak. The assumption made in Attachment A1 is that the liquid concentrations at the time of a leak are the same as the final concentrations in tank AY-101 after retrieval is completed.

Attachment A1 provides the calculated composition of the residual heel in tank C-104. Four residual heel calculations are presented, a 360 ft^3 (10,000 L [2,700 gal]) heel, a 800 ft^3 (23,000 L [6,000 gal]) heel, a 3,600 ft^3 (100,000 L [27,000 gal]) heel, and a 6,700 ft^3 (190,000 L [50,000 gal]) heel. The values include both the solid heel and liquid heel after retrieval. The compositions of three potential leakage volumes are also presented.

A.4.0 RESIDUAL WASTE INVENTORY CALCULATIONS FOR TANK C-106

For this task, it was assumed that tank C-106 would not be retrieved a second time. Therefore, the new BBI inventory was used for tank C-106 after waste retrieval. Tables A.6 and A.7 summarize these inventory estimate results.

It should be noted that work is in progress to validate the belief that the selenium-79 half-life value currently used in the scientific community and to generate the BBI is low by more than a factor of 10. It is postulated that the true half-life should be 1.1×10^6 years rather than 6.4×10^4 years (GE 1996). The BBI result for selenium-79 was developed through the ORIGIN2 computer model, which calculated the amount of selenium-79 that was produced from reactor fuel processing at the Hanford Site (SD-CP-TI-077). The ORIGIN2 model used the specific activity to convert from grams of selenium-79 to curies, and the specific activity has an inversely proportional relationship to the half-life. Therefore, an increase in the selenium-79 half-life would translate to less selenium-79 having been produced. This decrease in production would offset the increase in selenium-79 currently in the tank waste as a result of a slower decay rate, resulting in an overall decrease in the selenium-79 inventory. However, the BBI organization is not yet implementing corrections to the inventory data as a result of this change, so no revisions have been made to the selenium-79 inventory estimates for this report.

Table A.6. Residual Waste Inventory Estimate for Chemical Components in Tank C-106

Analyte	Total Inventory (kg)	Analyte	Total Inventory (kg)
Al	2.65E+03	NO_2	1.52E+03
Bi	4.58E+00	NO_3	9.99E+01
Ca	9.10E+01	OH	1.10E+04
Cl	3.48E+01	Pb	1.55E+02
Cr	6.07E+01	PO_4	1.28E+03
F	3.76E+01	Si	2.83E+01
Fe	2.46E+03	SO_4	5.14E+02
Hg	0.00E+00	Sr	9.69E+00
K	8.28E+01	TIC as CO_3	1.42E+04
La	1.15E+01	TOC	3.52E+02
Mn	1.02E+03	U_{TOTAL}	1.07E+02
Na	1.30E+04	Zr	3.78E-01
Ni	1.57E+02		

Table A.7. Residual Waste Inventory Estimate for Radiological Components in Tank C-106 (Decayed to January 1, 1994)

Analyte	Total Inventory (Ci)	Analyte	Total Inventory (Ci)
^{106}Ru	1.38E-03	^{236}U	9.60E-04
^{113}mCd	1.66E+01	^{237}Np	8.14E-02
^{125}Sb	1.41E+01	^{238}Pu	6.64E-01
^{126}Sn	8.31E-01	^{238}U	3.59E-02
^{129}I	5.04E-02	^{239}Pu	4.17E+01
^{134}Cs	6.42E-01	^{240}Pu	6.37E+00
^{137}Cs	1.86E+04	^{241}Am	2.64E+01
^{137}mBa	1.76E+04	^{241}Pu	4.83E+01
^{14}C	3.71E+00	^{242}Cm	2.26E-01
^{151}Sm	1.94E+03	^{242}Pu	1.88E-04
^{152}Eu	6.26E-01	^{243}Am	3.59E-04
^{154}Eu	8.03E+01	^{243}Cm	6.08E-03
^{155}Eu	4.11E+01	^{244}Cm	3.66E-02
^{226}Ra	1.72E-05	^{3}H	1.64E+00
^{227}Ac	9.98E-05	^{59}Ni	4.02E-01
^{228}Ra	6.97E-06	^{60}Co	8.39E-01
229Th	3.24E-06	^{63}Ni	3.93E+01
^{231}Pa	5.54E-04	^{79}Se	5.54E-01
^{232}Th	2.99E-05	^{90}Sr	2.53E+05
^{232}U	1.02E-02	^{90}Y	2.53E+05
^{233}U	3.96E-02	^{93}mNb	1.94E+00
^{234}U	3.68E-02	^{93}Zr	2.77E+00
^{235}U	1.53E-03	^{99}Tc	2.60E+01

A.5.0 RETRIEVAL AND RESIDUAL INVENTORY CALCULATIONS FOR RETRIEVAL OF REMAINING C FARM TANKS

The methodology for the inventory calculations for the rest of the C farm tanks was similar to the method used for tank C-104, with two principal differences.

1. An average supernate was used as the retrieval liquid. (The determination of the composition of this average supernate is described below.)

2. The amount of retrieval liquid used was based on not exceeding the limitation of 10 wt% solids in the solution transferred out of the tank. No limitation was placed on the retrieval liquid volume.

To prevent generation of new volumes of liquid waste it was decided to calculate retrieval using existing supernate. Consequently, calculations of leakage during retrieval of the C farm tanks be based on using available DST supernate. A spreadsheet of Hanford Tank Waste Operation Simulator model projections of DST compositions during the time when C tank farm waste retrieval is planned was supplied by CH2M HILL Hanford Group, Inc.

An average DST supernate composition used in the calculations was determined as follows.

1. All tanks on the spreadsheet with a sodium concentration greater than 4.1 and less than 2.5 Molar were eliminated. This provides a mid-range average for sodium concentration.

2. Tanks SY-102 and SY-103 were eliminated because they are in the 200 West Area.

3. Values obviously much larger or smaller than other values for that component in the tank were eliminated.

4. No zero values were used.

5. Concentrations of the contaminants of concern were verified to be similar for all the tanks used in the average.

The values in the spreadsheet supplied were predicted quantities of each component. These values were then converted to a concentration by dividing by the volume. Tables A.8 and A.9 provide the composition of the average DST supernate to be used in the calculations for retrieval liquid compositions during retrieval of the C farm tanks.

Because no wash factors were available with which to estimate the soluble components in the supernate retrieval medium, the wash factors associated with water as the retrieval medium were used. Tank-specific water wash factors have been developed for each component in the waste and are documented in the *Best-Basis Wash and Leach Factor Analysis* (HNF-3157). The wash factors 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.

