Draft Waste Incidental to Reprocessing Evaluation for Closure of Waste Management Area C at the Hanford Site

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Acronyms and Abbreviations

1C	first decontamination cycle (waste)
2C	second decontamination cycle (waste)
244-CR vault	244-CR process tank vault
AEA	Atomic Energy Act of 1954
ALARA	as low as reasonably achievable
AMS	articulating mast system
BBI	Best-Basis Inventory
bgs	below ground surface
BiPO4	bismuth phosphate
BP	bismuth phosphate
B Plant	221-B and 224-B Buildings
catch tank C-301	241-C-301 catch tank
CAW	current acid waste
CCMS	camera/computer-aided-design modeling system
CFR	Code of Federal Regulations
CRBG	Columbia River Basalt Group
CW	coating (cladding) waste
D2EHPA	Di(2-ethylhexyl)phosphoric acid
DOE	U.S. Department of Energy
DOE-ORP	U.S. Department of Energy Office of River Protection
DST	double-shell tank
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ERSS	extended reach sluicer system
ETF	Effluent Treatment Facility
FFTF	Fast Flux Test Facility

H3	Hanford formation
H3/CCu/RF	(undifferentiated) H3, Cold Creek Unit, and Ringold Formation
HFFACO	Hanford Federal Facility Agreement and Consent Order
HFSUWG	Hanford Future Site Uses Working Group
HLW	high-level waste
HPU	hydraulic power unit
HS	201-C Hot Semiworks
HTWOS	Hanford Tank Waste Operations Simulator
HPW	High Power Wash
ICRP	International Commission on Radiological Protection
IX	ion exchange
ITS	In-Tank Solidification
K_d	distribution coefficient
LIGO	Laser Interferometer Gravitational Wave Observatory
LLW	low-level waste
MARS	mobile arm retrieval system
MARS-S	sluice-mode mobile arm retrieval system
MARS-V	vacuum-mode mobile arm retrieval system
MRT	mobile retrieval tool
MS	modified sluicing
MMI	Modified Mercalli Intensity
MW	metal waste
NPH	normal paraffin hydrocarbon
NRC	U.S. Nuclear Regulatory Commission
OWW	organic wash waste
PA	performance assessment
PNNL	Pacific Northwest National Laboratory
PSN	PUREX supernate waste
PSS	PUREX sludge supernate
PUREX	Plutonium Uranium Extraction (Plant)

RBA	radiological buffer area
RCRA	Resource Conservation and Recovery Act of 1976
RDR	retrieval data report
REDOX	Reduction-Oxidation (S Plant)
RSN	REDOX waste supernate
SNF	spent nuclear fuel
SOF	sum of fractions
SpG	specific gravity
SST	single-shell tank
STOMP	Subsurface Transport Over Multiple Phases
TBP	Tri-Butyl Phosphate
TC&WM EIS	Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site (DOE/EIS-0391)
TED	total effective dose
TEDE	total effective dose equivalent
TEDF	Treated Effluent Disposal Facility
TFeCN	scavenged ferrocyanide waste
TH	thorium (waste)
TOC	Tank Operations Contractor
TOE	total operating efficiency
TRU	transuranic
UCL	upper confidence level
UR	uranium recovery (waste)
USACE	United States Army Corp of Engineers
VRS	vacuum retrieval system
WAC	Washington Administrative Code
WIR	waste incidental to reprocessing
WMA	waste management area
WMA C	Waste Management Area C

WMA C PA	Performance Assessment of Waste Management Area C, Hanford Site, Washington (RPP-ENV-58782)

Units

~	approximate
>	greater than
≥	greater than or equal to
<	less than
±	plus or minus
%	percent
°	degree
°F	degree Fahrenheit
µg	microgram
ac	acre
bgs	below ground surface
Ci	curie
cm	centimeter
ft	foot
ft^2	square foot
ft^3	cubic foot
g	gram
g	gravitational acceleration
gal	gallon
gpm	gallons per minute
hr	hour
Hz	hertz
in	inch
kg	kilogram
kgal	thousand gallons

L	liter
lb	pound(s)
M	molar
m	meter
m^2	square meter
mL	milliliter
mm	millimeter
mi	mile
mi^2	square mile
min	minute
mrem	millirem
mSv	millisievert
MW	Metal Waste
nCi	nanocurie
pCi	picocurie
psi	pounds per square inch
sec	second
V	volt
vol	volume
wt	weight
yd	yard
yr	year

1.0 INTRODUCTION

Section Purpose

This section provides the overview, purpose and scope of this document, "Draft Waste Incidental to Reprocessing Evaluation for Closure of Waste Management Area C at the Hanford Site."

Section Contents

This section contains a brief introduction to Hanford Site Waste Management Area (WMA) C and describes the purpose and scope of this Draft Waste Incidental to Reprocessing (WIR) Evaluation (hereinafter referred to as Draft WIR Evaluation).

Key Points

- The U.S. Department of Energy (DOE) has completed a multi-year program to remove the vast majority of the radioactive waste and key radionuclides stored in 16 underground, single-shell tanks (SSTs), located in WMA C at the Hanford Site. The tanks contained a variety of wastes, including waste generated by DOE and its predecessors from the prior reprocessing of spent nuclear fuel (SNF), to produce material for nuclear weapons during the Manhattan Project and Cold War eras.
- Following removal of the waste, the tanks, a relatively small amount of remaining waste (residual waste or residuals), and certain ancillary structures (a catch tank, a process vault with smaller tanks, and diversion boxes) will be filled with grout to stabilize them and immobilize the waste. Thereafter, the WMA C tanks, residual waste, and ancillary structures (including integral equipment and buried pipelines) will be covered with an engineered surface barrier and closed in place.
- DOE is issuing this Draft WIR Evaluation to provide a basis, when finalized, for a potential WIR Determination by DOE, pursuant to DOE Order 435.1, *Radioactive Waste Management* (DOE O 435.1), and the associated DOE Manual 435.1-1, *Radioactive Waste Management Manual* (DOE M 435.1-1).
- In keeping with the criteria in DOE M 435.1-1, this Draft WIR Evaluation shows, among other things, that at closure of WMA C, key radionuclides will have been removed to the maximum extent technically and economically practical, that potential doses to the public and human intruder are projected to be well below the doses set forth in the performance objectives and performance measures for land disposal of LLW, and that the solidified waste meets concentration limits for Class C LLW.
- This Draft WIR Evaluation and its supporting documents, including a Performance Assessment for WMA C, demonstrate that the grouted tanks, residual waste, and ancillary structures at closure of WMA C will satisfy the criteria in DOE M 435.1-1 for determining that the wastes are incidental to the reprocessing of SNF, are not high-level radioactive waste (HLW), and may be managed as low-level radioactive waste (LLW).

- DOE is consulting with the U.S. Nuclear Regulatory Commission (NRC) concerning this Draft WIR Evaluation. DOE is also making this Draft WIR Evaluation available for comments by States, Tribal Nations and the public.
- A final WIR Evaluation will be issued by DOE following completion of consultation with the NRC and consideration of comments from the States, Tribal Nations, and the public. Based on the final WIR Evaluation and supporting documents, DOE may determine whether the stabilized tanks, residuals and ancillary structures at closure of WMA C meet the criteria in DOE M. 435.1-1, are not HLW, and are to be managed (disposed of in place) as LLW.

1.1 OVERVIEW

DOE has conducted a multi-year program to remove the vast majority of the radioactive waste and key radionuclides contained in 16 underground, single-shell tanks and ancillary structures, located in WMA C at the Hanford Site.[1] For example, approximately 96 percent of the waste volume and radionuclide activity in the largest (100 series) tanks has been removed, using a series of advanced technologies tailored to the specific wastes.[2] The tanks and ancillary structures previously stored or transferred a variety of wastes, including liquid waste generated by DOE and its predecessor agencies from the prior reprocessing of SNF, to produce plutonium and other material for nuclear weapons during the Manhattan Project and Cold War eras.

Following removal of the waste, the tanks and certain ancillary structures (a catch tank, a process vault with smaller tanks, and diversion boxes) will be filled with grout to stabilize them and immobilize the waste residuals.[3] Thereafter, the WMA C tanks, residuals, and ancillary

[1] All of the waste tanks in WMA C are single-shell tanks, that is, tanks which do not have secondary containment. The waste removed from the SSTs in WMA C has been transferred to double-shell tanks (DSTs) with full secondary containment (essentially a tank within a tank) in another tank farm (the AN tank farm) at the Hanford Site, for eventual removal and disposition.
Ancillary structures in WMA C consist of the 241-C-301 catch tank, the 244-CR process vault with small tanks, diversion boxes, and buried pipelines. This Draft WIR Evaluation uses the term "ancillary structures," which is synonymous with the term "ancillary equipment" as used in Appendix I, titled *Single Shell Tank System Waste Retrieval and Closure Process*, of the Action Plan implementing the Hanford Federal Facility Agreement and Consent Order.
The information summarized in the Overview section is discussed in detail in subsequent sections of this Draft WIR Evaluation, and the references cited therein.

[2] The percentages reflected in this Draft WIR Evaluation should not be viewed as limits or goals, and should not be viewed as precedent for other tanks at the Hanford Site or other DOE sites.

[3] For purposes of this Draft WIR Evaluation, "residual waste" or "residuals" means the relatively small amount of waste remaining in a waste tank or ancillary structure after completion of waste retrieval activities and removal of key radionuclides to the maximum extent that is technically and economically practical.
Stabilization of these residuals will be carried out by filling the waste tanks with grout after completion of waste removal activities. Ancillary structures will be filled with grout, as necessary, to prevent subsidence of the structures or final engineered surface barrier. DOE does not plan to add grout to the buried waste-transfer pipelines (previously used to transfer waste to and within WMA C) because the pipelines do not present a significant risk of destabilizing subsidence.
Grout will be formed from materials such as cement, fly ash, fine aggregate, and water to create a free-flowing material, which will be used to fill the tanks and applicable ancillary structures after waste retrieval is completed.

structures (including integral equipment[4] and buried pipelines) will be covered with an engineered surface barrier[5] and closed in place.

In accordance with DOE O 435.1 and DOE M 435.1-1, DOE may determine (in a WIR Determination) that certain waste is incidental to the reprocessing of SNF, is not HLW, and may be managed as LLW if an evaluation shows that the criteria in DOE M 435.1-1 are met.[6] The criteria in DOE M 435.1-1, Section II.B.(2)(a), are that the wastes:

> "(1) Have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical; and
>
> (2) Will be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR Part 61, Subpart C, *Performance Objectives*; and
>
> (3) Are to be managed, pursuant to DOE's authority under the *Atomic Energy Act of 1954*, as amended, and in accordance with the provisions of Chapter IV of this Manual, provided the waste will be incorporated in a solid physical form at a concentration that

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The grout will harden in the tanks and ancillary structures to stabilize the residual waste and provide structural stability for closure of the tank farm. The grout will also serve to immobilize the residuals, minimize water infiltration, and discourage human intrusion. DOE will tailor and finalize the specific formulation of the grout in the future, before it is added to the tanks and applicable ancillary structures.

[4] Integral equipment refers to pumps, instrumentation, jumpers, and other small equipment that may be abandoned in place and entombed in grout within tanks, risers or pits.

[5] The final engineered surface barrier is also commonly referred to as a "closure cover" or "closure cap."

[6] DOE has issued DOE O 435.1, DOE M 435.1-1, and the associated DOE G 435.1-1 pursuant to DOE's authority and responsibilities under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.) (AEA).

"High-level radioactive waste" is defined in Section 2(12) of the Nuclear Waste Policy Act of 1982, as amended (42 U.S.C. 10101 et seq.), as: "(A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (B) other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation." Section 11.dd of the AEA, and Section 2(10) of the Waste Isolation Pilot Plant Land Withdrawal Act, as amended (P.L. 102-579), incorporate the above definition. A similar definition is found in DOE M 435.1-1.

Although the term "reprocessing" is not defined statutorily, DOE guidance describes reprocessing as "those actions necessary to separate fissile elements (U-235, Pu-239, U-233, and Pu-241) and/or transuranium elements (e.g., Np, Pu, Am, Cm, Bk) from other materials (e.g., fission products, activated metals, cladding) contained in spent nuclear fuel for the purposes of recovering desired materials." Department of Energy Guide 435.1-1, *Implementation Guide for Use with DOE M 435.1-1*, at p. II-5. That Guide goes on to explain that decladding and other head-end processes are not part of reprocessing. Id, at II-6.

The term "spent nuclear fuel" is defined in DOE M 435.1-1 in relevant part as: "Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing." NRC regulations include a similar definition. See 10 CFR 71.4.

Low-level radioactive waste is essentially defined in relevant part in Section 2(9) of the Low-Level Radioactive Waste Policy Amendments Act of 1985, as amended (42 USC 2021, et seq.), and Section 2(16) of the Nuclear Waste Policy Act (42 USC 10101, et seq.) as "radioactive material … that is not high-level radioactive waste, spent nuclear fuel, or byproduct material (as defined in the Atomic Energy Act of 1954)[.]" DOE M 435.1-1, similarly defines low-level waste in relevant part as "radioactive waste that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, [or] byproduct material[.]"

does not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR 61.55, *Waste Classification*[.]"[7]

The analyses set forth in this Draft WIR Evaluation demonstrate that the cleaned[8] tanks, ancillary structures and their residuals at closure of WMA C will meet the above-referenced criteria in DOE M 435.1-1. DOE is predicating this Draft WIR Evaluation on extensive analyses and scientific rationale, using a risk-informed approach, including analyses presented in the "Performance Assessment of Waste Management Area C, Hanford Site, Washington" (WMA C PA). Specifically, this Draft WIR Evaluation shows that key radionuclides have been or will have been removed to the maximum extent technically and economically practical.[9] Based on analyses in the WMA C PA, this Draft WIR Evaluation also projects that potential doses to a hypothetical member of the public and hypothetical inadvertent intruder will be well below the doses specified in the performance objectives and performance measures for LLW.[10] In addition, the analyses demonstrate that there is reasonable expectation[11] that safety requirements comparable to the performance objectives in 10 CFR Part 61, Subpart C will have been met. As further shown in this Draft WIR Evaluation, the residuals, tanks and ancillary structures will be incorporated into a solid form that does not exceed concentration limits for Class C LLW.

DOE is consulting with the NRC concerning this Draft WIR Evaluation and is providing the opportunity for comments by States, Tribal Nations and the public. After consideration of comments from NRC, States, Tribal Nations and the public, DOE plans to issue a final WIR Evaluation, to provide the basis for a potential WIR Determination by DOE in the future.

[7] This provision in DOE M 435.1 also includes the following language: "or will meet alternative requirements for waste classification and characterization as DOE may authorize." DOE is not using or relying upon this language in this Draft WIR Evaluation to any degree whatsoever.

[8] As used in this Draft WIR Evaluation, "cleaned" tanks refer to tanks from which waste and key radionuclides have been removed to the maximum extent technically and economically practical, as discussed further in Section 4 of this Draft WIR Evaluation. Tanks from which waste has been retrieved are also referred to as "retrieved" tanks.

[9] Key radionuclides are those that contribute most significantly to radiological dose to workers, the public, and the environment, as well as radionuclides listed in 10 CFR 61.55 for LLW. These radionuclides are identified in Section 4.2 of this Draft WIR Evaluation.

[10] A performance assessment is required and maintained pursuant to DOE M 435.1-1 and Appendix I, *Single Shell Tank System Waste Retrieval and Closure Process*, of the Action Plan implementing the Hanford Federal Facility Agreement and Consent Order. Generally, a performance assessment is a multi-disciplined assessment (e.g., geochemistry, hydrology, materials science, and health physics) which uses a variety of computational modeling codes to evaluate groundwater concentrations and doses at various points of assessment over time. In doing this assessment, DOE evaluates the impact of natural features (e.g., hydrology, soil properties, groundwater infiltration) and engineered barriers (e.g., closure cap, fill grout, waste tank design) on the release of radionuclides, to estimate, among other things, the potential dose to a hypothetical member of the public and a hypothetical inadvertent intruder. The results of the WMA C PA, as reported here, should not be considered limits or thresholds. As required by DOE M 435.1-1, maintenance of the WMA C PA will include future performance assessment revisions or special analyses to incorporate new information, update model codes and reflect analysis of actual residual inventories.

[11] DOE M 435.1-1 uses the phrase "reasonable expectation," which is analogous to "reasonable assurance" used in 10 CFR Part 61, Subpart C. This Draft WIR Evaluation uses the phrase "reasonable expectation," except when quoting directly from NRC regulations at 10 CFR Part 61, Subpart C.

1.2 PURPOSE

The purpose of this Draft WIR Evaluation is to assess and document whether the residuals, waste tanks, and ancillary structures at closure[12] of WMA C meet DOE M 435.1-1 criteria (which are discussed in Section 3 and addressed in detail in Sections 4, 5, and 6, respectively), and may be determined to be incidental to reprocessing, not HLW, and managed as LLW.

1.3 SCOPE AND OPPORTUNITY FOR COMMENT

This Draft WIR Evaluation addresses the stabilized residuals which, based on experience to date, will remain in the WMA C waste tanks and ancillary structures, the stabilized waste tanks, and the ancillary structures (including integral equipment) at the time of WMA C closure. This Draft WIR Evaluation does not address other facilities or systems, waste removed from the waste tanks and ancillary structures, or the contaminated soil and groundwater from previous leaks or unplanned or planned releases. This Draft WIR Evaluation is premised on the facts, assumptions and analyses contained or referenced herein. Accordingly, a WIR Determination made in reliance on the final WIR Evaluation can only cover situations consistent with those facts, assumptions and analyses.

DOE is consulting with the NRC and making this Draft WIR Evaluation available for comment by States, Tribal Nations and the public.[13] After consideration of comments on this Draft WIR Evaluation from NRC, States, Tribal Nations, and the public, DOE will issue a final WIR Evaluation and potentially a determination on whether the stabilized residuals in the WMA C waste tanks and ancillary structures, the waste tanks, and the ancillary structures (including integral equipment) at the time of closure are not HLW and may be managed (disposed of in place) as LLW.

1.4 TECHNICAL BASIS FOR THE DRAFT EVALUATION

This Draft WIR Evaluation has been prepared in accordance with DOE M 435.1-1, following guidance in DOE Guide 435.1-1, Implementation Guide For Use With DOE M 435.1-1, *Radioactive Waste Management Manual* (DOE G 435.1-1). The method used involves evaluating whether stabilized residuals in the WMA C single-shell waste tanks and ancillary structures, as well as the single-shell waste tanks, and the ancillary structures (including integral equipment) at the time of closure are incidental to reprocessing and may be managed under DOE's authority in accordance with requirements for LLW.