Table A.8. Concentrations of Chemicals in Average Double-Shell Tank Supernate for C Farm Retrieval

Component	Concentration (g/L)	Component	Concentration (g/L)
Ag	5.1E-07	Mg	2.1E-06
Al	6.9E+00	Mn	2.1E-03
As	4.6E-07	Na	8.3E+01
Ba	7.0E-05	*Na Molarity (moles/L)*	*3.6*
Bi	7.3E-03	NH_3	3.2E-01
Ca	2.4E-02	Ni	1.6E-02
Cd	7.7E-06	NO_2	1.9E+01
Ce	2.3E-04	NO_3	8.8E+01
Cl	1.3E+00	OH Bound	2.8E+00
TIC as CO_3	2.6E+01	OH	4.4E+00
Cr	6.5E-01	Pb	8.3E-03
Cs	1.7E-03	PO_4	5.2E+00
Cu	4.9E-07	Si	5.3E-01
F	1.8E+00	SO_4	6.2E+00
Fe	3.4E-02	Sr	5.0E-03
H_2O	9.2E+02	TOC	9.8E-01
Hg	2.5E-04	U_{TOTAL}	9.0E-05
K	1.0E+00	V	6.2E-06
La	1.6E-04	Zr	2.4E-02
Li	1.3E-06		

Table A.9. Concentrations of Radionuclides in Average Double-Shell Tank Supernate for C Farm Retrieval

Component	Concentration (g/L)	Component	Concentration (g/L)
^{106}Ru	3.8E-10	^{236}U	8.4E-10
^{113}mCd	6.5E-06	^{237}Np	5.2E-08
^{125}Sb	1.6E-05	^{238}Pu	3.9E-08
^{126}Sn	2.5E-07	^{238}U	2.7E-08
^{129}I	9.4E-08	^{239}Pu	1.4E-06
^{134}Cs	2.4E-06	^{240}Pu	2.3E-07
^{137}Cs	5.4E-02	^{241}Am	2.8E-06
^{137}mBa	5.3E-02	^{241}Pu	2.7E-06
^{14}C	7.5E-06	^{242}Cm	2.7E-08
^{151}Sm	4.0E-04	^{242}Pu	1.4E-11
^{152}Eu	2.4E-07	^{243}Am	3.3E-10
^{154}Eu	1.8E-05	^{243}Cm	2.6E-09
^{155}Eu	1.5E-05	^{244}Cm	3.0E-08
^{226}Ra	1.5E-11	^{3}H	4.6E-05
^{227}Ac	3.5E-11	^{59}Ni	1.4E-07
^{228}Ra	3.0E-08	^{60}Co	2.1E-06
229Th	3.4E-10	^{63}Ni	1.4E-05
^{231}Pa	6.5E-10	^{79}Se	1.4E-06
^{232}Th	1.1E-09	^{90}Sr	1.3E-02
^{232}U	1.6E-08	^{90}Y	1.4E-02
^{233}U	6.2E-08	^{93}mNb	1.8E-06
^{234}U	2.7E-08	^{93}Zr	1.4E-06
^{235}U	1.1E-09	^{99}Tc	5.3E-05

This method for determining residual waste inventories was chosen because it relies on the same data currently being used in the Hanford Tank Waste Operation Simulator model to simulate all of the tank farm retrieval operations. The Hanford Tank Waste Operation 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 200-series tanks, with a similar porosity. The average calculated heel porosity for the 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.

This method provides the basis for calculating the residual solids volume fraction and residual liquid volume fraction for each of the 100- and 200-series tanks. The results of the calculations are in Attachment A2.

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ATTACHMENT A1

CALCULATION OF TANK C-104 INVENTORY

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Tank C-104 Inventories Leak Data

Analyte	Retrieval Leak Loss		
	8,000 gal	40,000 gal	80,000 gal
NO_2 (kg)	1.3E+06	6.5E+06	1.3E+07
NO_3 (kg)	7.4E+05	3.7E+06	7.4E+06
U_{TOTAL} (kg)	3.6E+03	1.8E+04	3.6E+04
^{14}C (Ci)	2.9E+04	1.4E+05	2.9E+05
^{60}Co (Ci)	1.1E+06	5.3E+06	1.1E+07
^{63}Ni (Ci)	3.1E+06	1.5E+07	3.1E+07
^{79}Se (Ci)	4.1E+05	2.0E+06	4.1E+06
^{90}Sr (Ci)	5.8E+09	2.9E+10	5.8E+10
^{90}Y (Ci)	5.8E+09	2.9E+10	5.8E+10
^{99}Tc (Ci)	8.7E+05	4.3E+06	8.7E+06
^{126}Sn (Ci)	1.2E+05	6.2E+05	1.2E+06
^{129}I (Ci)	2.0E+02	1.0E+03	2.0E+03
^{137}Cs (Ci)	2.5E+09	1.2E+10	2.5E+10
^{137m}Ba (Ci)	2.3E+09	1.2E+10	2.3E+10
^{233}U (Ci)	4.6E+03	2.3E+04	4.6E+04
^{234}U (Ci)	1.4E+03	6.9E+03	1.4E+04
^{235}U (Ci)	5.5E+01	2.7E+02	5.5E+02
^{236}U (Ci)	5.5E+01	2.7E+02	5.5E+02
^{238}U (Ci)	1.2E+03	6.0E+03	1.2E+04
^{238}Pu (Ci)	9.5E+03	4.7E+04	9.5E+04
^{239}Pu (Ci)	1.3E+05	6.3E+05	1.3E+06
^{240}Pu (Ci)	3.1E+04	1.6E+05	3.1E+05
^{241}Pu (Ci)	6.5E+05	3.3E+06	6.5E+06
^{242}Pu (Ci)	4.4E+00	2.2E+01	4.4E+01
^{241}Am (Ci)	5.2E+05	2.6E+06	5.2E+06
^{243}Am (Ci)	3.4E+01	1.7E+02	3.4E+02
^{243}Cm (Ci)	3.0E+02	1.5E+03	3.0E+03
^{244}Cm (Ci)	1.1E+04	5.7E+04	1.1E+05