This Draft WIR Evaluation focuses on the criteria of DOE M 435.1-1, Section II.B(2)(a), which are discussed in Section 3, and addressed in detail in Sections 4, 5, and 6, respectively. Although the criteria in DOE M 435.1-1 for managing evaluated waste or equipment as LLW are generally similar to the provisions in Section 3116(a) of the Ronald W. Reagan National Defense

[12] The tank closure schedules are established pursuant to the Hanford Federal Facility Agreement and Consent Order process. Negotiations are ongoing to revise the closure schedule and final closure dates.

[13] Although not required by DOE M 435.1-1, DOE is providing the States, Tribal Nations and the public with the opportunity to comment and is providing the NRC with the opportunity for consultative review. However, NRC does not have licensing and related regulatory authority over the WMA C waste, waste tanks or ancillary structures.

Authorization Act for Fiscal Year 2005, that Act does not apply to the Hanford Site [14] because Washington is not a "covered state" under the Act.

1.5 BACKGROUND

The following general information is provided to put the Draft WIR Evaluation into context. Section 2 provides more detailed background information on the Hanford Site, the WMA C environment, spent nuclear fuel reprocessing activities that involved the WMA C tanks, WMA C layout and design, and residual radioactivity inventories in WMA C tanks and ancillary structures.

The Hanford Site encompasses ~586 mi^2 in Benton, Franklin, and Grant counties, located in south-central Washington State within the semi-arid Pasco Basin of the Columbia Plateau. In the past, the Hanford Site was a U.S. Government defense materials production site that included nuclear reactor operation, uranium and plutonium processing, the storage and processing of SNF, and the management of radioactive and hazardous chemical wastes. The current mission at Hanford includes managing waste products, remediation, researching new technologies for waste disposal and cleanup, and reducing the size of the Site [PNNL-20548, "Hanford Site Environmental Report for Calendar Year 2010 (Including Some Early 2011 Information)," pp. v].

For more than four decades beginning in 1944, DOE and its predecessors routed liquid, radioactive waste from spent nuclear fuel reprocessing and other operations in the 200 Areas of the Hanford Site through buried transfer pipelines to the SST system (including the 16 underground SSTs in WMA C) for storage. The SST system was taken out of service in 1980.

WMA C is located in the 200 East Area of the Central Plateau of the Hanford Site. The WMA C was originally constructed from 1943 to 1945. The facility contains 12 first-generation, reinforced-concrete tanks with carbon steel liners covering the sides and bottoms. The tanks are 75 ft in diameter with a capacity of 530,000 gal. The tanks are arranged in four rows of three tanks. The tanks in each row are piped together so that when the first tank fills, it overflows (cascades) into the second tank, and from the second into the third. The tank farm also contains four smaller 200-series tanks that are 20 ft in diameter and hold 55,000 gal. These four tanks are piped to diversion box C-252. In addition to diversion box C-252, three other diversion boxes were originally constructed in WMA C; another three diversion boxes, the 244-CR vault, the 271-CR control room, 271-CRL laboratory, and the 241-C-801 [15] cesium loadout facility were built later.

As explained in Section 2.3.2 of this Draft WIR Evaluation, WMA C operations can be described in terms of five historical phases:

- Manhattan Project production operations (1944 to 1952)

[14] DOE considered the Section 3116(a)(1) criteria for perspective and information in this Draft WIR Evaluation, as explained in Appendix A.

[15] Hanford Site tank farms, tanks, and diversion boxes are numbered with the prefix '241-'. The prefix is generally omitted in this report to aid readability.

- Uranium recovery operations (1952 to 1957)
- PUREX operations (1956 to 1972)
- Waste fractionation operations (1961 to 1978)
- Tank interim stabilization and isolation (begun in 1975)

The waste originally stored in the WMA C tanks consisted of supernate and solids from the processing of irradiated uranium fuel. Supernate is free-standing liquid from the waste processing operations, and the solids are precipitates from the supernate. Because of its long operational history, WMA C received waste generated by the various processing operations at the Hanford Site as discussed in Section 2.3.2 of this Draft WIR Evaluation.

DOE has been retrieving the waste from the tanks in WMA C, using a variety of methods and advanced technologies, including those tailored to the specific wastes, in a series of campaigns and steps.[16] In addition, operations records show that the pits, diversion boxes and pipelines were well-flushed, thereby removing waste containing key radionuclides. DOE's experience to date indicates that after waste retrieval operations are complete,[17] some residual waste will remain in the SST system at closure, and will be contained in tanks, vaults, pits/boxes, and pipelines. After retrieval of the waste, DOE anticipates that the SSTs and some of the ancillary structures and components (i.e., catch tank C-301, 244-CR vault, and diversion boxes but not pipelines) containing waste residuals within WMA C will be filled with grout and left in place. Grout is formed from materials such as cement, fly ash, fine aggregate, and water to create a free-flowing material that can be used to fill the tanks after waste retrieval is completed. The grout hardens in the tanks to stabilize the residual waste and provide structural stability for landfill closure of the tank farm. WMA C tank closures are anticipated to occur during the next decade, at which time the tanks will be filled with grout. At a later date, DOE anticipates that WMA C will be covered with a final closure barrier.

1.6 SCHEDULE AND PLANS FOR CLOSING WASTE TANKS

Because the Hanford Site is also subject to both the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA), the WMA C closure process is complex and regulated by multiple agencies: DOE, Washington State Department of Ecology (Ecology), and U.S. Environmental Protection Agency (EPA). Various aspects of activities in WMA C are covered by both the HFFACO and Consent Decrees.

The HFFACO (Ecology et al. 1989) that was signed by DOE, Ecology, and EPA on May 15, 1989, is an enforceable agreement that requires DOE to clean up and dispose of radioactive and hazardous waste at the Hanford Site and close facilities that have been used to treat, store, or dispose of such waste. The HFFACO establishes work requirements (milestones), methods for resolving disputes, and an Action Plan for cleanup that addresses priority activities. The

[16] These technologies are discussed in detail later in this Draft WIR Evaluation (see Sections 2 and 4).
[17] Physical waste retrieval has been completed for all 100-series and 200-series SSTs. For Tank C-105, the last 100-series tank from which waste was retrieved, the final sampling, analysis, and submittal of completion of retrieval certification documents will occur in the near future.

HFFACO is a Federal facility agreement under CERCLA Section 120, which incorporates a corrective action order under RCRA, and a consent order under the Washington State Hazardous Waste Act (Revised Code of Washington Chapter 70.105, "Hazardous Waste Management"). Retrieval and closure of the Hanford tank farms has been addressed by the HFFACO since approximately January 1994.

Specified waste retrievals from single-shell tanks (SSTs) have also been addressed under Consent Decrees filed in United States District Court for the Eastern District of Washington. This litigation was filed in 2008 by the State of Washington alleging that DOE had "missed or was certain to miss" certain HFFACO milestones, including tank retrieval milestones. The State of Oregon is an Intervener and has separate consent decrees requiring DOE to provide notifications and reports. Both the HFFACO and Consent Decrees have standards for tank retrieval that are similar but not exactly the same. Some of the tanks in WMA C have been retrieved under the HFFACO while the most recent retrievals have been conducted under the Consent Decrees. Closure of the tanks is expressly excluded from the Consent Decrees.

An integrated regulatory closure process titled "Single-Shell Tank System Waste Retrieval and Closure Process" has been developed in Appendix I of the HFFACO Action Plan that was intended to streamline regulatory approval for closure of Hanford Site WMAs. This integrated regulatory process (1) uses the existing HFFACO process, Action Plan, and milestones; (2) completes the RCRA closure process as negotiated by DOE and Ecology; and (3) recognizes that SST WMA closure and other waste site cleanup activities via compliance with Federal and State requirements need to be integrated. The process also integrates applicable requirements of the above regulatory processes consistent with DOE M 435.1-1. DOE is the response agency responsible for the closure of all Hanford SST WMAs. Under the HFFACO, Ecology is the lead regulatory agency for these activities.

At the time of closure of WMA C, the grouted tanks, residuals, and ancillary structures will meet safety requirements comparable to the performance objectives for the disposal of Class C LLW provided in Title 10, CFR, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives. In addition, because the residual waste is mixed waste, it must also meet Washington State dangerous waste requirements for closure (Washington Administrative Code [WAC] 173-303, "Dangerous Waste Regulations"). Per Appendix I of the HFFACO Action Plan, closure plans will be incorporated into the Hanford Site-Wide Permit (WA7 89000 8967, "Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion Revision 8C for the Treatment, Storage, and Disposal of Dangerous Waste").

Closure of the individual SSTs and of WMA C as a whole occurs in three major steps as identified in RPP-RPT-41918, "Assessment Context for Performance Assessment for Waste in C Tank Farm Facilities after Closure": (1) SST waste retrieval, (2) tank filling for stabilization, and (3) surface barrier placement. A general description of these steps follows.

Tank waste retrieval in WMA C began in 1998 and was completed in 2017. A variety of waste retrieval methods and advanced technologies have been deployed as described later in this document.

After waste retrieval operations are completed, the tanks and tank residuals will be stabilized by filling the tanks with grout to minimize subsidence and water infiltration into the waste residuals, and to discourage intruder access after closure.

The final closure activity will be placement of an engineered surface barrier. This surface barrier will provide additional protection from infiltration and intrusion. The specific design of the closure barrier has not been finalized, but it is likely to be based on the Modified RCRA Subtitle C barrier concept defined in DOE/EIS-0391, "Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site" (TC&WM EIS).

DOE will – pursuant to its authority including that under the Atomic Energy Act of 1954 (AEA) and applicable DOE orders, manuals, and policies – pursue closure of WMA C and monitor its activities to ensure compliance with regulatory and other applicable requirements.

1.7 ORGANIZATION OF THIS DRAFT WASTE INCIDENTAL TO REPROCESSING EVALUATION

Section 1.0 provides an introduction to the Draft WIR Evaluation**.**

Section 2.0 of this document provides an overview of the Hanford Site and WMA C, including the residuals inventory.

Section 3.0 describes DOE M 435.1-1 WIR determination criteria.

Section 4.0 describes how key radionuclides have been or will be removed from the tanks and ancillary structures to the maximum extent that is technically and economically practical.

Section 5.0 discusses how safety requirements comparable to NRC performance objectives in 10 CFR 61, Subpart C, will be achieved.

Section 6.0 explains that the radionuclide concentrations of the residuals, WMA C tanks and ancillary structures are less than Class C concentration limits for LLW in 10 CFR 61.55, and will be managed as LLW in accordance with DOE requirements.

Section 7.0 summarizes DOE's preliminary conclusions related to this Draft WIR Evaluation.

Section 8.0 identifies the references cited in the draft evaluation.

Appendix A discusses the criteria in Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005.

Appendix B compares DOE and NRC Requirements for LLW Disposal

Appendix C contains background economic evaluation information for representative WMA C tanks.

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2.0 BACKGROUND

Section Purpose

This section provides the background for the WMA C site environment, facilities, and determination of WMA C residual waste inventory.

Section Contents

The first part of this section contains a discussion of Hanford Site characteristics including the geology, seismology, volcanology, hydrogeology, and geochemistry. Then the characteristics of WMA C are provided. Finally, the facility waste history, retrieval technologies and residual waste inventory are discussed.

Key Points

- Background information on the Hanford Site and WMA C is provided and includes an overview of the Site and context to the WMA C PA analyses, and also to the analyses presented in this Draft WIR Evaluation.
- WMA C consists of 16 SSTs that do not have secondary containment.
- WMA C has twelve 100-series tanks with 530,000-gal capacity each.
- WMA C has four 200-series tanks with 55,000-gal capacity each.
- WMA C also contains catch tank C-301, 244-CR vaults with four tanks, seven diversion boxes, and approximately seven miles of pipeline.
- WMA C residual waste inventory is presented from the WMA C PA that provides a conservative assessment of the performance of WMA C after closure.

This section provides background information on the Hanford Site and WMA C. Details of the facility and infrastructure are provided along with the history of waste activities, retrieval technologies, and radionuclide inventories.[18]

2.1 HANFORD SITE

The Hanford Site encompasses ~586 mi^2 in Benton, Franklin, and Grant counties, located in south-central Washington State (Figure 2-1) within the semi-arid Pasco Basin of the Columbia Plateau. Nearby towns are Richland (25 mi to the southeast) and Yakima (~50 mi to the west),

[18] Sections 2.1 through 2.3.2, as well as Appendices A and B, of this Draft WIR Evaluation contain information to further inform the reader, beyond the criteria specified in DOE M 435.1.

with the nearby major metropolitan areas being Spokane (125 mi to the northeast) and Seattle (150 mi to the northwest) in Washington, and Portland, Oregon (~250 mi downstream on the Columbia River). The Hanford Site stretches ~30 mi north to south and ~24 mi east to west. The Site lies immediately north-northwest of the confluence of the Yakima and Columbia Rivers, and the cities of Kennewick, Pasco, and Richland (the Tri-Cities), and the city of West Richland.

The Columbia River flows eastward through the northern part of the Hanford Site and then turns south, forming part of the eastern Site boundary. This section of the river is known as the Hanford Reach and is a free-flowing section of the Columbia River, ~51 mi long. The following seven dams are upstream of the Hanford Site and are listed from closest to furthest from the Hanford Site: Priest Rapids, Wanapum, Rock Island, Rocky Reach, Wells, Chief Joseph, and Grand Coulee. Other important rivers near the Hanford Site are the Yakima River to the south and southwest and the Snake River to the east. The Cascade Mountains, which are ~100 mi to the west, have an important effect on the climate of the area.

The Yakima River runs near the southern boundary of the Hanford Site, joining the Columbia River at the city of Richland. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries of Hanford, and Saddle Mountain forms its northern boundary. The plateau of the central portion of the Hanford Site is punctuated by two small east-west ridges, Gable Butte and Gable Mountain. Lands adjoining the Hanford Site to the west, north, and east are principally range and agricultural areas.

The Hanford Site is a relatively undeveloped area of shrub-steppe (a drought-resistant, shrub and grassland ecosystem) that contains a rich diversity of plant and animal species. This area has been protected from disturbance, except for fire, over the past 70+ years. This protection has allowed plant species and communities that have been displaced by agriculture and development in other parts of the Columbia Basin to thrive at the Hanford Site.

In the past, the Hanford Site was used as a U.S. Government defense materials production site that included nuclear reactor operation, uranium and plutonium processing, the storage and processing of SNF, and the management of radioactive and hazardous chemical wastes. The current mission at Hanford includes managing waste products, remediation, researching new technologies for waste disposal and cleanup, and reducing the size of the Site (PNNL-20548 [pp. v]). Present Hanford programs are diversified and include the management of radioactive waste, cleanup of waste sites and soil and groundwater contaminated by past waste releases, stabilization and storage of SNF, research into renewable energy and waste disposal technologies, cleanup of contamination, and stabilization and storage of plutonium.

Hanford is owned and used primarily by DOE, but portions of it are owned, leased, or administered by other Government agencies. Public access to the site is limited to travel on the Route 4 and Route 10 access roads as far as the Wye Barricade, State Routes 24 and 240, and the Columbia River. By restriction of access, the public is shielded from portions of the Site formerly used for the production of nuclear materials and currently used for waste storage and disposal. Only ~6 percent of the land area has been disturbed and is actively used, leaving mostly vacant land with widely scattered facilities (PNNL-6415, “Hanford Site National Environmental Policy Act (NEPA) Characterization,” Rev. 17 [pp. 4.144]). Figure 2-2 shows

the generalized land use at Hanford as developed in the Hanford Comprehensive Land-Use Plan Environmental Impact Statement [DOE/EIS-0222-F, "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement"; 64 FR 61615, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)"] and modified by the designation of the Hanford Reach National Monument.

In June 2000, a Presidential proclamation established the 195,000-ac Hanford Reach National Monument to protect the nation's only un-impounded stretch of the Columbia River above Bonneville Dam and the largest remnant of the shrub-steppe ecosystem that once blanketed the Columbia River Basin (65 FR 37253, "Establishment of the Hanford Reach National Monument"). DOE and the U.S. Fish and Wildlife Service began management of the monument in 2003. The U.S. Fish and Wildlife Service administers three major management units of the monument totaling ~258 mi^2. These include: (1) the Fitzner/Eberhardt Arid Lands Ecology Reserve Unit, a 120-mi^2 tract of land in the southwestern portion of the Hanford Site; (2) the Saddle Mountain Unit, a 50-mi^2 tract of land located north-northwest of the Columbia River and generally south and east of State Highway 24; and (3) the Wahluke Unit, an 87-mi^2 tract of land located north and east of both the Columbia River and the Saddle Mountain Unit.

2.1.1 Future Hanford Site Land Use

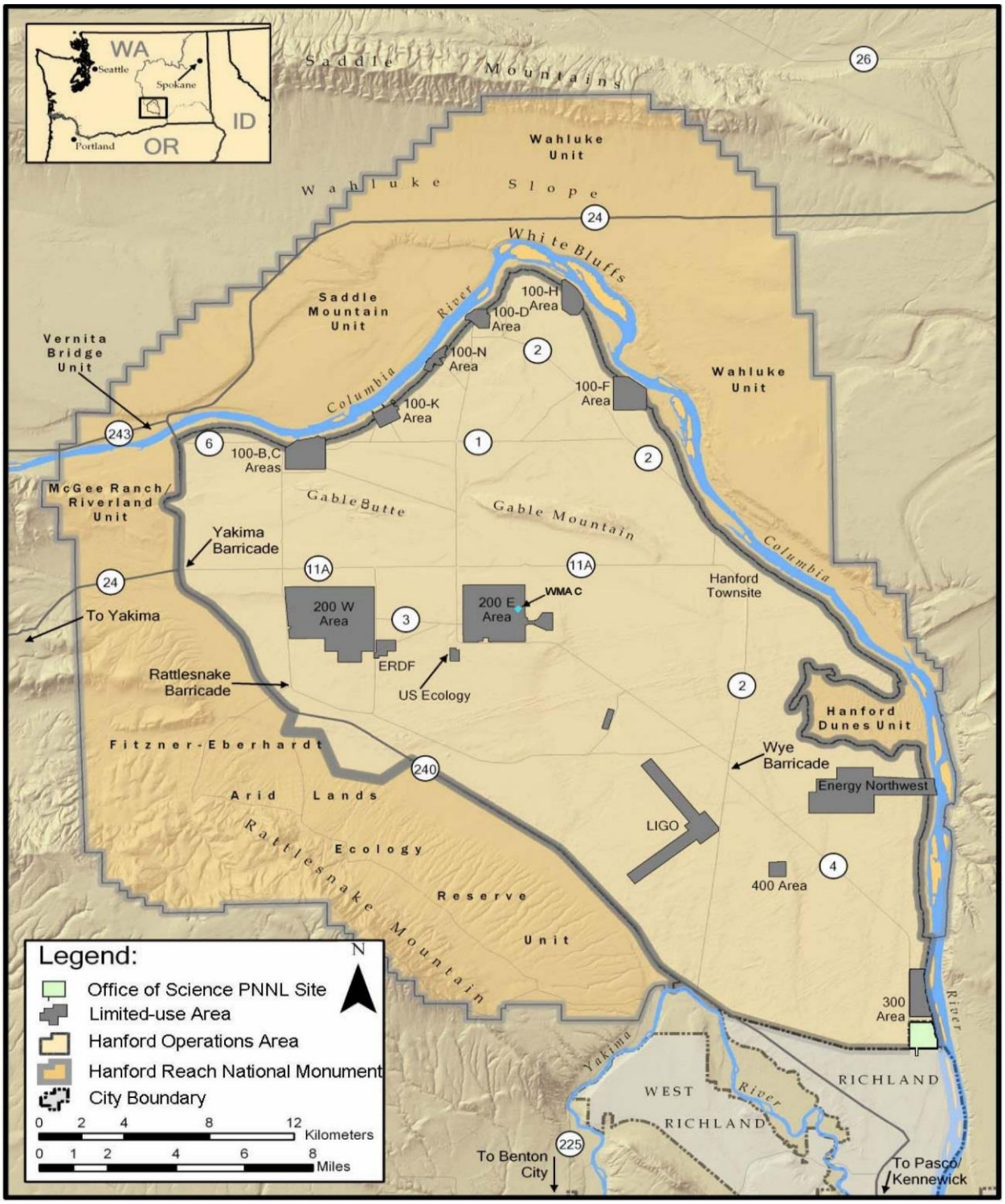
In 1992 DOE, EPA, and Ecology gathered a group of stakeholders (Hanford Future Site Uses Working Group [HFSUWG]) to study potential future uses for Hanford Site land. The HFSUWG issued a summary of its findings (HFSUWG 1992, "The Future for Hanford: Uses and Cleanup, Summary of the Final Report of the Hanford Future Site Uses Working Group"). DOE/EIS-0222-F is heavily based on the work of the HFSUWG. However, DOE land use planning extends for only 50 years instead of the 100 years forecast by the HFSUWG. The HFSUWG findings contain the following statement about near-term use of the 200 Areas, called the Central Plateau (HFSUWG 1992):

> "The presence of many different types of radionuclides and hazardous constituents in various volumes, forms and combinations throughout the site poses a key challenge to the Hanford cleanup. To facilitate cleanup of the rest of the site, wastes from throughout the Hanford Site should be concentrated in the Central Plateau. … Waste storage, treatment, and disposal activities in the Central Plateau should be concentrated within this area as well, whenever feasible, to minimize the amount of land devoted to, or contaminated by, waste management activities. This principle of minimizing land used for waste management should specifically be considered in imminent near-term decisions about utilizing additional uncontaminated Central Plateau lands for permanent disposal of grout."

The findings continue on the subject of future use options:

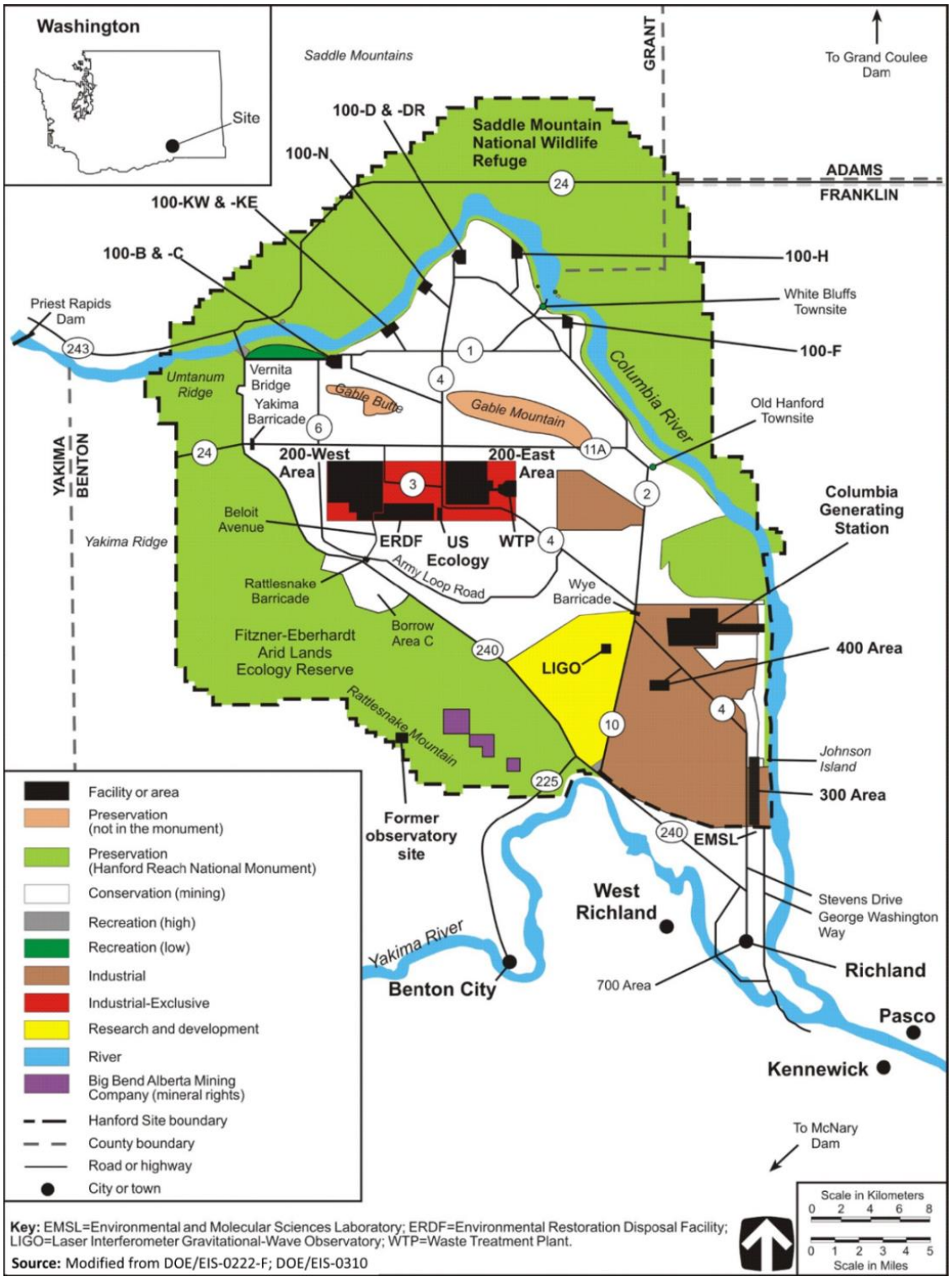
> "In general, the Working Group desires that the overall cleanup criteria for the Central Plateau should enable general usage of the land and groundwater for other than waste management activities in the horizon of 100 years from the decommissioning of waste management facilities and closure of waste disposal areas."

Figure 2-1. U.S. Department of Energy Hanford Site and Surrounding Area.



ERDF = Environmental Restoration Disposal Facility
LIGO = Laser Interferometer Gravitational Wave Observatory
PNNL = Pacific Northwest National Laboratory
WMA = Waste Management Area

Figure 2-2. Generalized Land Use of the Hanford Site and Adjacent Areas.



Sources:
DOE/EIS-0222-F, "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement."
DOE/EIS-0310, "Final Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility."

The HFSUWG could not agree on a definition of "general use." For the "foreseeable future," the HFSUWG developed options involving waste treatment, storage, and disposal of DOE LLW. The differences among the options are whether offsite waste (radioactive and/or hazardous) would be allowed to be disposed of on the Hanford Site. Finally, the HFSUWG findings state (HFSUWG 1992):

> "The working group identified a single cleanup scenario for the Central Plateau. This scenario assumes that future uses of the surface, subsurface, and groundwater in and immediately surrounding the 200 West and 200 East Areas would be exclusive. … Surrounding the exclusive area would be a temporary surface and subsurface exclusive buffer zone composed of at least the rest of the Central Plateau … As the risks from the waste management activities decrease, it is expected that the buffer zone would shrink commensurately."

The Hanford Comprehensive Land-Use Plan Environmental Impact Statement Record of Decision (64 FR 61615) identifies near-term land uses for the Hanford Site. It prescribes the use in the 200 Areas as exclusively industrial (primarily waste management) with much of the surrounding land having the use of preservation or conservation. The Hanford Reach National Monument extends along the Columbia River corridor and inland at the northern and western edges of the Site (65 FR 37253). For further discussion of Hanford land uses, refer to DOE/EIS-0222-F and DOE/RL-2009-10, Hanford Site Cleanup Completion Framework.

2.1.2 Hanford Site Geology, Seismology and Volcanology

Since the Hanford Site started operating in the early 1940s, a large volume of information on the geology, seismology, and volcanology of the Site has been collected and evaluated. Over the last several years, the following two data packages have been prepared to describe the geology, hydrology, and geochemistry of the SST system and WMA C:

- RPP-RPT-46088, "Flow and Transport in the Natural System at Waste Management Area C"
- PNNL-15955, "Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site."

Most of the data included in the geologic data package were collected by (or used by) several projects between about 1980 and the present. Those projects include the Basalt Waste Isolation Project, the Skagit Hanford Nuclear Project, the Washington Public Power Supply System safety analysis, several PAs, and numerous regulatory-driven geologic and hydrologic characterizations, assessments, and monitoring projects.

The technical aspects of all of these projects, and thus the data, interpretations of the data, and conclusions, have been reviewed by one or more regulatory agencies and stakeholder groups including: NRC; National Academy of Science; Defense Nuclear Facilities Safety Board; EPA; U.S. Geological Survey; Ecology; Washington State Department of Health; Oregon Department of Energy; and Yakama, Nez Perce, and Wanapum Indian Nations and the Confederated Tribes of the Umatilla Reservation. The high level of review has helped ensure a rigorous understanding of bounding geologic, seismic, and volcanic risks.

This section provides a summary of the data in the two data packages, highlighting those aspects that are important to developing the conceptual model describing transport of contaminants away from the waste facility to a receptor. Focus is on the regional and Hanford Site geologic framework. The geology of WMA C is discussed in Section 2.2.1.

2.1.2.1 Hanford Site Geologic Structure

The Cold Creek syncline (Figure 2-3) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift and is an asymmetric and relatively flat-bottomed structure. The Cold Creek syncline began developing during the eruption of the Columbia River Basalt Group (CRBG) and has continued to subside since that time. The 200 Areas lie on the northern flank, and the bedrock dips gently (approximately 5°) to the south. The deepest parts of the Cold Creek syncline, the Wye Barricade depression and the Cold Creek depression, are ~7.5 mi southeast of the 200 Areas and southwest of the 200 West Area, respectively (Figure 2-3).

The Wahluke syncline north of Gable Mountain is the principal structural unit that contains the 100 Areas. The Wahluke syncline is an asymmetric and relatively flat-bottomed structure similar to the Cold Creek syncline. The northern limb dips gently (approximately 5°) to the south. The steepest limb is adjacent to the Umtanum Ridge-Gable Mountain structure.

The 200 East Area is located on the eastern part of the Cold Creek bar, which is along the northern flank of the Cold Creek syncline (Figure 2-3). Another deep structural low, the Wye Barricade depression, developed along the Cold Creek syncline southeast of the 200 East Area. The May Junction fault is a normal fault that marks the western boundary of the depression.

The 200 East Area sits at the southern end of a series of secondary doubly-plunging anticlines and synclines that are associated with the Umtanum Ridge-Gable Mountain anticlinal structure. WMAs A-AX, B-BX-BY, and C in the 200 East Area lie near the southern flank of the closest secondary anticline. A fault was recently detected during drilling of seismic test boreholes at the Waste Treatment and Immobilization Plant. The fault caused some displacement in the Pomona Basalt that lies beneath the Elephant Mountain Member but is not thought to have caused any displacement in younger basalts or overlying sediments (PNNL-16407, “Geology of the Waste Treatment Plant Seismic Boreholes”).

2.1.2.1.1 Hanford Site Stratigraphy

The unconsolidated sediments and rocks beneath the Hanford Site consist of Miocene-age (5 million to 24 million years old) and younger strata that overlie older Cenozoic sedimentary and volcanic basement rocks (DOE/EIS-0222-F [pp. 4-12, 4-16]; PNNL-6415, “Hanford Site National Environmental Policy Act (NEPA) Characterization,” Rev. 18 [pp. 31]). The major geologic units immediately underlying the Hanford Site are, in ascending order: (1) the CRBG and interbedded Ellensburg Formation and (2) the Ringold Formation (RF), Cold Creek Unit (CCu), and Hanford formation (H3), collectively known as the suprabasalt sediments. Figure 2-4 presents a stratigraphic profile of Hanford.

Figure 2-3. Geologic and Geomorphic Map of the 200 Areas and Vicinity.

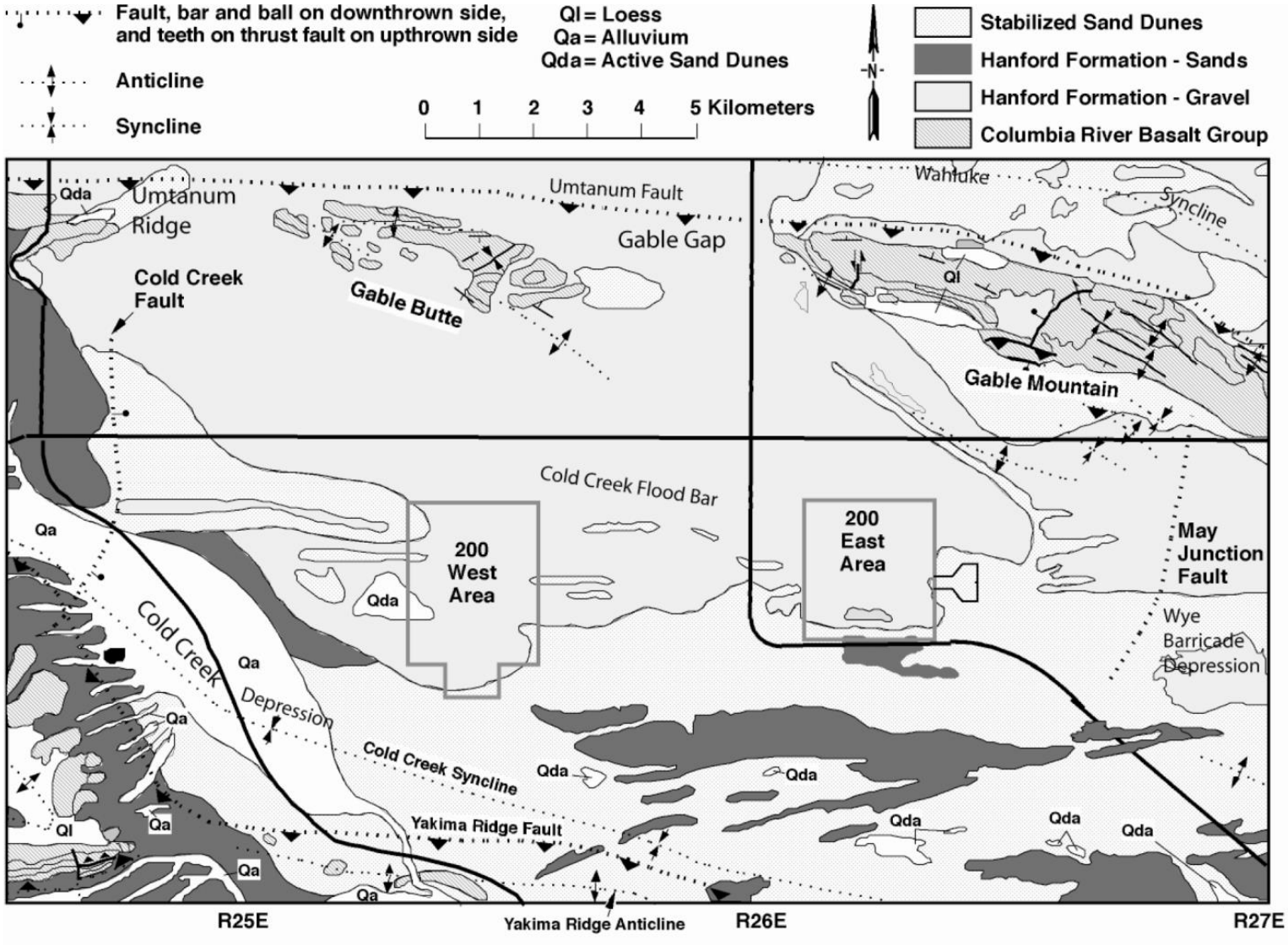
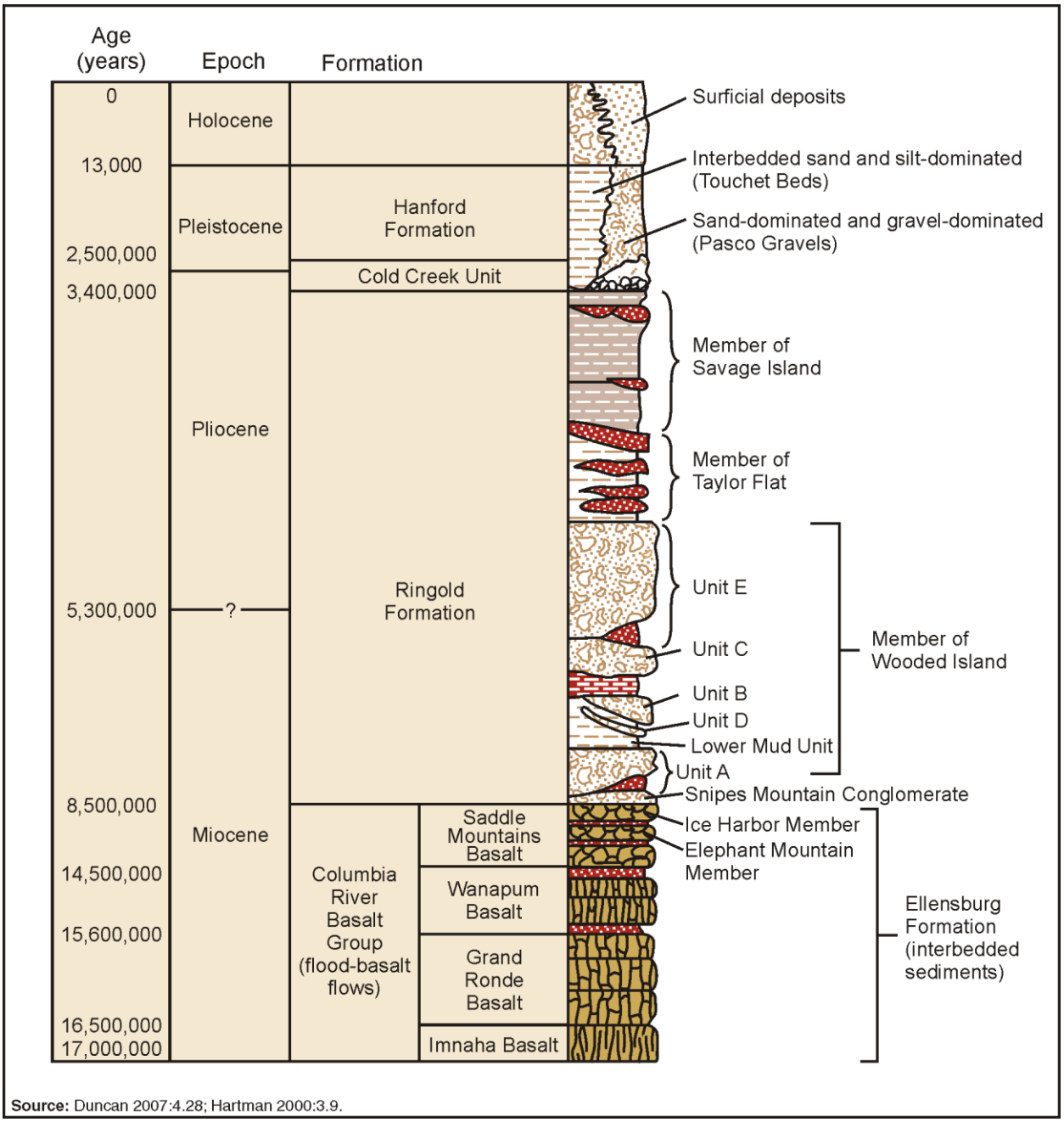


Figure 2-4. Generalized Stratigraphy of the Hanford Site Including the Central Plateau.