Tank C-104 Inventories Heel Data

Analyte	Heel Volume			
	360 ft^3	802 ft^3	3,600 ft^3	6,700 ft^3
Cr	2.3E+01	5.1E+01	2.3E+02	4.3E+02
NO_2	2.8E+01	2.2E+02	9.7E+02	1.8E+03
NO_3	1.6E+01	1.2E+02	5.5E+02	1.0E+03
U_{TOTAL}	9.2E+02	2.0E+03	9.2E+03	1.7E+04
^{14}C	1.2E-03	6.1E-03	2.7E-02	5.0E-02
^{60}Co	1.1E+01	2.5E+01	1.1E+02	2.1E+02
^{63}Ni	3.8E+01	8.4E+01	3.8E+02	7.0E+02
^{79}Se	8.9E-03	6.8E-02	3.0E-01	5.6E-01
^{90}Sr	6.7E+03	1.6E+04	7.0E+04	1.3E+05
^{90}Y	6.7E+03	1.6E+04	7.0E+04	1.3E+05
^{99}Tc	5.6E-02	2.3E-01	1.0E+00	1.9E+00
^{126}Sn	3.0E-01	6.8E-01	3.1E+00	5.7E+00
^{129}I •	1.4E-04	3.4E-04	1.5E-03	2.8E-03
^{137}Cs	9.0E+02	2.3E+03	1.0E+04	1.9E+04
^{137}mBa	8.5E+02	2.2E+03	9.7E+03	1.8E+04
^{233}U	1.5E+00	3.3E+00	1.5E+01	2.8E+01
^{234}U	3.6E-01	8.1E-01	3.6E+00	6.7E+00
^{235}U	1.4E-02	3.2E-02	1.4E-01	2.6E-01
^{236}U	1.6E-02	3.6E-02	1.6E-01	3.0E-01
^{238}U	3.1E-01	6.8E-01	3.1E+00	5.7E+00
^{238}Pu	4.1E+00	9.2E+00	4.1E+01	7.6E+01
^{239}Pu	9.4E+01	2.1E+02	9.4E+02	1.7E+03
^{240}Pu	1.9E+01	4.1E+01	1.9E+02	3.4E+02
^{241}Pu	2.8E+02	6.2E+02	2.8E+03	5.2E+03
^{242}Pu	1.6E-03	3.6E-03	1.6E-02	3.0E-02
^{241}Am	1.1E+02	2.4E+02	1.1E+03	2.0E+03
^{243}Am	5.6E-03	1.2E-02	5.6E-02	1.0E-01
^{243}Cm	9.0E-03	2.0E-02	9.0E-02	1.7E-01
^{244}Cm	3.4E-01	7.7E-01	3.5E+00	6.4E+00

ATTACHMENT A2

RETRIEVAL LIQUID AND RESIDUAL HEEL INVENTORIES FOR CONTAMINANTS OF CONCERN

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C Farm Tank Inventories (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
NO_2 (kg)	5.3E+03	2.2E+04	1.1E+04	5.1E+03	2.1E+04	8.7E+03	1.2E+04	6.7E+03	5.3E+03	3.6E+04	8.0E+01	2.0E+02	5.9E+01	2.5E+01
NO_3 (kg)	3.7E+04	6.7E+04	1.5E+03	6.8E+03	5.2E+04	1.6E+04	1.2E+04	1.1E+05	1.1E+04	4.8E+04	4.3E+02	6.1E+02	2.2E+03	8.2E+02
U_{TOTAL} (kg)	5.1E+03	1.6E+04	2.1E+03	6.4E+03	3.9E+03	1.5E+02	3.7E+03	2.1E+03	4.2E+03	3.6E+04	2.2E+00	1.1E+00	3.9E+00	1.6E+00
^{14}C (Ci)	2.8E-01	2.1E-01	2.0E-01	5.9E-01	6.0E-01	6.8E-02	5.7E-03	3.1E-01	3.2E-02	2.7E+00	1.1E-02	1.1E-03	4.2E-02	2.2E-02
^{60}Co (Ci)	9.9E+01	6.1E+02	1.3E+03	1.9E+02	7.5E+02	1.5E-02	3.3E-02	8.6E-03	9.1E-03	4.6E-02	1.4E-03	1.2E-03	1.9E-03	1.5E-03
^{63}Ni (Ci)	1.6E+00	4.0E+00	1.1E+03	2.0E+00	4.6E+03	4.8E+01	4.7E+02	1.5E+00	2.0E+01	9.1E+02	4.2E+01	4.2E+01	4.2E+01	4.2E+01
^{79}Se (Ci)	1.3E-02	4.4E-02	5.3E+00	1.6E-02	2.6E+01	1.4E-02	5.8E-02	1.8E+00	6.6E-03	2.4E-01	5.2E-03	4.9E-03	6.0E-03	5.5E-03
^{90}Sr (Ci)	2.7E+05	1.8E+05	1.9E+06	4.7E+05	1.7E+06	9.5E+03	2.2E+05	4.6E+03	1.2E+06	1.3E+06	9.3E+02	1.5E+04	9.3E+03	7.1E+02
^{90}Y (Ci)	2.7E+05	1.8E+05	1.9E+06	4.7E+05	1.7E+06	9.5E+03	2.2E+05	4.6E+03	1.2E+06	1.3E+06	9.3E+02	1.5E+04	9.3E+03	7.1E+02
^{99}Tc (Ci)	4.0E+01	1.2E+00	2.0E+02	6.5E+01	1.1E+02	4.7E-01	3.1E+01	3.2E+01	2.2E-01	8.0E+01	1.7E-02	8.0E-03	4.3E-02	2.6E-02
^{126}Sn (Ci)	2.0E-02	6.2E-02	8.6E+00	2.5E-02	4.1E+01	2.2E-02	9.0E-02	1.9E-02	1.0E-02	6.6E-02	8.3E-03	7.9E-03	9.5E-03	8.7E-03
^{129}I (Ci)	4.5E-02	2.6E-03	1.4E-02	6.5E-02	7.8E-03	8.9E-04	1.5E-03	7.9E-04	4.1E-04	2.4E-03	3.2E-05	1.5E-05	8.1E-05	4.8E-05
^{137}Cs (Ci)	4.2E+04	6.3E+04	6.2E+04	8.1E+04	3.1E+04	9.1E+04	2.4E+05	1.8E+04	1.2E+04	2.5E+05	1.8E+02	9.2E+01	3.2E+02	1.3E+02
^{137m}Ba (Ci)	4.0E+04	5.9E+04	5.9E+04	7.7E+04	2.9E+04	8.6E+04	2.2E+05	1.7E+04	1.2E+04	2.3E+05	1.7E+02	8.7E+01	3.0E+02	1.3E+02
^{233}U (Ci)	4.2E-01	3.4E+00	2.4E-01	3.7E-06	1.3E-01	3.5E-08	8.8E-07	4.9E-07	1.3E-06	9.0E-01	5.1E-10	7.0E-10	9.1E-10	3.8E-10
^{234}U (Ci)	1.7E+00	5.4E+00	6.8E-01	2.1E+00	1.3E+00	4.9E-02	1.2E+00	6.9E-01	1.4E+00	1.2E+01	7.1E-04	3.8E-04	1.3E-03	5.4E-04
^{235}U (Ci)	7.4E-02	2.3E-01	2.9E-02	8.9E-02	5.7E-02	2.2E-03	5.5E-02	3.1E-02	6.2E-02	5.3E-01	3.2E-05	1.6E-05	5.8E-05	2.4E-05
^{236}U (Ci)	3.0E-02	1.5E-01	1.2E-02	3.6E-02	1.2E-02	3.1E-04	7.9E-03	4.4E-03	1.2E-02	1.5E-01	4.6E-06	8.8E-06	8.2E-06	3.5E-06
^{238}U (Ci)	1.7E+00	5.2E+00	6.9E-01	2.1E+00	1.3E+00	4.9E-02	1.2E+00	7.0E-01	1.4E+00	1.2E+01	7.2E-04	3.8E-04	1.3E-03	5.5E-04
^{238}Pu (Ci)	1.7E+01	1.7E+02	7.7E+01	7.5E+00	3.8E+01	1.2E-02	2.2E+00	2.4E-01	3.2E+00	5.5E+00	2.8E+00	7.6E-01	5.8E-01	6.9E-03
^{239}Pu (Ci)	8.1E+02	5.9E+03	4.7E+03	4.8E+02	1.2E+03	3.1E+00	9.2E+01	7.4E+01	2.1E+02	6.0E+01	1.2E+02	3.2E+01	2.5E+01	2.9E-01
^{240}Pu (Ci)	1.4E+02	1.1E+03	7.2E+02	7.3E+01	2.1E+02	2.0E-01	1.5E+01	4.3E+00	3.2E+01	9.5E+00	1.9E+01	5.3E+00	4.1E+00	4.8E-02
^{241}Pu (Ci)	1.3E+03	1.3E+04	5.6E+03	5.5E+02	2.8E+03	2.6E-01	1.6E+02	2.8E+00	2.3E+02	8.3E+01	2.0E+02	5.5E+01	4.2E+01	5.0E-01