Source: Duncan 2007:4.28; Hartman 2000:3.9.

Duncan 2007 is PNNL-6415, "Hanford Site National Environmental Policy Act (NEPA) Characterization," Rev. 18.
Hartman 2000 is PNNL-13080, "Hanford Site Groundwater Monitoring: Setting, Sources, and Methods."

The CRBG consists of sequences of Miocene-age continental flood basalts that cover an extensive area across the States of Washington, Oregon, and Idaho. These basalts erupted over a period ranging from approximately 6 million to 17 million years ago. Columbia River basalt flows erupted from north-northwest trending fissures or linear vent systems mostly in north-central and northeastern Oregon, eastern Washington, and western Idaho. Beneath the

Hanford Site is a minimum of 50 basalt flows with a combined thickness greater than 9,800 ft. Basalt outcrops are exposed on ridges at Gable Mountain, Gable Butte, and the Saddle Mountains in the northern part of the Hanford Site, and on Rattlesnake Hills and Yakima Ridge on the western and southwestern edges of the Site. Basalt flows at the Site have eroded to various degrees in localized areas. Interbedded with, and in some places overlying the CRBG, are the volcaniclastic (volcanic-sedimentary) and fluvial (stream-deposited) sedimentary materials of the Ellensburg Formation. In the western Columbia Basin, the Ellensburg Formation is mostly volcaniclastic sediment; in the central and eastern basin, fluvial mainstream and overbank sediments of the ancestral Clearwater-Salmon and Columbia Rivers form the dominant lithologies (PNNL-6415, Rev. 18 [pp. 4.29]; "Late Cenozoic Structure and Stratigraphy of South-Central Washington" [Reidel et al. 1994] [pp. 2-4]).

The Ringold Formation consists of a mix of variably cemented gravel, sand, silt, and clay deposited by the ancestral Columbia River system (PNNL-6415, Rev. 18 [pp. 4.32]; PNNL-13080, "Hanford Site Groundwater Monitoring: Setting, Sources, and Methods" [pp. 32]). Ringold Formation deposits represent an eastward shift of the Columbia River across Hanford. The Columbia River first flowed across the west side of Hanford (where Dry Creek is now), crossing through Rattlesnake Hills. The river eventually shifted to a course that took it through Gable Mountain–Gable Butte Gap (Gable Gap) and south across the present 200 East Area (PNNL-13080 [pp. 3.2]). In summary, about 8.5 million years ago, the river meandered across a gravelly braided plain, depositing the extensive gravel and interbedded sand of the oldest Ringold sediments, Unit A, Member of Wooded Island (Figure 2-4). Between 5 and 7 million years ago, the Columbia River abandoned the Yakima River water gap (near present-day Benton City) and began to exit the Pasco Basin through Wallula Gap. Around 6.7 million years ago, the Columbia River became a sandy alluvial system, depositing extensive lake and stream overbank sediments known as the Ringold Formation Lower Mud Unit. The Lower Mud Unit was covered by another extensive sequence of mainstream gravels and sands in the central Pasco Basin and fine-grained overbank deposits near the 100 Areas. The most extensive of the coarse sediments, Unit E, Member of Wooded Island, underlies much of the 200 Areas. The Columbia River sediments became more sand-dominated about 5 million years ago when over 295 ft of interbedded fluvial sand and overbank deposits accumulated at Hanford. These deposits are collectively called the Member of Taylor Flat. The fluvial sands of the Member of Taylor Flat dominate the lower cliffs of the White Bluffs but have been subsequently eroded from most of Hanford. The last Ringold unit (Member of Savage Island) was deposited between 3.4 and 4.8 million years ago in the form of lake deposits. A series of three successive lakes are recognized along the White Bluffs and elsewhere along the margin of the Pasco Basin. Then, regional uplift associated with the Cascade Mountains marked a change from sedimental disposition to removal and caused the river to cut through its own earlier deposits (the Ringold Formation), exposing the White Bluffs (PNNL-6415, Rev. 18 [pp. 4.31]). The Ringold Formation at Hanford is as much as 607 ft thick and attains a thickness of about 935 ft along White Bluffs (PNNL-6415, Rev. 17 [pp. 4.32]; Reidel et al. 1994 [pp. 3]).

The Plio-Pleistocene Cold Creek Unit includes all alluvial and eolian (wind-deposited) sediments, as well as a series of extensively weathered, carbonate-rich, buried soil profiles called paleosols. These sediments and paleosols overlie the Ringold Formation and underlie the Hanford formation in the vicinity of the 200 West Area, and may extend over most of the central

Pasco Basin. The Cold Creek Unit, which is also locally prevalent in the subsurface within the Cold Creek syncline, includes deposits referred to in older Hanford Site literature as the "Plio-Pleistocene Unit" and "pre-Missoula gravels, " as well as the 200 West Area's "early Palouse soils" and "caliche layer" (DOE/RL-2002-39 [pp. 3-1, 3-2]). Because the Plio-Pleistocene Cold Creek Unit was formed when the Ringold Formation was eroding and relatively little was being deposited, the distribution of the unit depends in part on erosion and weathering of the underlying Ringold Formation and postdepositional erosion by the Ice Age floods. As such, the Cold Creek Unit is discontinuous, with a thickness ranging from 0 to 66 ft (PNNL-6415, Rev. 18 [pp. 4.32]). Cold Creek Unit paleosols and small-stream drainages were developing in the 200 West Area while the Columbia River was still eroding the 200 East Area. The paleosols and side-stream sediments, which are referred to as the "Lower Cold Creek Unit," are consequently more numerous and heavily cemented, forming layers known as caliches or hardpans in the 200 West Area. Eolian and minor fine-grained stream sediments were deposited on the Lower Cold Creek Unit, resulting in a wide variety of sediments that are referred to as the "Upper Cold Creek Unit." The thickness and type of sediment are highly variable due to several localized environments. Because of their fine-grained or cemented nature, the Upper and Lower Cold Creek Units play important roles in the movement of water and contaminants through the vadose zone. Cold Creek Unit gravels of mixed lithologies in a sand matrix reflect deposition by the Columbia River as it flowed through Gable Gap. These mainstream gravel deposits, which are informally called the pre-Missoula gravels, immediately overlie the Ringold Formation. They are often difficult to differentiate from similar gravel deposits in the Ringold Formation and Hanford formation (PNNL-6415, Rev. 18 [pp. 4.32, 4.33]; PNNL-13080 [pp. 3.3]).

The gravel, sand, and silt deposits composing the strata informally called the Hanford formation are products of Ice Age floods that inundated the Pasco Basin and Hanford Site during the Pleistocene epoch as previously described in this section. The Hanford formation sediments were left after the floodwater receded and now blanket low-lying areas over most of the Hanford Site. Associated deposits occur in three distinct assemblages, dominated by coarse sand and gravel, sand, and interbedded sand and silt (PNNL-6415, Rev. 18 [pp. 4.33]). The sediments range up to boulder size, with the lithofacies (sediment types) grading or interfingering with one another in both the horizontal and vertical directions (DOE/RL-202-39 [pp. 3-9]). The gravel-dominated flood deposits are generally confined to tracts within or adjacent to flood channels and reflect higher-energy depositional environments. A major depositional feature called the Cold Creek bar underlies the Hanford Site 200 Areas and was deposited just south of one such channel. Gravel-dominated flood sediments deposited on the north side of the bar grade into sand-dominated sediments on the south side. Gravel- and sand-dominated sediments compose most of the vadose zone beneath the Hanford Site. Coarse- to fine-sand deposits represent a transitional depositional environment between the fluvial gravel-dominated deposits and the interbedded sands and silts. The interbedded sand- and silt-dominated sediments were deposited in low-energy slackwater areas around the margins of the Pasco Basin, and they are rarely encountered during Hanford Site operations. They specifically consist of rhythmically bedded silt and sand (referred to as "rhythmite deposits") and have been named the "Touchet Beds" at the Hanford Site (Figure 2-4) (PNNL-6415, Rev. 18 [pp. 4.33]; PNNL-13080 [pp. 3.3]).

Clastic dikes are vertical to subvertical tabular structures that crosscut normal sedimentary layers and are usually filled with multiple layers of unconsolidated sediments. They are common in Hanford Site vadose zone sediments (PNNL-6415, Rev. 18 [pp. 4.34]).

Surficial Quaternary-age (Holocene) deposits (gravel, sand, and silt), with a total thickness of generally less than 16 ft, span much of the Hanford Site. Eolian deposits of fine-grained sand and silt also occur, particularly in the southern part of the 200 East Area and in the 200 West Area (PNNL-13080 [pp. 3.4]). An extensive, stabilized field of sand dunes extends from the southern boundary of the 200 East Area to the south across the 300 Area and east to the Columbia River. An active dune field is located just north of Energy Northwest in Hanford Reach National Monument (DOE/EIS-0222-F [pp. 4-22]; PNNL-6415, Rev. 18 [pp. 4.33]).

2.1.2.2 Hanford Site Seismology

The historic record of earthquakes in the Pacific Northwest dates from about 1840. The early part of this record is based on newspaper reports of human perception of shaking and structural damage as classified using the Modified Mercalli Intensity (MMI) scale; the early record is probably incomplete because the region was sparsely populated. The historical record appears to be complete since 1905 for MMI V and since 1890 for MMI VI ("Earthquake Recurrence Rate Estimates for Eastern Washington and the Hanford Site" [PNL-6956]). Seismograph networks did not start providing earthquake locations and magnitudes of earthquakes in the Pacific Northwest until about 1960. A comprehensive network of seismic stations that provides accurate locating information for most earthquakes of magnitude greater than 2.5 was installed in eastern Washington during 1969. Currently, measured seismic activity for the Hanford Site is reported quarterly and annually (e.g., PNNL-20302, "First Quarter Hanford Seismic Report for Fiscal Year 2011"). Figure 2-5 provides summaries of known events at and around the Hanford Site between 1890 and 2005 (PNNL-6415).

Three horizontal layers of stratigraphy related to seismicity exist at the Hanford Site and vicinity including the CRBG, the pre-basalt sediments, and the crystalline basement. About 75 percent of Hanford Site earthquake events originate in the CRBG layer. The pre-basalt sedimentary layer has been the origin of 8 percent of the events, and the crystalline basement has been the origin of 17 percent of these events (RPP-13033, "Tank Farms Documented Safety Analysis").

The most frequent seismic occurrences at the Hanford Site are earthquake swarms (Figure 2-6) that consist of multiple small energy events that fall within a small energy range and are constrained temporally (weeks to months) and spatially (3 to 6 mi in length). Swarms tend to reoccur in particular locations, ~90 percent of individual earthquakes are at Richter scale magnitudes of 2 or less, and 70 to 80 percent of them occur at depths less than 2.5 mi below ground surface (bgs).

Larger isolated earthquakes also occur nearby (DOE/RW-0164, Consultation Draft Site Characterization Plan Reference Repository Location, Hanford Site, Washington). The largest single event earthquake recorded near the Hanford Site occurred in Milton-Freewater, Oregon, located ~50 mi away in 1936 at a Richter magnitude of 5.75 and a maximum MMI of VII. The two next largest nearby earthquakes occurred north of the Hanford Site in 1917 and 1973 near Othello, Washington, ~30 mi north of the 200 Areas with magnitudes above 4 on the Richter scale and MMI of V. The 1973 earthquake occurred ~0.6 mi bgs. Since 1973, 80 small

earthquakes (2.5 to 4.3 magnitudes) have been recorded within a radius of 56 mi of the Hanford Site Central Plateau, the closest being a magnitude 3.3 event with the epicenter 5 mi north of the 200 Areas. Earthquake depths vary for isolated events and have been estimated as deep as ~19 mi.

Greater magnitude earthquakes have been recorded at greater distances from the Hanford Site at the edges of the Columbia Plateau, along the coastal subduction zones to the west and in the Rocky Mountains to the east. The Columbia Plateau, which is made up of thick and extensive sequences of flood basalt layers in the Columbia River Group, extends well beyond the Hanford Site covering parts of eastern Washington, eastern Oregon, and Idaho. Notable events in these areas are the 2001 "Nisqually" earthquake in the Puget Sound (6.8 magnitude), an approximate magnitude 6.8 to 7.4 earthquake in north-central Washington in 1872 near Lake Chelan, the 1959 Hebgen Lake earthquake (7.5 magnitude) in western Montana, and the 1983 Borah Peak earthquake in eastern Idaho (7.3 magnitude).

The gross pattern of seismic activity around the Hanford Site is consistent with our understanding of regional tectonic characteristics of the Northwest. That is, the flood basalts form a large and relatively competent block of rock that is surrounded by numerous complex zones of active faults where large scale stresses imposed primarily by the ongoing subduction of the Pacific and Juan de Fuca Plates underneath the North American Plate are mostly relieved. Consequently, relatively minimal stress relief occurs in the Columbia Plateau and earthquake energy is correspondingly small. This means that potential ground motion that accompanies these earthquakes is also relatively small.

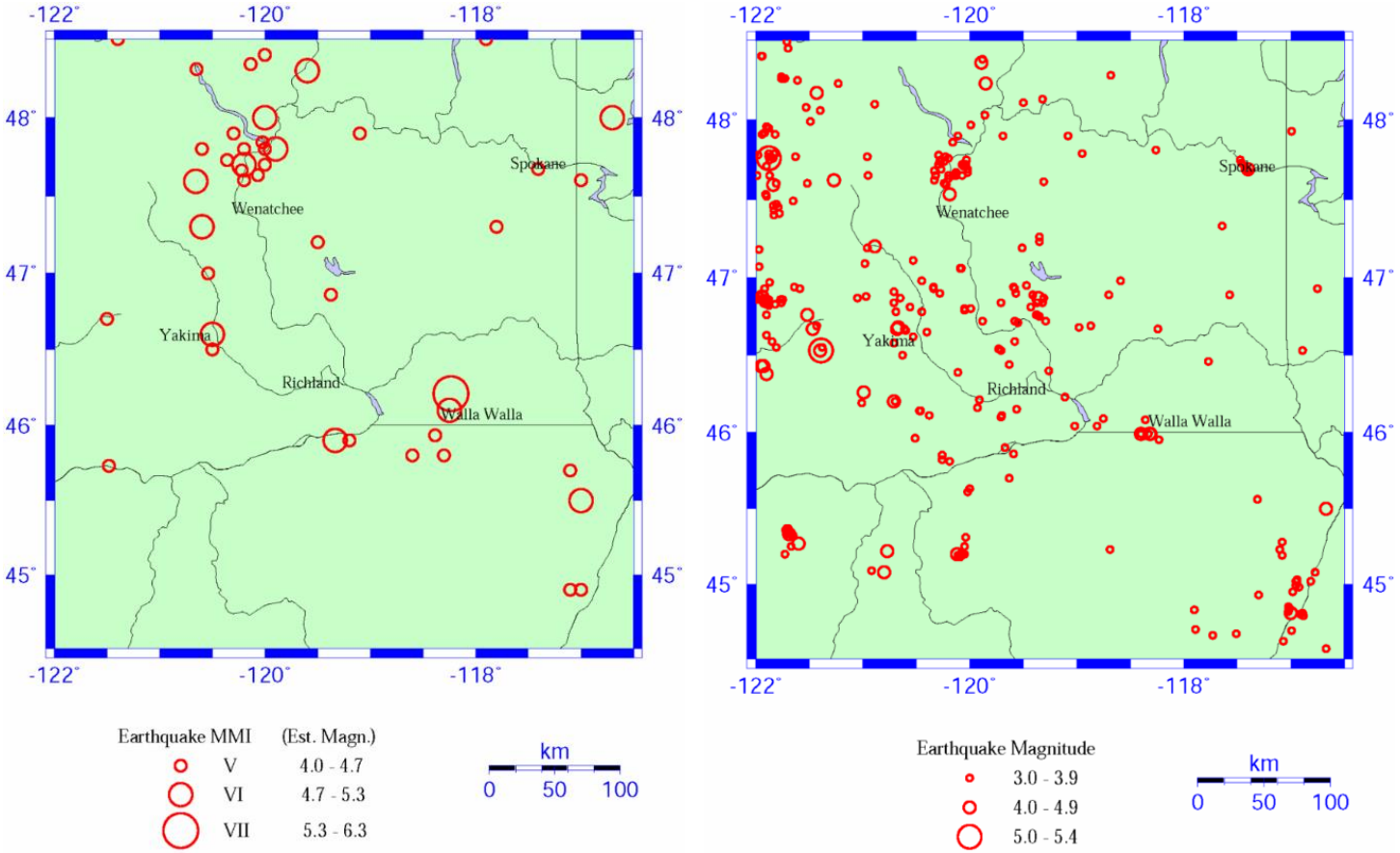
Relative movement is commonly quantified as some fraction of gravitational acceleration (*g*) and has been usually correlated with earthquake magnitude. For the range of earthquake magnitudes suggested by data summarized above for the Hanford Site (less than 3 to 6), peak accelerations between less than 0.0017 and 0.18 *g* are proposed. The associated range of motion is generally imperceptible compared to clearly felt movement that can result in minimal building damage. A probabilistic seismic hazard analysis (WHC-SD-W236A-TI-002, "Probabilistic Seismic Hazard Analysis, DOE Hanford Site,Washington") estimated that a 0.1 *g* horizontal acceleration would occur every 500 years and a 0.2 *g* acceleration would occur every 2,500 years.