C Farm Tank Inventories (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
^{242}Pu (Ci)	4.0E-03	5.0E-02	2.3E-02	2.1E-03	1.5E-02	1.1E-06	7.7E-04	8.5E-06	8.9E-04	3.0E-04	9.9E-04	2.7E-04	2.1E-04	2.5E-06
^{241}Am (Ci)	4.9E+02	1.5E+03	9.1E+02	9.8E+02	1.6E+03	1.2E-01	4.5E+01	2.1E-02	1.2E-01	2.2E+02	4.0E+01	1.1E+01	8.3E+00	9.9E-02
^{243}Am (Ci)	4.3E-03	1.4E-01	2.1E-02	9.2E-03	8.4E-02	7.9E-07	1.1E-03	6.0E-08	9.6E-07	5.0E-03	9.6E-04	2.6E-04	2.0E-04	2.4E-06
^{243}Cm (Ci)	2.0E-01	2.7E+00	7.5E-02	2.6E-01	1.2E-01	5.1E-05	4.0E-03	3.6E-07	3.8E-05	3.6E-02	3.5E-03	9.6E-04	7.3E-04	8.7E-06
^{244}Cm (Ci)	1.6E-01	5.9E+01	5.2E-01	4.4E-01	4.9E+00	1.9E-05	1.9E-03	9.1E-07	3.8E-05	8.7E-01	1.7E-03	4.7E-04	3.6E-04	4.2E-06

Source: BBI 2000.

C Farm Tank Post-Retrieval Heel Inventories (360 ft³ for 100-Series Tanks, 30 ft³ for 200-Series Tanks) (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
NO_2 (kg)	3.2E+01	3.1E+01	2.9E+01	2.9E+01	3.4E+01	4.1E+01	5.6E+01	7.1E+01	3.2E+01	8.3E+01	2.3E+00	2.8E+00	2.2E+00	2.2E+00
NO_3 (kg)	1.6E+02	1.3E+02	9.5E+01	1.2E+02	1.2E+03	1.4E+02	1.6E+02	1.0E+03	2.1E+02	2.4E+02	1.1E+01	1.2E+01	1.1E+01	1.1E+01
U_{TOTAL} (kg)	4.6E+02	3.3E+02	6.9E+01	2.7E+02	9.1E+01	1.7E+01	3.7E+02	1.6E+02	3.3E+02	2.2E+03	2.7E-01	2.8E-01	2.0E-01	1.2E-01
^{14}C (Ci)	1.1E-02	9.8E-03	8.4E-03	8.6E-04	1.9E-02	1.0E-02	9.8E-03	9.8E-03	1.0E-02	1.5E-02	8.6E-04	8.4E-04	8.7E-04	8.6E-04
^{60}Co (Ci)	8.8E+00	1.3E+01	7.1E+01	7.9E+00	2.3E+01	4.7E-03	6.0E-03	3.2E-03	3.6E-03	5.1E-03	4.3E-04	5.3E-04	3.3E-04	3.5E-04
^{63}Ni (Ci)	1.6E-01	1.0E-01	5.8E+01	9.0E-02	1.4E+02	6.2E+00	4.7E+01	1.4E-01	1.6E+00	5.3E+01	5.8E+00	1.0E+01	2.1E+00	3.0E+00
^{79}Se (Ci)	1.9E-03	1.8E-03	5.6E-03	1.9E-06	2.1E-02	1.9E-03	2.3E-03	3.7E-03	1.9E-03	2.9E-03	1.7E-04	1.7E-04	1.6E-04	1.6E-04
^{90}Sr (Ci)	2.4E+04	3.8E+03	1.0E+05	2.1E+04	5.1E+04	1.2E+03	2.2E+04	3.7E+02	8.7E+04	7.7E+04	6.7E+01	1.8E+03	2.4E+02	2.8E+01
^{90}Y (Ci)	2.4E+04	3.8E+03	1.0E+05	2.1E+04	5.1E+04	1.2E+03	2.2E+04	3.7E+02	8.7E+04	7.7E+04	6.7E+01	1.8E+03	2.4E+02	2.8E+01
^{99}Tc (Ci)	4.3E-01	7.1E-02	2.1E-01	1.0E+00	1.4E+00	7.1E-02	9.0E-01	3.0E-01	7.1E-02	1.4E+00	6.0E-03	6.0E-03	6.0E-03	6.0E-03
^{126}Sn (Ci)	2.0E-03	1.5E-03	4.8E-01	8.3E-04	1.2E+00	3.0E-03	9.3E-03	1.7E-03	1.1E-03	4.4E-03	1.2E-03	2.0E-03	5.1E-04	6.6E-04
^{129}I (Ci)	2.5E-03	1.5E-04	1.1E-04	1.7E-07	1.3E-04	1.3E-04	1.7E-04	1.1E-04	1.3E-04	1.7E-04	1.1E-05	1.1E-05	1.1E-05	1.1E-05
^{137}Cs (Ci)	1.1E+03	4.2E+02	2.9E+03	3.3E+03	6.7E+02	1.1E+04	2.4E+04	7.0E+02	8.6E+01	1.3E+04	1.7E+01	6.4E+00	6.3E+00	6.2E+00
^{137m}Ba (Ci)	1.0E+03	4.0E+02	2.7E+03	3.1E+03	6.3E+02	1.1E+04	2.2E+04	6.6E+02	8.4E+01	1.2E+04	1.6E+01	6.3E+00	6.2E+00	6.1E+00
^{233}U (Ci)	3.8E-02	7.2E-02	8.0E-03	2.4E-07	3.1E-03	8.2E-05	8.1E-05	7.4E-05	8.3E-05	5.3E-02	6.9E-06	6.9E-06	6.9E-06	6.9E-06
^{234}U (Ci)	1.5E-01	1.2E-01	2.3E-02	8.7E-02	3.0E-02	5.6E-03	1.2E-01	5.2E-02	1.1E-01	7.1E-01	9.3E-05	9.6E-05	6.8E-05	4.2E-05
^{235}U (Ci)	6.7E-03	4.8E-03	9.7E-04	3.7E-03	1.3E-03	2.5E-04	5.5E-03	2.4E-03	4.9E-03	3.1E-02	4.2E-06	4.0E-06	3.0E-06	1.9E-06
^{236}U (Ci)	2.7E-03	3.2E-03	4.2E-04	1.5E-03	2.9E-04	3.7E-05	7.9E-04	3.4E-04	9.7E-04	8.8E-03	6.7E-07	2.3E-06	5.1E-07	3.5E-07
^{238}U (Ci)	1.5E-01	1.1E-01	2.3E-02	9.0E-02	3.0E-02	5.7E-03	1.2E-01	5.3E-02	1.1E-01	7.2E-01	9.4E-05	9.5E-05	6.9E-05	4.3E-05
^{238}Pu (Ci)	1.5E+00	3.6E+00	4.3E+00	3.3E-01	1.2E+00	1.6E-03	2.1E-01	1.8E-02	2.5E-01	3.3E-01	3.9E-01	1.9E-01	2.9E-02	5.0E-04
^{239}Pu (Ci)	7.3E+01	1.3E+02	2.6E+02	2.1E+01	3.5E+01	3.9E-01	9.1E+00	5.6E+00	1.6E+01	3.6E+00	1.6E+01	7.9E+00	1.2E+00	2.1E-02
^{240}Pu (Ci)	1.2E+01	2.3E+01	4.0E+01	3.2E+00	6.4E+00	2.5E-02	1.5E+00	3.3E-01	2.5E+00	5.8E-01	2.7E+00	1.3E+00	2.0E-01	3.5E-03
^{241}Pu (Ci)	1.2E+02	2.8E+02	3.1E+02	2.4E+01	8.4E+01	3.6E-02	1.5E+01	2.1E-01	1.8E+01	5.0E+00	2.8E+01	1.4E+01	2.1E+00	3.6E-02

C Farm Tank Post-Retrieval Heel Inventories (360 ft^3 for 100-Series Tanks, 30 ft^3 for 200-Series Tanks) (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
^{242}Pu (Ci)	3.6E-04	1.1E-03	1.3E-03	9.2E-05	4.4E-04	1.5E-07	7.6E-05	6.6E-07	7.0E-05	1.8E-05	1.4E-04	6.6E-05	1.0E-05	1.8E-07
^{241}Am (Ci)	4.3E+01	3.0E+01	5.0E+01	1.1E+01	3.8E+01	1.7E-02	4.5E+00	5.0E-03	1.3E-02	1.3E+01	5.6E+00	2.7E+00	4.2E-01	7.5E-03
^{243}Am (Ci)	3.7E-04	2.8E-03	1.2E-03	1.0E-04	2.0E-03	5.3E-07	1.1E-04	4.0E-07	5.2E-07	3.1E-04	1.3E-04	6.4E-05	1.0E-05	2.1E-07
^{243}Cm (Ci)	1.8E-02	5.6E-02	4.2E-03	1.2E-02	3.7E-03	9.8E-06	4.1E-04	3.2E-06	6.4E-06	2.1E-03	3.1E-04	3.6E-06	8.1E-07	3.0E-07
^{244}Cm (Ci)	1.4E-02	1.2E+00	2.9E-02	2.0E-02	1.5E-01	4.2E-05	2.3E-04	3.6E-05	4.3E-05	5.1E-02	1.5E-04	4.9E-06	3.6E-06	3.3E-06