2.1.2.3 Hanford Site Volcanology

Two types of volcanic hazards have affected the Hanford Site in the past 20 million years. The hazards were (1) continental flood basalt volcanism that produced the CRBG and (2) volcanism associated with the Cascade Range. Several volcanoes in the Cascade Range are currently considered to be active, but activity associated with flood basalt volcanism has ceased.

The flood basalt volcanism that produced the CRBG occurred between 17 million and 6 million years ago. Most of the lava was extruded during the first 2 million to 2.5 million years of the 11-million-year volcanic episode. Volcanic activity has not recurred during the last 6 million years, suggesting that the tectonic processes that created the episode have ceased. The recurrence of CRBG volcanism is not considered to be a credible volcanic hazard (DOE/RW-0164).

Figure 2-5. Earthquake Activity of the Columbia Basin, Washington, and Surrounding Areas.

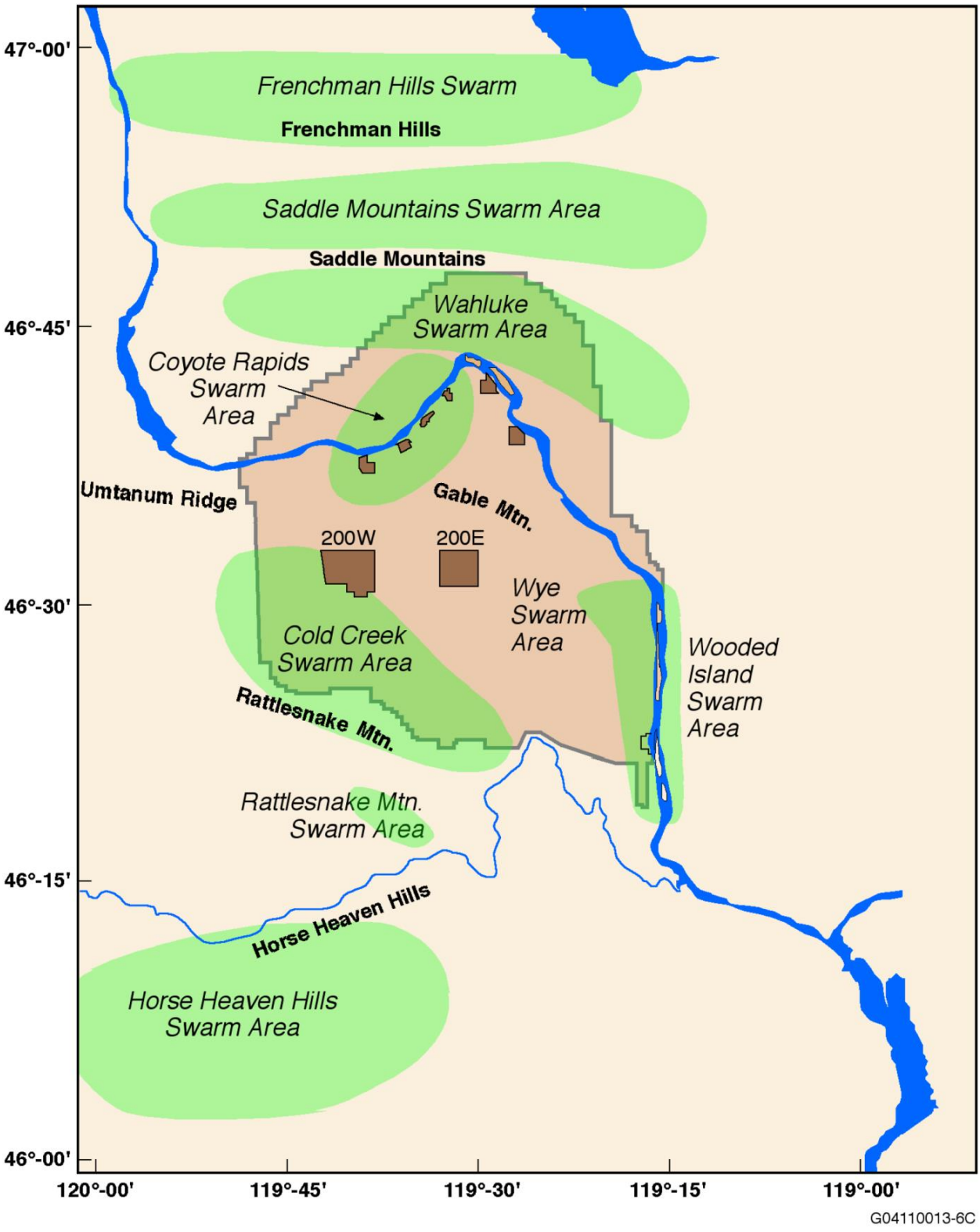


Left: Historical earthquake activity. All earthquakes between 1890 and 1970 with a Modified Mercalli Intensity (MMI) V or larger and/or a magnitude 4 or larger are shown ("Earthquake Recurrence Rate Estimates for Eastern Washington and the Hanford Site" [PNL-6956]).

Right: Earthquake activity as measured by seismographs. All earthquakes between 1970 and 2005 with Richter magnitudes of 3 or larger are shown (Northern California Earthquake Data Center, Queried 09/2005, [Advanced National Seismic System (ANSS) Catalog Search], http://www.quake.geo.berkeley.edu/anss/catalog-search.html).

Source: PNNL-6415, "Hanford Site National Environmental Policy Act (NEPA) Characterization."

Figure 2-6. Earthquake Swarm Areas in the Vicinity of the Hanford Site.



Volcanism in the Cascade Range was active throughout the Pleistocene Epoch and has remained active through the Holocene Epoch. The eruption history of the current Holocene Epoch best characterizes the most likely types of activity in the next 100 years. Many of the volcanoes have been active in the last 10,000 years, including Mount Mazama (Crater Lake) and Mount Hood in Oregon; and Mount Saint Helens, Mount Adams, and Mount Rainier in Washington. The Hanford Site is ~93 mi from Mount Adams, ~109 mi from Mount Rainier, and ~124 mi from Mount Saint Helens, the three closest active volcanoes. At these distances, the deposition of tephra (ash) is the only potential hazard. Mount Saint Helens has been considerably more active throughout the Holocene Epoch than Mount Rainier or Mount Adams, which is the least active of the three. WHC-SD-GN-ER-30038, "Volcano Ashfall Loads for the Hanford Site," concludes that the Hanford Site is sufficiently distant from the Cascade Range volcanoes that hazards from lava flows, pyroclastic flows and surges, landslides, lahars, and ballistic projectiles are below a probability of concern.

2.1.3 Hanford Site Subsurface Subsidence and Liquefaction

Field and laboratory studies that have been completed at many of the tank farm sites are summarized in WHC-SD-GN-ER-30009, "Bibliography and Summary of Geotechnical Studies at the Hanford Site." These studies reveal that there are no areas of potential surface or subsurface subsidence, uplift, or collapse at the Hanford Site, with the minor exceptions of the Cold Creek and Wye Barricade depressions, neither of which are close to WMA C. With the exception of the loose superficial wind-deposited silt and sand in some locations, the in-place soils are competent and form good foundations.

Liquefaction is the sudden decrease of shearing resistance of a cohesionless soil, caused by the collapse of the structure by shock or strain, and is associated with a sudden but temporary increase of the pore fluid pressure. Saturated or near-saturated soil (sediments) are required for liquefaction to occur. The average volumetric moisture content at WMA C is less than 10 percent. Therefore, liquefaction of soils beneath the tank farms would not be a credible hazard because the water table is greater than 213 ft bgs.

2.1.4 Hanford Site Topography

Figure 2-7 shows the 200 Areas and the WMAs in a perspective view (note that the vertical to horizontal exaggeration in this figure is 5:1). The 200 Areas Central Plateau contains a topographic high in between the 200 East and 200 West Areas with gently dipping sides, except in the northwest corner of the 200 West Area. The WMAs were always located downhill from the waste-generating facilities to allow gravity flow in the pipelines from the facilities to the tanks. The relative flatness of the WMAs means that the final topography will be determined by the surface barrier and grading of the surrounding soil.

2.1.5 Hanford Site Hydrology

This section presents the summary of the hydrology/hydrogeology (water and soil characteristics) of the Hanford Site, focusing on surface water, recharge, characteristics of the unsaturated zone or vadose zone and the saturated zone or groundwater. Due to waste disposal operations at the Hanford Site, the hydrology of the Site has been studied and monitored in

detail. Therefore, the information presented in this section will primarily be a summation of previous work highlighting those characteristics that affect the WMA C PA. For additional detail, see the following references:

- PNNL-20548 – Provides the overview of the characterization and monitoring activities conducted at the Hanford Site during the calendar year
- DOE/RL-2013-22, Hanford Site Groundwater Monitoring Report for 2012 – Describes the groundwater monitoring activities during the fiscal year
- PNNL-6415, Rev. 18 – Provides a standardized description of the Hanford Site environment
- DOE/ORP-2008-01, RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas – Describes the Phase 1 vadose zone characterization efforts at the SST farms.

These overview documents will contain references to site-specific documents that describe the hydrology for a particular waste site (e.g., WMA C).

2.1.5.1 Hanford Site Vadose Zone

The vadose zone is that part of the geologic media which extends from the Earth's surface to the water table. At the Hanford Site, the thickness of the vadose zone ranges from 0 ft near the Columbia River to greater than 328 ft. The average depth to groundwater under WMA C is 230 ft (PNNL-13080, "Hanford Site Groundwater Monitoring: Setting, Sources, and Methods"). Unconsolidated glacio-fluvial sands and gravels of the Hanford formation make up most of the vadose zone (Figure 2-4). In some areas, such as most of the 200 West Area and in some of the 100 Areas, the fluvial-lacustrine sediments of the Ringold Formation make up the lower part of the vadose zone. The Cold Creek Unit also makes up part of the vadose zone. The integrated knowledge obtained from previous and ongoing studies provides a good conceptual understanding of the geologic, hydraulic, and geochemical environment and its controls on the distribution and movement of contaminants within the vadose zone (PNNL-14702, "Vadose Zone Hydrogeology Data Package for Hanford Assessments").

The primary features relevant to the vadose zone flow and transport include the hydrogeologic materials (and their physical, hydraulic, and geochemical properties), subsurface conditions (e.g., fluid statics and thermal conditions), and fluid properties.

2.1.5.2 Hanford Site Hydrostratigraphy

The vadose zone stratigraphy influences the movement of liquid through the soil column. The vadose zone beneath the 200 East Area can be subdivided into six principal hydrostratigraphic units, including three units within the Hanford formation, a fluvial gravel facies of the Cold Creek Unit (equivalent to the Pre-Missoula Gravels of "Appendix 2R - Stratigraphic Investigation of the Skagit/Hanford Nuclear Project," in Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report [Webster and Crosby 1982], and WHC-SD-ER-TI-003, "Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports"), and two units belonging to the Ringold Formation

(WHC-SD-EN-TI-012, "Geologic Setting of the 200 East Area: An Update"; WHC-SD-EN-TI-019, "Hydrogeologic Model for the 200 East Groundwater Aggregate Area"; PNNL-12261, "Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington"; DOE/RL-2002-39, Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin).

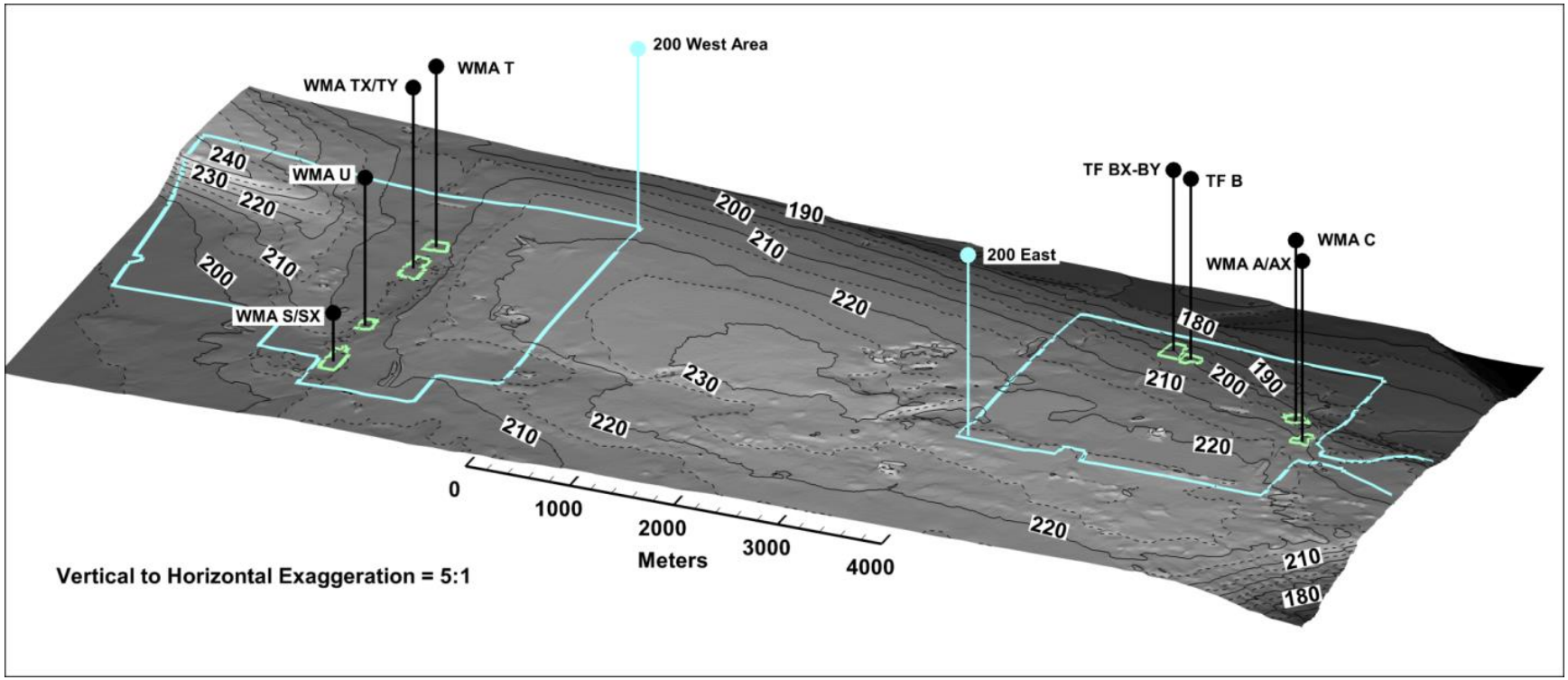
The Hanford formation units include (1) an upper gravel-dominated facies, (2) a sand-dominated facies, and (3) a lower gravel-dominated facies. Over most of the 200 East Area, the Hanford sand-dominated facies lies between the upper and lower gravel-dominated facies (WHC-SD-EN-TI-012; WHC-SD-EN-TI-019; DOE/RL-2002-39). Based on borehole samples, the upper and lower gravel-dominated facies appear to have similar physical and chemical properties. The Ringold Formation in the 200 East Area is, for the most part, eroded away in the northern half of the 200 East Area. Here, the Hanford formation lies directly on top of basalt bedrock. With the dropping water table, basalt crops out above the water table and, thus, is unsaturated beneath the northeastern portion of the 200 East Area. Underneath WMA C, the top of the unconfined aquifer lies within the undifferentiated H3/CCu/RF.

The vadose zone stratigraphy influences the potential for spreading of liquid within the soil column. Where conditions are favorable, lateral spreading of liquid effluent and/or local perched water zones may develop. Lateral spreading can occur along any strata with contrasting hydraulic conductivity. Where low-permeability layers within the Hanford formation have been documented, they are thin (1.6 ft or less) and laterally discontinuous. Low-permeability layers within the sand-dominated facies of the Hanford formation are generally thicker and more continuous than those in the gravel-dominated facies. Some paleosols and facies changes (i.e., the contact between fine-grained and coarser-grained facies) may be fairly continuous over the range of 100 yd or so, with some lateral spreading of crib effluent noted on that same scale. Lateral spreading can delay the arrival of contaminants at the water table but may cause mixing of the subsurface plume at one site with that of an adjacent site. Spreading may also require increasing the area of surface barriers to cover wider plumes.

Clastic dikes have also been observed in the Hanford formation beneath the 200 East Area. Their most important feature is their potential to either enhance or inhibit vertical and lateral movement of contaminants in the subsurface, depending on textural relationships (BHI-01103, "Injection Dikes of the Pasco Basin and Vicinity – Geologic Atlas Series"). For example, the vertically-oriented clay skins within clastic dikes may locally form an impediment to lateral flow. This could then cause ponding (perching) of the water and eventual breakthrough to underlying strata.

Sublinear channel-cut scour and fill features occur within the Hanford formation and may act as preferential pathways in the horizontal direction. Other types of heterogeneity are associated with stratigraphic pinch-out or offlapping/onlapping of facies.

Figure 2-7. Topography of the 200 Areas Central Plateau in Meters Above Mean Sea Level.



WMA = waste management area

2.1.5.2.1 Hanford Site Hydraulic and Transport Properties

Accurate predictions of flow and transport in the vadose zone require a detailed characterization of the hydrologic properties and their variability, as well as estimates of transport parameters such as dispersivity. In particular, data that are essential for quantifying the water storage and flow properties of unsaturated soil include the soil moisture characteristics (i.e., soil moisture content versus pressure head, and unsaturated hydraulic conductivity versus pressure head relations) for sediment in various geologic units.

Data on particle-size distribution, moisture retention, and saturated hydraulic conductivity (K_s) have been cataloged for over 284 samples from throughout the Hanford Site, including 12 locations in the 200 East and 200 West Areas (WHC-EP-0883, "Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site"; "Evaluation of van Genuchten-Mualem Relationships to Estimate Unsaturated Hydraulic Conductivity at Low Water Contents" [Khaleel et al. 1995]; "Correcting Laboratory-Measured Moisture Retention Data for Gravels" [Khaleel and Relyea 1997]; PNNL-13672, "A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site"; WMP-17524, "Vadose Zone Hydraulic Property Letter Reports"; "On the Hydraulic Properties of Coarse-Textured Sediments at Intermediate Water Contents" [Khaleel and Heller 2003]). Laboratory analyses of the hydraulic properties of samples collected at the Hanford Site have been performed at a number of different laboratories using techniques similar to those described in Methods of Soil Analysis, Part 1—Physical and Mineralogical Methods (Klute 1986).

Macrodispersivity estimates for non-reactive species have been estimated using the "Three-dimensional stochastic analysis of macrodispersion in aquifers" (Gelhar and Axness 1983) equation where the longitudinal macrodispersivity depends on the mean pressure head. HNF-4769, "Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste Performance Assessment," estimates a longitudinal macrodispersivity of ~3 ft for the sand-dominated facies of the Hanford formation in the 200 East Area. The transverse dispersivities have been estimated as one tenth of the longitudinal values ("A Critical Review of Data on Field-Scale Dispersion in Aquifers" [Gelhar et al. 1992]). Based on a survey of literature, Stochastic Subsurface Hydrology (Gelhar 1993) examines the longitudinal vadose zone dispersivities as a function of the scale of the experiment, and finds an increase of dispersivity with an increase in scale.

2.1.5.3 Hanford Site Groundwater

This section describes the relevant characteristics of the groundwater hydrogeology, which has been studied and monitored in detail because of the waste disposal and past discharges to the vadose zone at the Site. The hydrogeology characteristics of the Hanford Site are important to the definition of potential pathways for the WMA C contaminants to the public and the estimation of the magnitudes of the environmental impacts. Evaluating this pathway requires information about the types of aquifers present, depths to the water table, and regional flow paths toward surface water discharge points. Surface water flow represents a pathway for carrying contaminants to the public. Because the uppermost unconfined aquifer is considered the primary

pathway for possible contaminant transport from WMA C, it is especially important in the WMA C PA.

This section focuses on the hydrogeology of the 200 Areas but also includes information on the Hanford Site in general. This information was summarized largely from material presented in three key reports, as follows:

- PNNL-20548 – Provides the updated overview of the characterization and monitoring activities conducted at the Hanford Site during each calendar year
- DOE/RL-2014-32, Hanford Site Groundwater Monitoring Report for 2013 – Describes the groundwater monitoring activities during the fiscal year
- PNNL-6415 – Provides a standardized description of the Hanford Site environment.

Groundwater beneath the Hanford Site is found in both an upper unconfined aquifer system and deeper basalt-confined aquifers. The unconfined aquifer system is also referred to as the suprabasalt aquifer system because it is within the sediments that overlie the basalt bedrock. Portions of the suprabasalt aquifer system are locally confined. However, because the entire suprabasalt aquifer system is interconnected on a Site-wide scale, it is referred to in this report as the Hanford Site unconfined aquifer system.

2.1.5.3.1 Basalt-Confined Aquifer System

The upper basalt-confined aquifer groundwater system occurs within basalt fractures and joints, interflow contacts, and sedimentary interbeds within the upper Saddle Mountains Basalt. The thickest and most widespread sedimentary unit in this system is the Rattlesnake Ridge interbed, which is present beneath much of the Hanford Site. Groundwater also occurs within the Levey interbed, which is present only in the southern portion of the Site. A small interflow zone occurs within the Elephant Mountain Member of the upper Saddle Mountains Basalt and may be significant to the lateral transmission of water. The upper basalt-confined aquifer system is confined by the dense, low-permeability interior portions of the overlying basalt flows and in some places by silt and clay units of the lower Ringold Formation that overlie the basalt. Approximately 50 wells screened in the upper basalt-confined aquifer have been sampled or had water levels measured in recent years.

DOE monitors groundwater quality in the upper basalt-confined aquifer system because of the potential for downward migration of contaminants from the overlying unconfined aquifer in areas where confining units are absent or fractured. The upper basalt-confined aquifer system is not affected by contamination as much as the unconfined aquifer. Contamination found in the upper basalt-confined aquifer system is most likely to occur in areas where the confining units have been eroded away or were never deposited, and where past disposal of large amounts of wastewater resulted in downward hydraulic gradients.

2.1.5.3.2 Unconfined Aquifer System

The base of the uppermost aquifer system is defined as the top of the uppermost basalt flow, with the top of the system being the water table. This aquifer system is bounded laterally by anticlinal basalt ridges and is ~500 ft thick near the center of the Pasco Basin. Within the Hanford Site,

this uppermost aquifer system lies at depths ranging from less than 1 ft bgs near West Lake and the Columbia and Yakima Rivers, to more than 350 ft in the central portion of the Cold Creek syncline. Groundwater in the unconfined aquifer at the Hanford Site generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site toward the Columbia River on the eastern and northern boundaries. The Columbia River is the primary discharge area for the unconfined aquifer. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of recharge.

The unconfined aquifer system underlying the Hanford Site exists within sediments deposited on top of the Columbia River Basalts. It is composed primarily of the Ringold Formation and overlying Hanford formation. Figure 2-8 is a hydrogeologic map of the units present at the water table surface in June 1998, which represents the top of the unconfined aquifer just prior to the start of active remediation. In the 200 West Area, the water table occurs almost entirely in the Ringold Unit E gravels, while in the 200 East Area, it occurs primarily in the Hanford formation and in the Ringold Unit A gravels. Along the southern edge of the 200 East Area, the water table is in the Ringold Unit E gravels. The upper Ringold facies were eroded in most of the 200 East Area by the ancestral Columbia River and, in some places, by the Missoula floods that subsequently deposited Hanford formation gravels and sands on what was left of the Ringold Formation (DOE/RL-2002-39). Because the Hanford formation and possibly the Cold Creek Unit sand and gravel deposits are much more permeable than the Ringold gravels, the water table is relatively flat in the 200 East Area, but groundwater flow velocities are higher.

The hydrogeology of the 200 Areas has been strongly influenced by the discharge of large quantities of wastewater to the ground. Between 1944 and the mid-1990s, an estimated 4.44×10^{11} gal of liquid was discharged to disposal ponds, trenches, and cribs. Wastewater discharge has decreased since 1984 and currently only contributes a volume of recharge in the same range as the estimated natural recharge from precipitation. The largest volumes of discharge around the 200 East Area were to the 216-B pond system, the 216-A-25 (Gable Mountain) pond system, and several of the PUREX Plant cribs in the southeast corner of the 200 East Area. The Gable Mountain pond is estimated to have received ~77 billion gal of effluent, while the 216-B pond to have received ~67 billion gal of effluent. In the 200 West Area, the largest volumes of discharge were to the 216-T pond system and the 216-U-10 pond. The 216-T pond system is estimated to have received ~112 billion gal of effluent (WHC-EP-0815, “Groundwater Impact Assessment Report for the 216-T-4-2 Ditch”), while the 216-U pond is estimated to have received ~42 billion gal of effluent (WHC-EP-0707, “216-U-10 Pond and 216-Z-19 Ditch Characterization Studies”).

Figure 2-9, Figure 2-10, and Figure 2-11 show a series of water table elevation maps for the time periods representing Hanford Site pre-operational conditions, operational conditions, and present-day conditions. The first water table map (Figure 2-9) is a hind cast map of water table elevations (ERDA-1538, “Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington”) prior to the start of significant Hanford Site wastewater discharges. This water map includes the effects of limited irrigation near the former towns of White Bluffs and Hanford, but not the effects of extensive irrigation now common in Cold and Dry Creeks. The 1944 water table contours indicate that groundwater flow is easterly toward the Columbia River with a relatively uniform hydraulic gradient

(~5 ft/mi). Regional groundwater flow was generally toward the east-northeast, while flow north of Gable Mountain was more to the north.

The pre-Manhattan Project water table in the 200 West and 200 East Areas was ~403 ft and 394 ft above sea level, respectively (BNWL-B-360, "Selected Water Table Contour Maps and Well Hydrographs for the Hanford Reservation, 1944-1973"). In the 200 West Area, the water table elevation increased rapidly from 1949 to 1956, but appeared to stabilize between the late 1960s and the late 1980s. Water levels began to decline in the late 1980s when wastewater discharges in the 200 West Area were reduced. In the 200 East Area, the water-table elevation increased rapidly from 1954 to 1963. The water table declined somewhat in the late 1960s and early 1970s, but then increased again in the early 1980s before beginning a final decline throughout the 1990s when wastewater discharges in the 200 East Area were reduced.

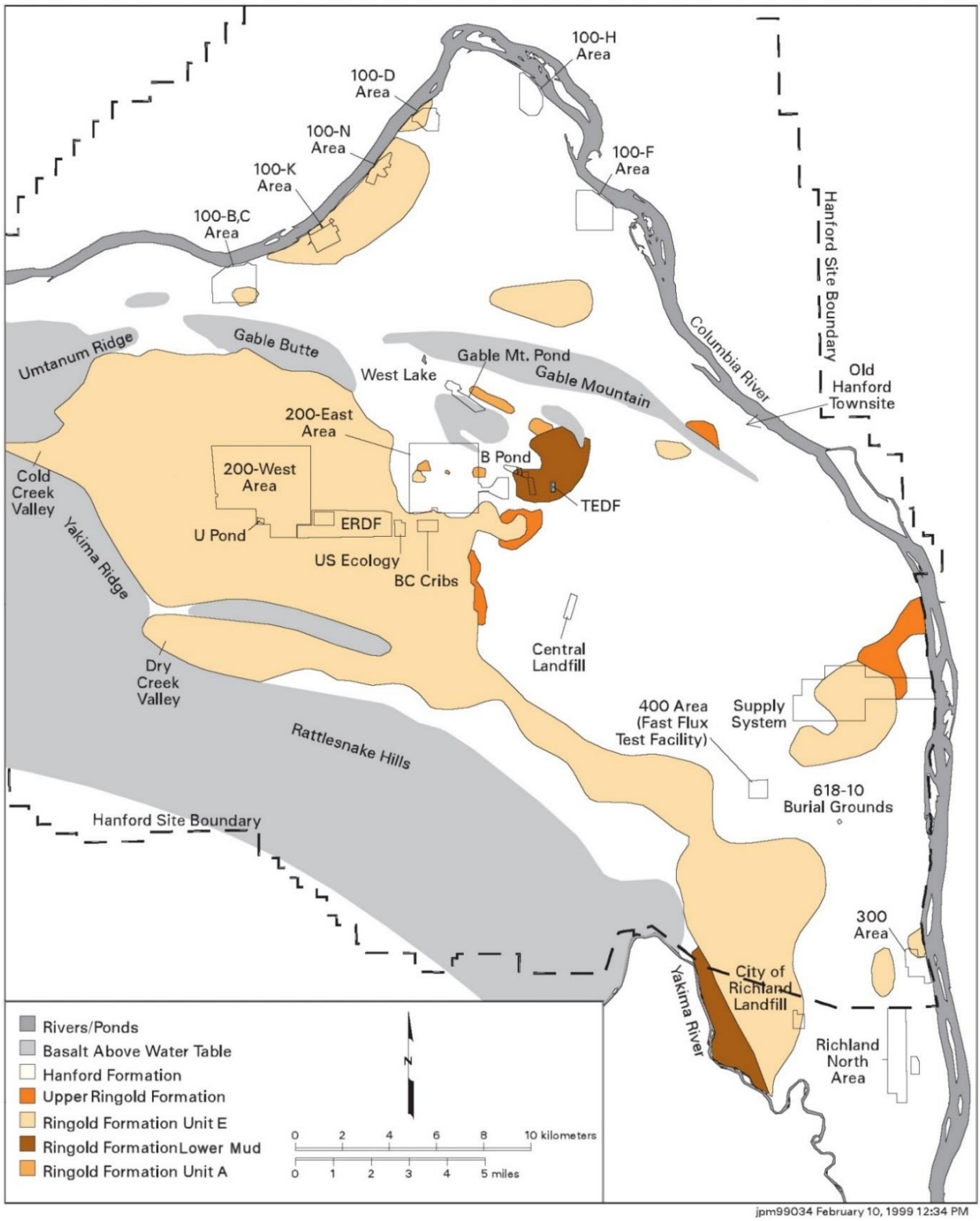
During operations, water levels in the uppermost and unconfined aquifer rose as much as 85 ft and 30 ft beneath the 200 West Area and 200 East Area, respectively, because of artificial recharge caused by liquid waste disposed from the mid-1940s to 1995. Figure 2-10 shows water table mounding present in the 200 Areas for June 1987. The volume of water that was discharged to the ground at the 200 West Area was actually less than that discharged at the 200 East Area. However, the lower hydraulic conductivity of the aquifer near the 200 West Area inhibited groundwater movement in this area, resulting in a higher groundwater mound.

Presently, groundwater in the unconfined aquifer generally flows from upland areas in the west toward the regional discharge area north and east along the Columbia River (Figure 2-11). Steep hydraulic gradients occur in the western, eastern, and northern regions of the Site. Shallow gradients occur southeast of 100-FR and in a broad arc extending from west of 100-BC toward the southeast between Gable Butte and Gable Mountain (Gable Gap), through the 200 East Area and into the central portion of the Site. The reduction of wastewater discharges has caused water levels to drop significantly; however, a residual groundwater mound beneath the 200 West Area is still present today as shown by the curved water table contours near this area. Additionally small groundwater mounds exist near the 200 Area Treated Effluent Disposal Facility and State-Approved Land Disposal Site wastewater disposal sites.

The groundwater mounds drastically changed the flow direction causing radial flow from the discharge areas, and, in some areas, resulted in a complete reversal of flow direction. Until about 1980, the edge of the mounds migrated outward from the sources. Groundwater levels have declined over most of the Hanford Site since 1984 because of decreased wastewater discharges (DOE/RL-2014-32), and since 1996, when all non-permitted discharges to the ground ceased, groundwater flow has begun to return to pre-Hanford Site conditions.

The dominant source of water in the unconfined aquifer beneath the 200 East Area and vicinity is inflow from the west. The direction of groundwater flow formerly diverged beneath the 200 East Area, with some water flowing toward the north through Gable Gap and some flowing southeast. The flow direction changed during 2011; since then flow has been toward the south and southeast across much of the 200 East Area. This change in flow directions is important because contaminant plumes located in the northwest corner of the 200 East Area located near and under the B Complex (WMA B-BX-BY and nearby cribs) could flow under WMA C.

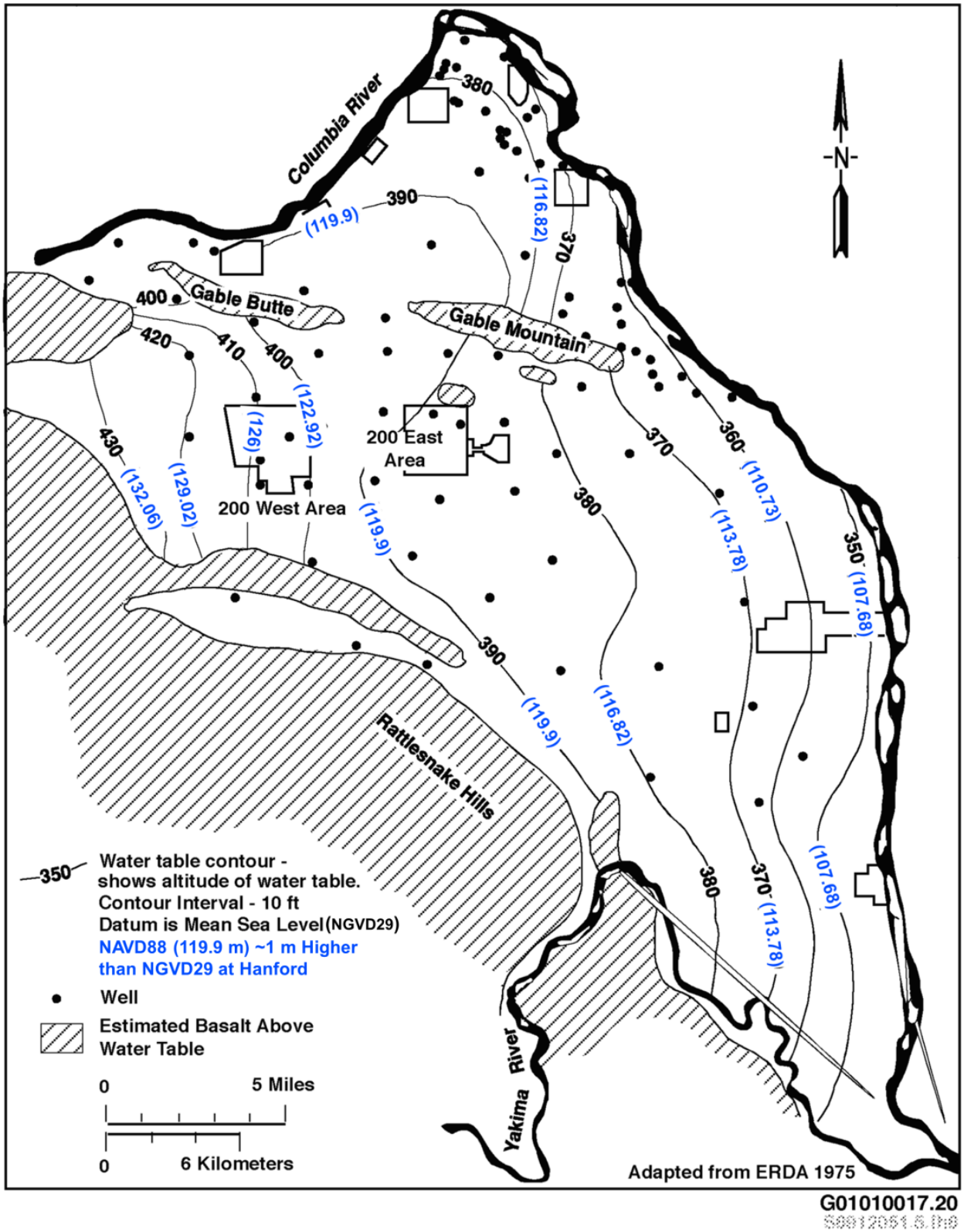
Figure 2-8. Hydrogeologic Units Present at the Water Table in June 1998.