C Farm Tank Post-Retrieval Heel Inventories (802 ft^3 for 100-Series Tanks, 80 ft^3 for 200-Series Tanks) (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
NO_2 (kg)	3.2E+02	3.1E+02	2.8E+02	2.8E+02	3.3E+02	4.0E+02	4.4E+02	3.8E+02	3.1E+02	6.1E+02	1.8E+01	2.2E+01	1.7E+01	1.7E+01
NO_3 (kg)	1.6E+03	1.3E+03	9.3E+02	1.2E+03	3.6E+03	1.4E+03	1.4E+03	3.9E+03	1.4E+03	1.7E+03	8.3E+01	9.3E+01	8.9E+01	8.3E+01
U_{TOTAL} (kg)	1.0E+03	7.3E+02	1.6E+02	6.0E+02	2.0E+02	3.8E+01	8.3E+02	3.5E+02	7.4E+02	4.8E+03	4.9E-01	4.9E-01	3.5E-01	2.1E-01
^{14}C (Ci)	1.0E-01	9.5E-02	8.0E-02	2.0E-03	1.2E-01	9.8E-02	9.6E-02	9.2E-02	9.8E-02	1.3E-01	6.7E-03	6.6E-03	6.8E-03	6.7E-03
^{60}Co (Ci)	2.0E+01	2.8E+01	1.6E+02	1.8E+01	5.2E+01	3.2E-02	3.5E-02	2.6E-02	3.0E-02	3.3E-02	2.2E-03	2.4E-03	2.0E-03	2.1E-03
^{63}Ni (Ci)	5.0E-01	3.6E-01	1.3E+02	2.0E-01	3.1E+02	1.4E+01	1.0E+02	4.3E-01	3.7E+00	1.2E+02	1.0E+01	1.8E+01	3.7E+00	5.4E+00
^{79}Se (Ci)	1.9E-02	1.8E-02	5.5E-02	1.8E-05	1.4E-01	1.8E-02	2.0E-02	3.6E-02	1.8E-02	2.2E-02	1.3E-03	1.4E-03	1.3E-03	1.3E-03
^{90}Sr (Ci)	5.4E+04	8.6E+03	2.3E+05	4.6E+04	1.1E+05	2.9E+03	5.0E+04	9.4E+02	1.9E+05	1.7E+05	1.3E+02	3.4E+03	4.5E+02	6.0E+01
^{90}Y (Ci)	5.4E+04	8.6E+03	2.3E+05	4.6E+04	1.1E+05	2.9E+03	5.0E+04	9.5E+02	1.9E+05	1.7E+05	1.3E+02	3.4E+03	4.5E+02	6.0E+01
^{99}Tc (Ci)	1.9E+00	6.8E-01	2.1E+00	2.3E+00	3.8E+00	7.0E-01	2.8E+00	1.4E+00	7.0E-01	4.0E+00	4.7E-02	4.7E-02	4.7E-02	4.7E-02
^{126}Sn (Ci)	7.0E-03	5.8E-03	1.1E+00	1.8E-03	2.7E+00	9.1E-03	2.3E-02	6.1E-03	5.0E-03	1.2E-02	2.3E-03	3.6E-03	1.1E-03	1.3E-03
^{129}I (Ci)	6.8E-03	1.3E-03	1.1E-03	1.6E-06	1.2E-03	1.2E-03	1.3E-03	1.1E-03	1.2E-03	1.3E-03	8.3E-05	8.3E-05	8.3E-05	8.3E-05
^{137}Cs (Ci)	3.2E+03	1.6E+03	6.9E+03	7.3E+03	2.1E+03	2.6E+04	5.3E+04	2.1E+03	8.4E+02	2.9E+04	6.8E+01	5.0E+01	4.9E+01	4.9E+01
^{137m}Ba (Ci)	3.1E+03	1.5E+03	6.5E+03	6.9E+03	2.0E+03	2.4E+04	5.0E+04	2.0E+03	8.2E+02	2.7E+04	6.6E+01	4.9E+01	4.8E+01	4.8E+01
^{233}U (Ci)	8.5E-02	1.6E-01	1.9E-02	1.1E-06	7.6E-03	8.1E-04	8.0E-04	7.2E-04	8.1E-04	1.2E-01	5.4E-05	5.4E-05	5.4E-05	5.4E-05
^{234}U (Ci)	3.4E-01	2.6E-01	5.2E-02	1.9E-01	6.8E-02	1.3E-02	2.7E-01	1.2E-01	2.4E-01	1.6E+00	1.8E-04	1.9E-04	1.4E-04	9.3E-05
^{235}U (Ci)	1.5E-02	1.1E-02	2.2E-03	8.3E-03	3.0E-03	5.8E-04	1.2E-02	5.3E-03	1.1E-02	6.9E-02	8.2E-06	7.9E-06	6.2E-06	4.1E-06
^{236}U (Ci)	6.0E-03	7.2E-03	9.6E-04	3.4E-03	6.6E-04	9.1E-05	1.8E-03	7.6E-04	2.2E-03	2.0E-02	1.8E-06	4.6E-06	1.5E-06	1.2E-06
^{238}U (Ci)	3.4E-01	2.4E-01	5.3E-02	2.0E-01	6.9E-02	1.3E-02	2.8E-01	1.2E-01	2.5E-01	1.6E+00	1.9E-04	1.9E-04	1.4E-04	9.4E-05
^{238}Pu (Ci)	3.3E+00	8.1E+00	9.6E+00	7.4E-01	2.6E+00	3.9E-03	4.8E-01	4.0E-02	5.6E-01	7.4E-01	6.9E-01	3.3E-01	5.2E-02	9.2E-04
^{239}Pu (Ci)	1.6E+02	2.8E+02	5.8E+02	4.7E+01	7.8E+01	8.7E-01	2.0E+01	1.2E+01	3.7E+01	8.1E+00	2.9E+01	1.4E+01	2.2E+00	3.9E-02
^{240}Pu (Ci)	2.7E+01	5.1E+01	9.0E+01	7.2E+00	1.4E+01	5.8E-02	3.3E+00	7.4E-01	5.5E+00	1.3E+00	4.8E+00	2.3E+00	3.6E-01	6.3E-03
^{241}Pu (Ci)	2.6E+02	6.2E+02	7.0E+02	5.4E+01	1.9E+02	1.1E-01	3.4E+01	5.0E-01	4.1E+01	1.1E+01	5.0E+01	2.4E+01	3.7E+00	6.6E-02

C Farm Tank Post-Retrieval Heel Inventories (802 ft^3 for 100-Series Tanks, 80 ft^3 for 200-Series Tanks) (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
^{242}Pu (Ci)	8.1E-04	2.4E-03	2.8E-03	2.1E-04	9.8E-04	4.7E-07	1.7E-04	1.6E-06	1.6E-04	4.1E-05	2.4E-04	1.2E-04	1.8E-05	3.3E-07
^{241}Am (Ci)	9.5E+01	6.7E+01	1.1E+02	2.4E+01	8.5E+01	6.6E-02	9.9E+00	3.7E-02	5.8E-02	3.0E+01	9.9E+00	4.7E+00	7.4E-01	1.5E-02
^{243}Am (Ci)	8.3E-04	6.3E-03	2.6E-03	2.3E-04	4.5E-03	4.5E-06	2.4E-04	3.9E-06	4.5E-06	6.8E-04	2.4E-04	1.1E-04	1.8E-05	6.0E-07
^{243}Cm (Ci)	3.9E-02	1.2E-01	9.4E-03	2.6E-02	8.2E-03	4.8E-05	9.3E-04	3.1E-05	4.1E-05	4.8E-03	5.7E-04	2.8E-05	6.3E-06	2.4E-06
^{244}Cm (Ci)	3.2E-02	2.8E+00	6.5E-02	4.3E-02	3.3E-01	3.9E-04	8.1E-04	3.5E-04	4.0E-04	1.1E-01	3.0E-04	3.9E-05	2.8E-05	2.6E-05