ERDF = Effluent Restoration Disposal Facility TEDF = Treated Effluent Disposal Facility

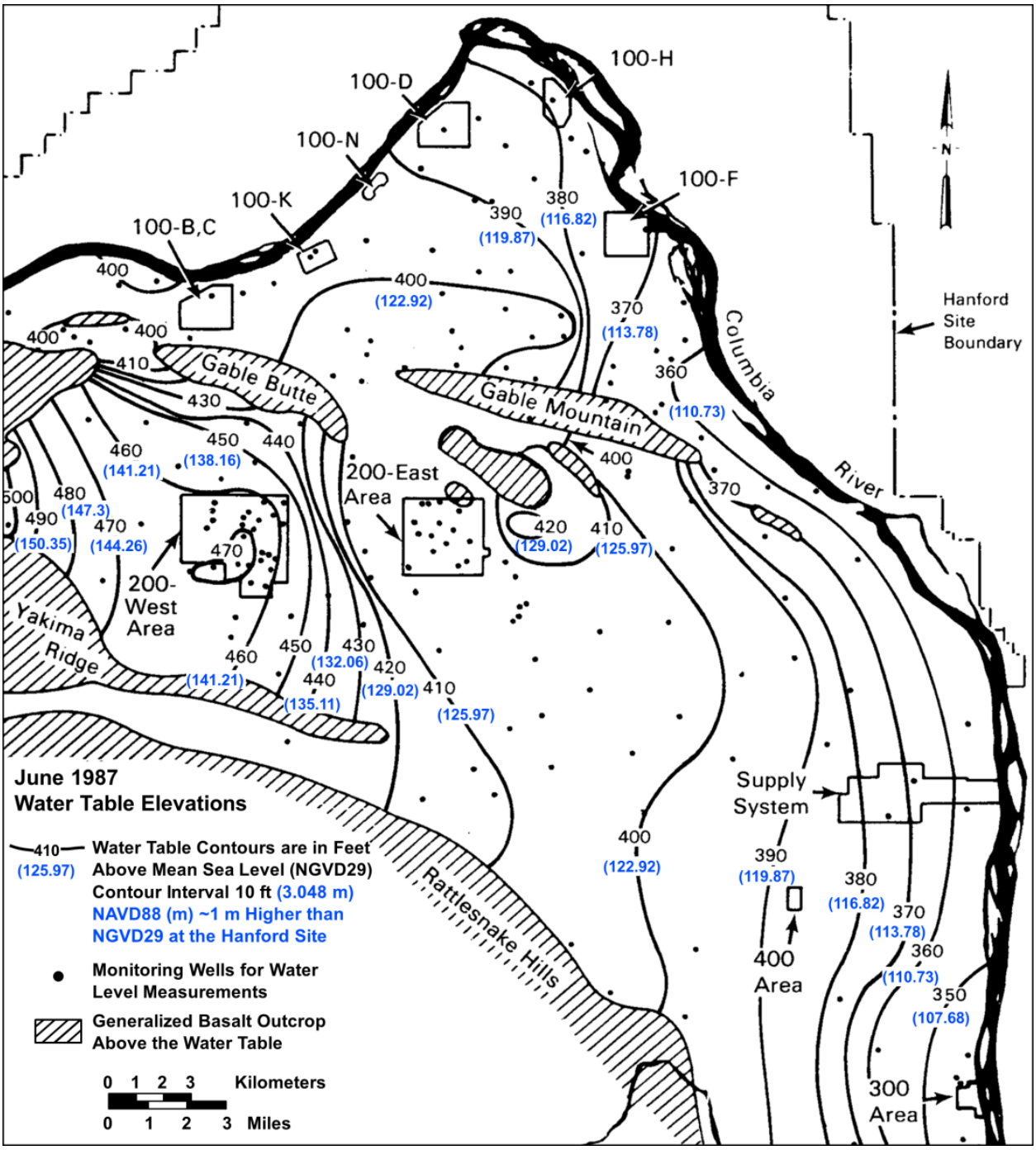
Source: WCH-520, "Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington."

Figure 2-9. Hind Cast Water Table Map of the Hanford Site, January 1944.



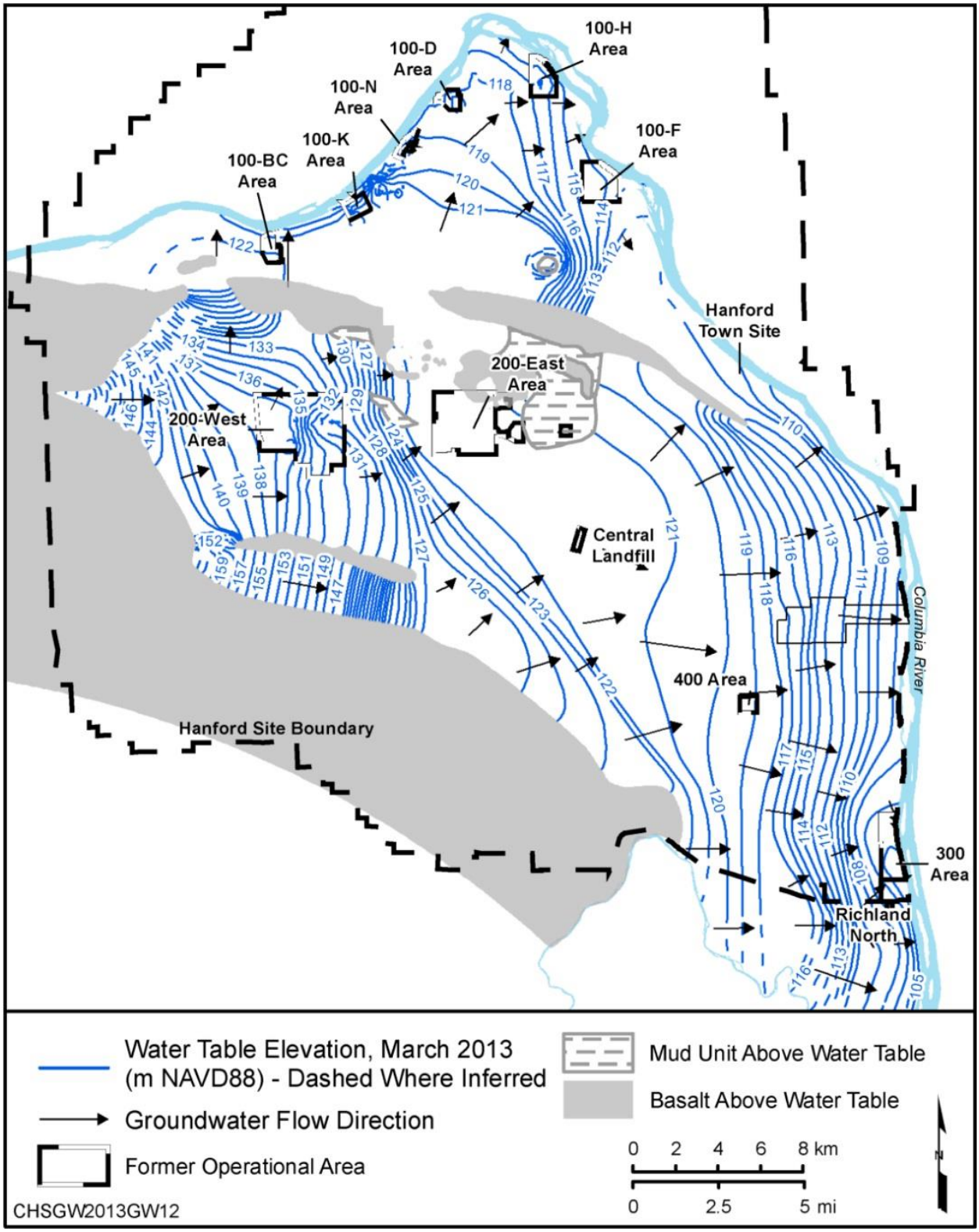
ERDA 1975 refers to ERDA-1538, "Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington."

Figure 2-10. Water Table Elevations for June 1987.



Source: PNL-6464, "Environmental Monitoring at Hanford for 1987."

Figure 2-11. Water Table Elevations for 2013.



Source: DOE/RL-2014-32, Hanford Site Groundwater Monitoring Report for 2013.

A limited amount of hydraulic property data is available from testing of wells. Hydraulic test results from wells on the Hanford Site have been compiled for the Hanford Groundwater Monitoring Project and for environmental restoration efforts (BNWL-1709, "Collection and Analysis of Pump Test Data for Transmissivity Values"; PNL-8337, "Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System"; PNL-10835, "Comparison of Constant-Rate Pumping Test and Slug Interference Test Results at the Hanford Site B Pond Multilevel Test Facility"; PNNL-13342, "Analysis of the Hydrologic Response Associated with Shutdown and Restart of the 200-ZP-1 Pump-and-Treat System"; PNNL-13378, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 1999"; PNNL-13514, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2000"; PNNL-14058, "Prototype Database and User's Guide of Saturated Zone Hydraulic Properties for the Hanford Site"; PNNL-14113, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2001"; WHC-SD-EN-TI-014, "Hydrogeologic Model for the 200 West Groundwater Aggregate Area"; WHC-SD-EN-TI-019). Most hydraulic tests were conducted within the upper 49 ft of the aquifer, and many were open to more than one geologic unit. In some cases, changes in water table elevation may have significantly changed the unconfined aquifer transmissivity at a well since the time of the hydraulic test. Few hydraulic tests within the Hanford Site unconfined aquifer system have yielded accurate estimates of aquifer-specific yield.

Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from ~1 to 100 m/day, compared to 10 to 7,000 m/day for the Hanford formation and the coarse-grained multi-lithic facies of the Cold Creek Unit (pre-Missoula gravels) (DOE/RW-0164; PNNL-13641, "Uncertainty Analysis Framework – Hanford Site-Wide Groundwater Flow and Transport Model"; PNNL-14058; PNNL-14656, "Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington"; PNNL-14804, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2003"; WHC-SD-EN-TI-019). Because the Ringold Formation sediments are more consolidated and partially cemented, they are a factor of ~10 to 100 less permeable than the sediments of the overlying Hanford formation. Before wastewater disposal operations at the Hanford Site, the uppermost aquifer was mainly within the Ringold Formation, and the water table extended into the Hanford formation at only a few locations ("Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington" [Newcomb et al. 1972]). However, wastewater discharges raised the water table elevation across the Hanford Site. The general increase in groundwater elevation caused the unconfined aquifer to extend upward into the Hanford formation over a larger area, particularly near the 200 East Area. This resulted in an increase in groundwater velocity because of both the greater volume of groundwater and the higher permeability of the newly-saturated Hanford formation sediments.

2.1.5.3.3 Hanford Site Groundwater Travel Times

Travel time of water through the unconfined aquifer from the 200 East Area to the Columbia River has been estimated to be in the range of 10 to 30 years (Open File Report 87-222, "Subsurface Transport of Radionuclides in Shallow Deposits of the Hanford Nuclear Reservation, Washington – Review of Selected Previous Work and Suggestions for Further Study"; PNL-6328, "Estimation of Ground-Water Travel Time at the Hanford Site: Description,

Past Work, and Future Needs"). This is because of large volumes of recharge from wastewater that were disposed in the 200 Areas between 1944 and the mid-1990s, and the relatively high permeability of Hanford formation sediments, which are below the water table between the 200 East Area and the Columbia River. Analysis of the tritium plume in DOE/RL-2009-85, Remedial Investigation Report for the 200-PO-1 Groundwater Operable Unit, estimated a travel time of 33 years. It further states that this estimate is likely to be conservative (i.e., overstates the groundwater contamination migration rates compared to current conditions) because of the past groundwater mounding in the Central Plateau.

2.1.5.4 Geochemistry

Hanford formation sediment is typified as having low organic carbon content, generally less than 0.1 percent by weight, and low-to-moderate cation exchange capacity (2.6 to 7.8 milli-equivalents per 100 g) (PNL-8889, "Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions, Volume 1: Batch Leach and Adsorption Tests and Sediment Characterization"). The sediment has a slightly basic pH when wetted (PNL-8889 finds the pH of saturation extract ranging from 7.66 to 8.17). Small amounts of detrital calcium carbonate (calcite) are common and can act as a weak buffer.

Empirical bulk distribution coefficient (K_d) data for Hanford formation and Ringold Formation sediments are fairly abundant for dilute waste solutions and groundwater (PNNL-13895, "Hanford Contaminant Distribution Coefficient Database and Users Guide"). Fewer K_d data are available for the Cold Creek Unit sediments, or for high ionic strength waste solutions with slightly acidic to slightly basic pH values. A relatively small amount of K_d data exists for the combined high ionic-strength/highly-basic tank liquors for many common radionuclides. These K_d data have been well tabulated (PNNL-13895; PNNL-11800, "Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site"; PNL-7297, "Hanford Waste-Form Release and Sediment Interaction – A Status Report with Rationale and Recommendations for Additional Studies"; PNNL-13037, "Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW PA)," Rev. 1 and PNNL-13037, "Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment," Rev. 2; PNNL-11485, "Radionuclide Adsorption Distribution Coefficients Measured in Hanford Sediments for the Low Level Waste Performance Assessment Project"; PNNL-11965, "Effects of Aging Quartz Sand and Hanford Site Sediment with Sodium Hydroxide on Radionuclide Sorption Coefficients and Sediment Physical and Hydrologic Properties: Final Report for Subtask 2a"). In most instances, adsorption appears to be the controlling geochemical process, but neutralization of acid waste by the alkaline sediment and neutralization of basic tank waste can cause precipitation of some contaminant species within the sediment pores. Outside the zone of pH neutralization, adsorption is considered to be the dominant contaminant retardation process in the vadose zone.

2.2 WASTE MANAGEMENT AREA C LOCATION

WMA C encompasses one of 12 SST farms that were built from 1943 to 1964 and designed to store and transfer mixed waste generated as a part of Hanford Site operations. It is located within the Hanford Site in the east central portion of the 200 East Area (Figure 2-12). WMA C

is located 7 mi west of the Columbia River, with the groundwater gradient southeast toward the Columbia River. The WMA C facility is discussed in detail in Section 2.3.

2.2.1 Waste Management Area C Geologic Framework

The geology of WMA C is summarized from the information provided in DOE/ORP-2008-01; RPP-RPT-46088; and RPP-RPT-56356, "Development of Alternative Digital Geologic Models of Waste Management Area C." A generalized fence diagram through WMAs A-AX and C is shown in Figure 2-13.

Six stratigraphic units lie within WMAs A-AX and C. From oldest to youngest, the primary geologic units are as follows:

- CRBG
- Undifferentiated Hanford formation lower gravelly sequence (H3 unit), Cold Creek Unit, and Ringold Formation
- Hanford formation sand sequence (H2 unit)
- Hanford formation upper gravelly sequence (H1 unit)
- Backfill
- Recent deposits.

The general characteristics of these units are described in more detail in RPP-RPT-46088 and RPP-RPT-56356. At WMA C, it is not possible to separate out the Ringold Formation, Cold Creek Unit, and the lower gravely sequence of the Hanford formation (H3). In the vicinity of WMA C, this unit is therefore referred to as undifferentiated H3/CCu/RF. The SSTs at WMA C were emplaced in an excavation of the Hanford formation sediments of the upper, gravel-dominated (H1) unit. This excavation may also locally intercept the upper portions of the sand-dominated Hanford formation (H2) unit. Once the tanks were built, the excavation was backfilled with reworked sediments of the upper, gravel-dominated (H1) unit. The water table or the unconfined aquifer's surface lies ~200 ft below the bottom of the tank farms excavations within the undifferentiated H3/CCu/RF.

The geologic strata underlying WMA C was characterized in conjunction with soil sampling and borehole logging for radionuclides and hazardous waste constituents as part of the Phase 1 and 2 RCRA Facility Investigations at WMA C. The borehole and geologic logging was used to identify the elevations of tops of the geologic units in the vicinity of WMA C. Specifically, potassium, uranium, thorium data from geophysical logs were used to map the tops of the different geologic units at WMA C (RPP-RPT-56356).

Following is an overview of the hydrology of the vadose zone and uppermost, unconfined aquifer beneath WMA C. More detailed information supporting this section can be found in DOE/ORP-2008-01; RPP-RPT-46088; and RPP-RPT-58339, "Phase 2 RCRA Facility Investigation Report for Waste Management Area C."

Figure 2-12. Facilities in the 200 East and 200 West Areas.