Retrieval Leak Loss Inventory Estimates, Assuming Supernate as Retrieval Fluid (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
Leakage (gal)	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	800	800	800	800
NO_2 (kg)	7.2E+02	7.0E+02	6.4E+02	6.4E+02	7.6E+02	9.2E+02	9.3E+02	6.7E+02	7.1E+02	1.3E+03	6.2E+01	7.7E+01	5.9E+01	5.9E+01
NO_3 (kg)	3.7E+03	3.0E+03	2.1E+03	2.7E+03	2.7E+03	3.2E+03	2.9E+03	4.8E+03	2.9E+03	3.5E+03	2.9E+02	3.2E+02	3.1E+02	2.9E+02
U_{TOTAL} (kg)	1.5E+00	1.1E+00	1.5E+01	4.8E+00	8.9E+00	5.9E-01	8.7E-01	2.2E+00	2.7E-03	2.8E+01	1.1E-02	3.1E-04	2.9E-04	2.9E-04
^{14}C (Ci)	2.3E-01	2.2E-01	1.8E-01	2.3E-01	2.2E-01	2.2E-01	2.2E-01	2.1E-01	2.2E-01	2.7E-01	2.3E-02	2.3E-02	2.3E-02	2.3E-02
^{60}Co (Ci)	1.2E-01	1.5E-01	4.0E-01	1.5E-01	6.2E-02	6.3E-02	6.2E-02	5.7E-02	6.4E-02	6.4E-02	6.4E-03	6.4E-03	6.4E-03	6.4E-03
^{63}Ni (Ci)	4.0E-01	3.9E-01	6.1E-01	4.0E-01	3.9E-01	4.1E-01	4.8E-01	3.6E-01	4.0E-01	1.5E+00	4.1E-02	4.1E-02	4.1E-02	4.1E-02
^{79}Se (Ci)	4.2E-02	4.1E-02	1.3E-01	4.2E-02	2.9E-01	4.2E-02	4.3E-02	8.3E-02	4.2E-02	4.6E-02	4.5E-03	4.7E-03	4.4E-03	4.4E-03
^{90}Sr (Ci)	6.3E+02	4.2E+02	3.2E+02	4.1E+02	4.2E+02	3.9E+02	4.0E+02	3.6E+02	1.8E+03	5.3E+02	6.4E+01	7.1E+02	1.3E+02	5.0E+01
^{90}Y (Ci)	6.4E+02	4.3E+02	3.3E+02	4.2E+02	4.4E+02	4.0E+02	4.1E+02	3.7E+02	1.8E+03	5.4E+02	6.6E+01	7.2E+02	1.3E+02	5.1E+01
^{99}Tc (Ci)	2.6E+00	1.5E+00	4.7E+00	2.2E+00	2.2E+00	1.6E+00	2.3E+00	2.2E+00	1.6E+00	2.7E+00	1.6E-01	1.6E-01	1.6E-01	1.6E-01
^{126}Sn (Ci)	7.4E-03	7.1E-03	7.0E-03	7.4E-03	2.1E-02	7.3E-03	7.2E-03	6.6E-03	7.3E-03	7.3E-03	7.4E-04	7.4E-04	7.4E-04	7.4E-04
^{129}I (Ci)	3.4E-03	2.7E-03	2.5E-03	3.7E-03	2.8E-03	2.8E-03	2.8E-03	2.5E-03	2.8E-03	2.8E-03	2.9E-04	2.9E-04	2.9E-04	2.9E-04
^{137}Cs (Ci)	2.5E+03	1.9E+03	1.5E+03	1.7E+03	1.7E+03	1.8E+03	1.7E+03	1.7E+03	1.9E+03	2.5E+03	1.7E+02	1.7E+02	1.7E+02	1.7E+02
^{137m}Ba (Ci)	2.4E+03	1.8E+03	1.5E+03	1.7E+03	1.7E+03	1.7E+03	1.6E+03	1.7E+03	1.9E+03	2.4E+03	1.7E+02	1.7E+02	1.7E+02	1.6E+02
^{233}U (Ci)	2.0E-03	2.0E-03	3.1E-03	1.8E-03	2.1E-03	1.8E-03	1.8E-03	1.7E-03	1.8E-03	2.5E-03	1.9E-04	1.9E-04	1.9E-04	1.9E-04
^{234}U (Ci)	1.3E-03	1.1E-03	5.4E-03	2.4E-03	3.7E-03	9.9E-04	1.1E-03	1.4E-03	8.0E-04	1.0E-02	8.5E-05	8.1E-05	8.1E-05	8.1E-05
^{235}U (Ci)	5.6E-05	4.8E-05	2.3E-04	1.0E-04	1.6E-04	4.2E-05	4.6E-05	6.3E-05	3.4E-05	4.4E-04	3.6E-06	3.4E-06	3.4E-06	3.4E-06
^{236}U (Ci)	3.4E-05	3.5E-05	1.1E-04	5.2E-05	5.3E-05	2.6E-05	2.6E-05	2.7E-05	2.5E-05	1.4E-04	2.6E-06	2.5E-06	2.5E-06	2.5E-06
^{238}U (Ci)	1.3E-03	1.1E-03	5.5E-03	2.4E-03	3.8E-03	9.9E-04	1.1E-03	1.5E-03	8.0E-04	1.0E-02	8.5E-05	8.1E-05	8.1E-05	8.1E-05
^{238}Pu (Ci)	1.4E-03	1.8E-03	1.4E-03	1.2E-03	4.2E-03	1.2E-03	2.2E-03	1.3E-03	1.2E-03	2.8E-03	6.9E-04	1.3E-04	1.2E-04	1.2E-04
^{239}Pu (Ci)	5.4E-02	6.2E-02	5.9E-02	4.7E-02	1.3E-01	4.4E-02	8.5E-02	1.2E-01	4.2E-02	5.9E-02	2.8E-02	4.6E-03	4.3E-03	4.2E-03
^{240}Pu (Ci)	9.1E-03	1.1E-02	9.6E-03	7.8E-03	2.4E-02	7.1E-03	1.4E-02	1.1E-02	7.0E-03	9.7E-03	4.7E-03	7.7E-04	7.2E-04	7.1E-04

Retrieval Leak Loss Inventory Estimates, Assuming Supernate as Retrieval Fluid (2 Sheets)

Analyte	C-101	C-102	C-103	C-105	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204
^{241}Pu (Ci)	1.0E-01	1.3E-01	9.7E-02	8.7E-02	3.0E-01	8.1E-02	1.5E-01	7.5E-02	8.2E-02	1.0E-01	5.0E-02	8.9E-03	8.4E-03	8.3E-03
^{242}Pu (Ci)	4.7E-07	5.8E-07	4.6E-07	4.3E-07	1.6E-06	4.1E-07	7.7E-07	3.8E-07	4.1E-07	5.0E-07	2.5E-07	4.5E-08	4.3E-08	4.2E-08
^{241}Am (Ci)	6.1E-01	4.5E-01	1.6E-01	1.0E+01	3.8E+00	8.4E-02	9.3E-02	7.5E-02	8.5E-02	1.3E-01	1.0E-02	8.9E-03	8.6E-03	8.6E-03
^{243}Am (Ci)	1.5E-05	4.4E-05	1.0E-05	1.1E-04	2.0E-04	9.9E-06	1.0E-05	8.9E-06	1.0E-05	1.1E-05	1.0E-06	1.0E-06	1.0E-06	1.0E-06
^{243}Cm (Ci)	1.8E-04	4.0E-04	6.4E-05	8.4E-05	8.8E-05	7.8E-05	7.8E-05	7.0E-05	7.9E-05	1.1E-04	7.8E-05	9.7E-05	2.2E-05	8.2E-06
^{244}Cm (Ci)	9.7E-04	8.1E-03	7.2E-04	8.9E-04	1.3E-03	8.8E-04	8.7E-04	7.9E-04	8.9E-04	1.8E-03	1.2E-04	1.3E-04	9.7E-05	9.0E-05

Retrieval Leak Loss Inventory Estimates, Assuming Water as Retrieval Fluid

Analyte	C-101	C-110	C-111	C-201	C-202	C-203	C-204
Leak Loss (gal)	**8,000**	**8,000**	**8,000**	**800**	**800**	**800**	**800**
NO_2 (kg)	1.5E+02	1.3E+02	1.5E+02	4.2E+00	1.9E+01	1.1E+00	6.8E-01
NO_3 (kg)	1.1E+03	2.4E+02	2.4E+03	2.3E+01	5.6E+01	4.3E+01	2.2E+01
U_{TOTAL} (kg)	1.5E+00	0.0E+00	2.2E+00	1.1E-02	3.4E-05	1.8E-05	2.0E-05
^{14}C (Ci)	7.6E-03	7.7E-04	7.6E-03	6.0E-04	1.0E-04	8.1E-04	6.0E-04
^{60}Co (Ci)	6.0E-02	6.2E-11	1.5E-07	9.8E-09	9.6E-09	3.6E-09	3.4E-09
^{63}Ni (Ci)	7.5E-04	1.4E-07	2.7E-05	3.0E-04	3.3E-04	7.8E-05	9.0E-05
^{79}Se (Ci)	3.7E-04	1.6E-04	4.5E-02	2.8E-04	4.6E-04	1.1E-04	1.5E-04
^{90}Sr (Ci)	2.4E+02	1.4E+03	4.9E+00	2.5E+01	6.7E+02	8.9E+01	9.7E+00
^{90}Y (Ci)	2.4E+02	1.4E+03	4.9E+00	2.5E+01	6.7E+02	8.9E+01	9.7E+00
^{99}Tc (Ci)	1.0E+00	5.4E-03	7.4E-01	8.9E-04	7.3E-04	8.3E-04	7.0E-04
^{126}Sn (Ci)	4.4E-05	1.1E-08	3.3E-05	0.0E+00	5.2E-13	3.8E-09	4.4E-13
^{129}I (Ci)	5.5E-04	1.0E-05	2.0E-05	1.7E-06	1.4E-06	1.5E-06	1.3E-06
^{137}Cs (Ci)	9.0E+02	3.0E+02	2.6E+02	5.3E+00	8.5E+00	6.1E+00	3.7E+00
^{137}mBa (Ci)	8.5E+02	2.8E+02	2.5E+02	5.0E+00	8.0E+00	5.7E+00	3.5E+00
^{233}U (Ci)	1.3E-04	0.0E+00	5.2E-10	2.6E-12	2.1E-14	4.2E-15	4.6E-15
^{234}U (Ci)	5.1E-04	0.0E+00	7.3E-04	3.6E-06	1.1E-08	6.0E-09	6.5E-09
^{235}U (Ci)	2.2E-05	0.0E+00	3.3E-05	1.6E-07	4.7E-10	2.7E-10	2.9E-10
^{236}U (Ci)	8.9E-06	0.0E+00	4.7E-06	2.3E-08	2.6E-10	3.8E-11	4.2E-11
^{238}U (Ci)	5.1E-04	0.0E+00	7.4E-04	3.7E-06	1.1E-08	6.0E-09	6.6E-09
^{238}Pu (Ci)	2.7E-04	1.0E-05	2.7E-04	5.8E-04	9.4E-06	2.9E-06	1.6E-06
^{239}Pu (Ci)	1.3E-02	6.7E-04	8.6E-02	2.4E-02	4.0E-04	1.2E-04	6.8E-05
^{240}Pu (Ci)	2.2E-03	1.0E-04	5.0E-03	4.0E-03	6.5E-05	2.0E-05	1.1E-05
^{241}Pu (Ci)	2.1E-02	7.4E-04	3.2E-03	4.2E-02	6.8E-04	2.1E-04	1.2E-04
^{242}Pu (Ci)	6.4E-08	2.8E-09	9.9E-09	2.0E-07	3.3E-09	1.0E-09	5.7E-10
^{241}Am (Ci)	5.2E-01	0.0E+00	1.7E-05	1.6E-03	3.2E-04	3.8E-05	1.2E-06
^{243}Am (Ci)	4.6E-06	0.0E+00	4.7E-11	3.8E-08	7.8E-09	9.2E-10	2.8E-11
^{243}Cm (Ci)	1.0E-04	5.3E-09	7.3E-10	7.0E-05	8.9E-05	1.4E-05	2.4E-07
^{244}Cm (Ci)	8.2E-05	5.4E-09	1.9E-09	3.4E-05	4.3E-05	6.8E-06	1.2E-07

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