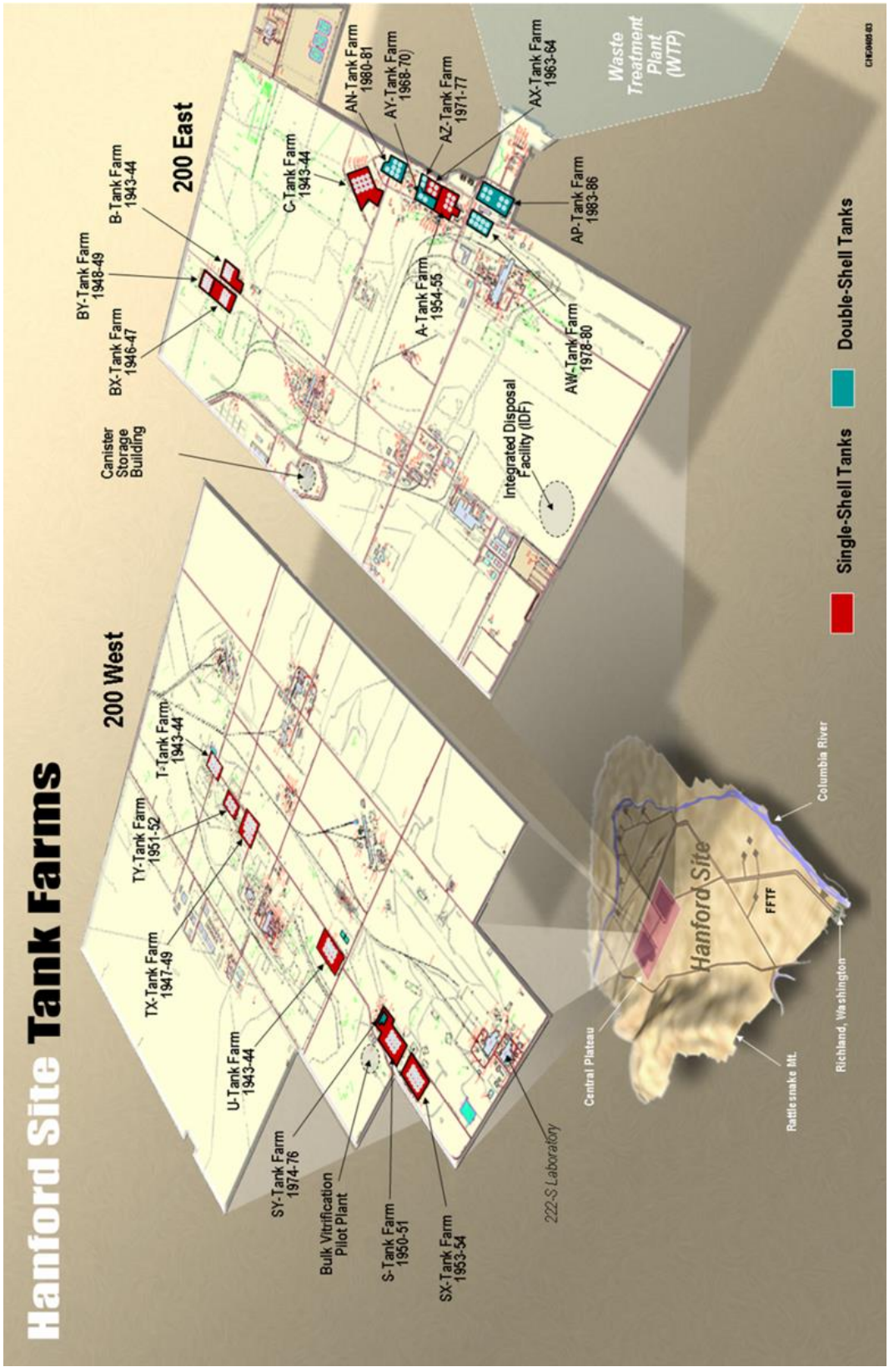
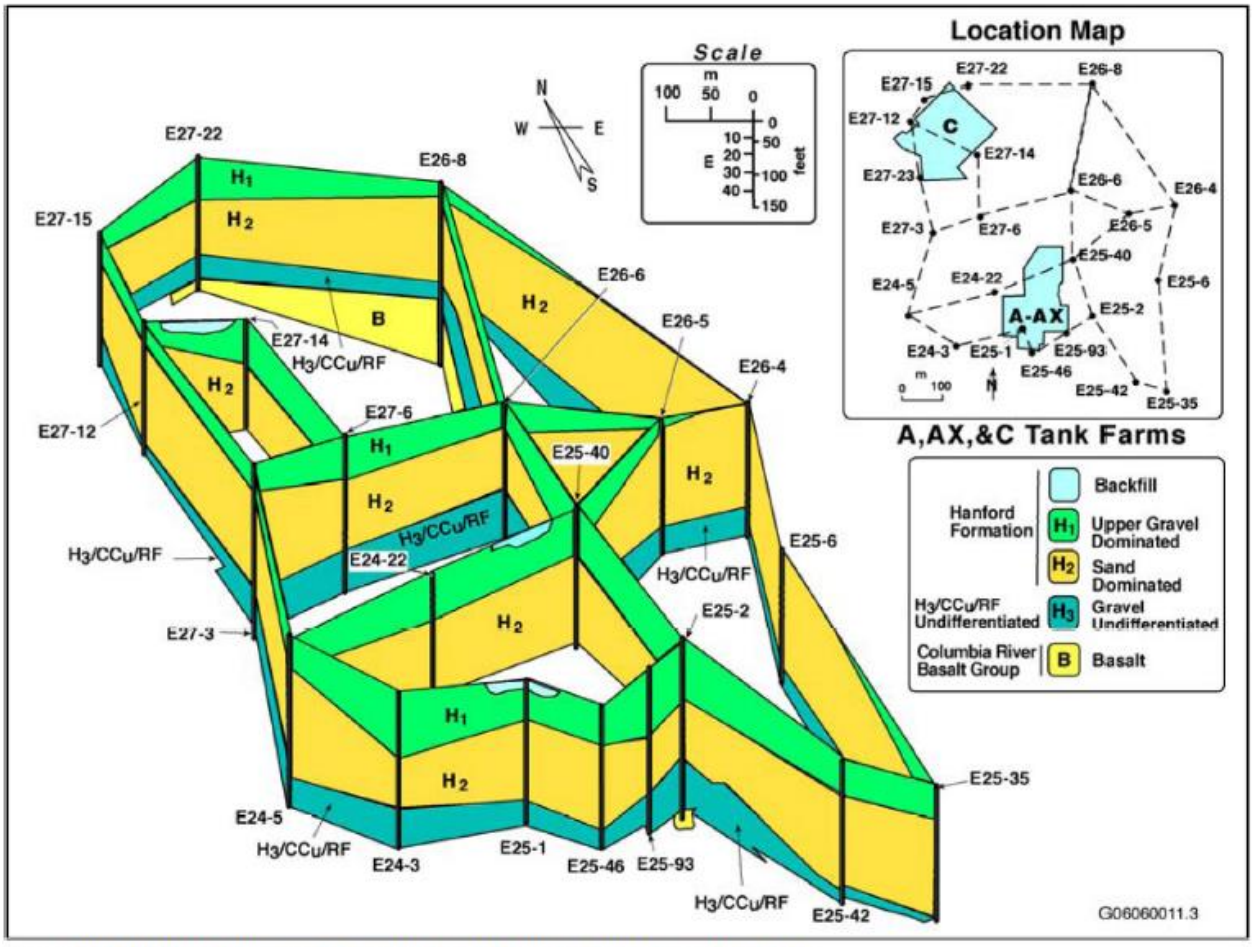


Figure 2-13. Fence Diagram Showing Cross-Section through Waste Management Areas A-AX and C.



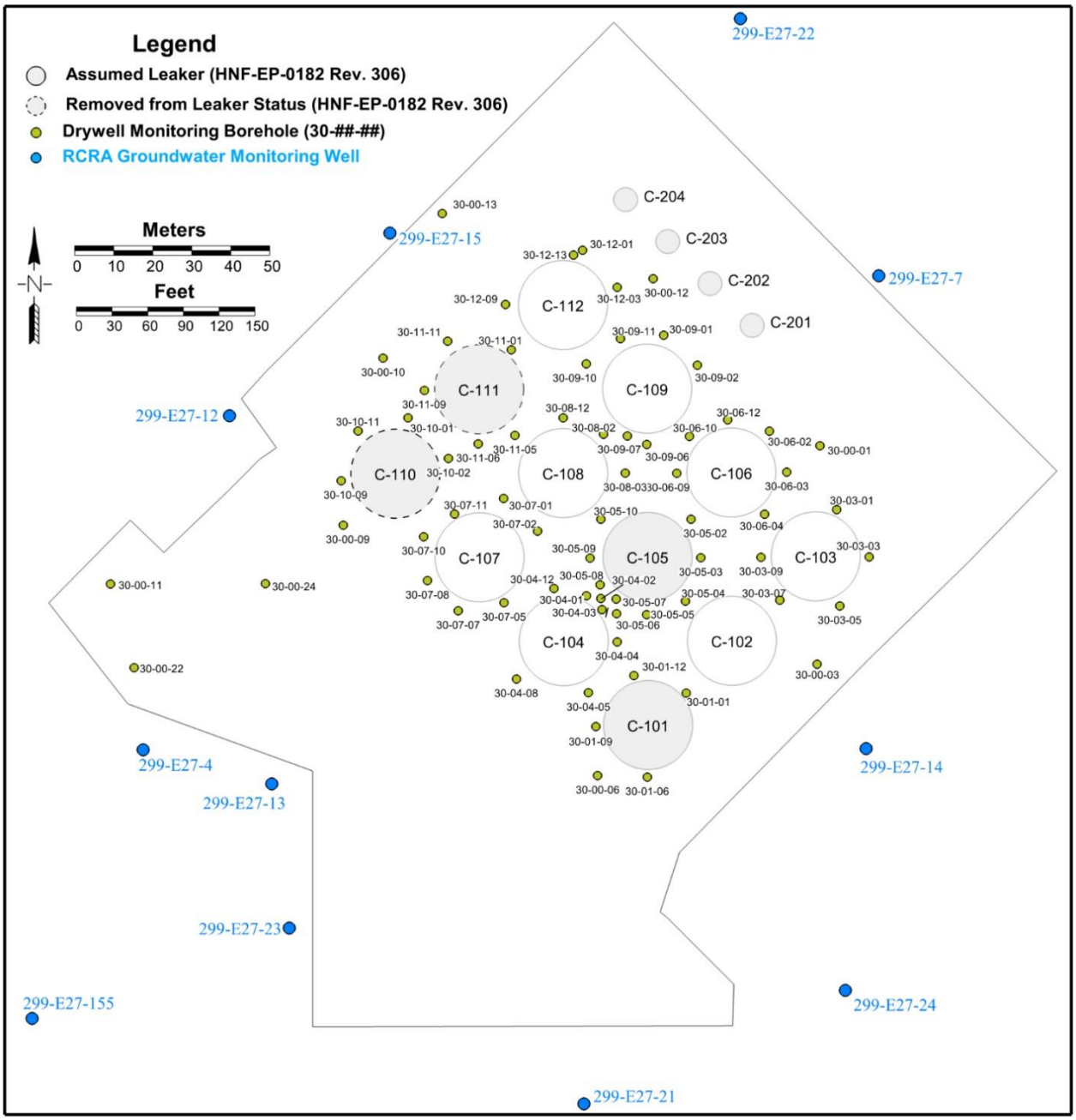
Source: RPP-RPT-46088, "Flow and Transport in the Natural System at Waste Management Area C."

2.2.2 Waste Management Area C Vadose Zone – Monitoring and Characterization Activities

WMA C has 70 drywell monitoring boreholes (Figure 2-14) available for leak detection monitoring and to provide access for limited vadose zone characterization (e.g., geophysical logging). The depth ranges for most of these drywells is between 100 and 150 ft bgs. The deepest drywell in WMA C is 155 ft bgs (drywell 30-00-03), and the maximum logged depth is 143 ft bgs (drywell 30-04-08).

Vadose characterization activities have been conducted at WMA C in support of the RCRA corrective action process. The characterization was divided into two phases. The first phase concentrated on characterizing an area of high ^{137}Cs concentrations observed in drywells at the depth of the base of tank C-105 below the cascade line running between tanks C-104 and C-105. Complete results of the first phase of characterization are documented in DOE/ORP-2008-01 Appendix L.

Figure 2-14. Vadose Zone and Groundwater Monitoring Network for Waste Management Area C.



Source: HNF-EP-0182, "Waste Tank Summary Report for Month Ending September 30, 2013," Rev. 306.
RCRA = Resource Conservation and Recovery Act of 1976

The second phase of characterization activities included the following:

- Soil collection and analysis through direct push boreholes technology
- Geophysical logging at drywell boreholes and groundwater monitoring wells

- Surface geophysical exploration
- Tissue sampling for ecological risk assessment
- Possible sampling of vadose zone during the installation of any new groundwater wells within ~100 ft of WMA C.

The results of the Phase 2 characterization efforts are given in RPP-RPT-58339.

2.2.3 Waste Management Area C Unconfined Aquifer – Groundwater Flow Conditions

The water table or potentiometric surface lies ~200 ft below the bottom of the tank farm excavations within the H3/CCu/RF. The aquifer materials consist dominantly of sandy gravel or silty sandy gravel. The water table elevation beneath WMA C is ~400 ft with ~255 ft of vadose zone. The aquifer thickness, based on the top of basalt at 355 ft, is ~44 ft. Hydraulic conductivity values reported for the aquifer in this area vary considerably, ranging from 0.04 (silt lenses within the sandy gravel) to 6,900 m/day. Additional hydraulic property data from aquifer testing at wells near WMA C is provided in RPP-RPT-46088.

Currently, the general groundwater flow direction in the unconfined aquifer beneath WMA C is to the south/southeast. The water table is very flat overall, with an estimated hydraulic gradient between 1.0×10^{-5} to 2.0×10^{-5} m/min. The estimated groundwater flow velocity ranges from 0.2 to 0.4 m/day (RPP-RPT-46088). Those hydraulic gradient estimates are also consistent with those recently reported in SGW-54165, "Evaluation of the Unconfined Aquifer Hydraulic Gradient Beneath the 200 East Area, Hanford Site," for the unconfined aquifer near the Integrated Disposal Facility and PUREX cribs. Also coincident with the flow change are decreasing concentrations of other contaminants in monitoring wells west of WMA C, indicating a change in flow direction. These observations and other interpretations discussed in SGW-58561, "WMA C Quarterly October through December 2014 Quarterly Groundwater Monitoring Report," provide sufficient evidence for the determination of a south-to-southeast flow direction at WMA C.

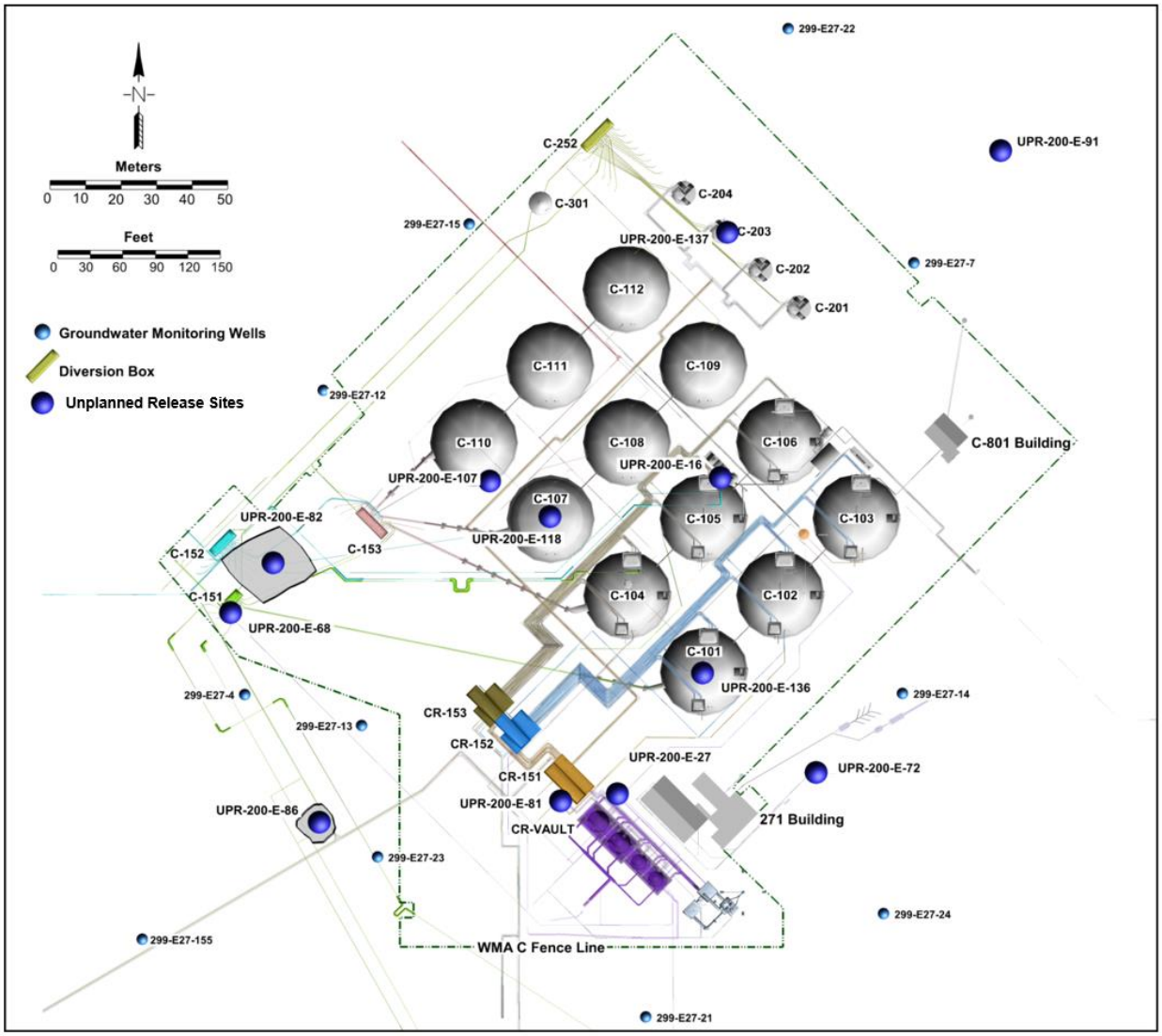
The discharge of large volumes of wastewater in the early 1950s to B pond raised the water table in the vicinity of WMAs C and A-AX as much as 16 ft above the pre-Hanford Site operations level (PNNL-14548, "Hanford Site Groundwater Monitoring for Fiscal Year 2003"). The corresponding flow direction underneath WMA C at this time was toward the southwest (DOE/ORP-2008-01 Appendix H). Water levels began to decline in the late 1980s when wastewater discharges were reduced. The decline has become even more pronounced since other effluent discharges throughout the 200 Areas ceased in 1995. Water levels are expected to continue declining within the region surrounding WMAs A-AX and C, with the flow direction changing to the southeast. With the change in flow direction, contamination originating in the B Complex in the northwest corner of the 200 East Area may flow underneath WMA C in the not-too-distant future.

2.3 WASTE MANAGEMENT AREA C FACILITY

WMA C is part of the Hanford Site SST system consisting of 149 underground SSTs and processing equipment designed and constructed between 1940 and 1964 to transport and store radioactive and hazardous chemical wastes generated from irradiated nuclear fuel processing.

WMA C contains 16 SSTs located downgradient from the operations facilities from which they received waste (Figure 2-15). These tanks were constructed from 1943 to 1944, along with interconnecting pipelines. Additional support structures were constructed prior to the start of operations in 1946. Utilization of the 100-series tanks began in 1946, and the 200-series tanks began operations in 1947. Additional facilities were constructed in WMA C in 1951 and 1952, and pipelines were constructed throughout its operating life.

Figure 2-15. Waste Management Area C Tanks, Infrastructure, and Associated Unplanned Releases.



WMA = waste management area

Waste was routed to the tanks through a network of underground waste transfer piping, with interconnections provided in concrete pits that allowed changes to the routing through instrumentation. Processing vaults used during waste handling operations, evaporators used to reduce the waste stored in the system, and other miscellaneous structures used for a variety of waste handling operations are also included in the system. The SST system was taken out of

service in 1980 and no additional waste has been added to the tanks except as authorized for retrieval operations.

2.3.1 Waste Management Area C Facility Description

WMA C is one of seven WMAs (A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U) containing 149 SSTs built from 1943 to 1964 (Figure 2-12). In general, the WMA C boundary is represented by the fence line surrounding the historical C Tank Farm (Figure 2-15).

WMA C consists of 16 SSTs and supporting facilities and ancillary structures, such as diversion boxes, catch tanks, and vaults:

- Twelve 100-series SSTs (C-101 through C-112) of 530,000-gal capacity each
- Four 200-series SSTs (C-201 through C-204) of 55,000-gal capacity each
- Catch tank C-301 of 36,000-gal capacity
- 244-CR vault which includes four integral tanks: two tanks of 45,000-gal capacity and two tanks of 15,000-gal capacity
- Seven diversion boxes

The WMA C 100-series tanks are 75 ft in diameter, with a 16-ft operating depth, and an operating capacity of 530,000 gal each. The 200-series tanks are 20 ft in diameter with a 24-ft operating depth and an operating capacity of 55,000 gal each. Both the 100-series and 200-series tanks sit below grade with at least 7 ft of soil cover to provide radiation shielding for operating personnel. Tank pits and risers are located on top of the tanks and provide access to the tank, pumps, and monitoring equipment (Figure 2-16).

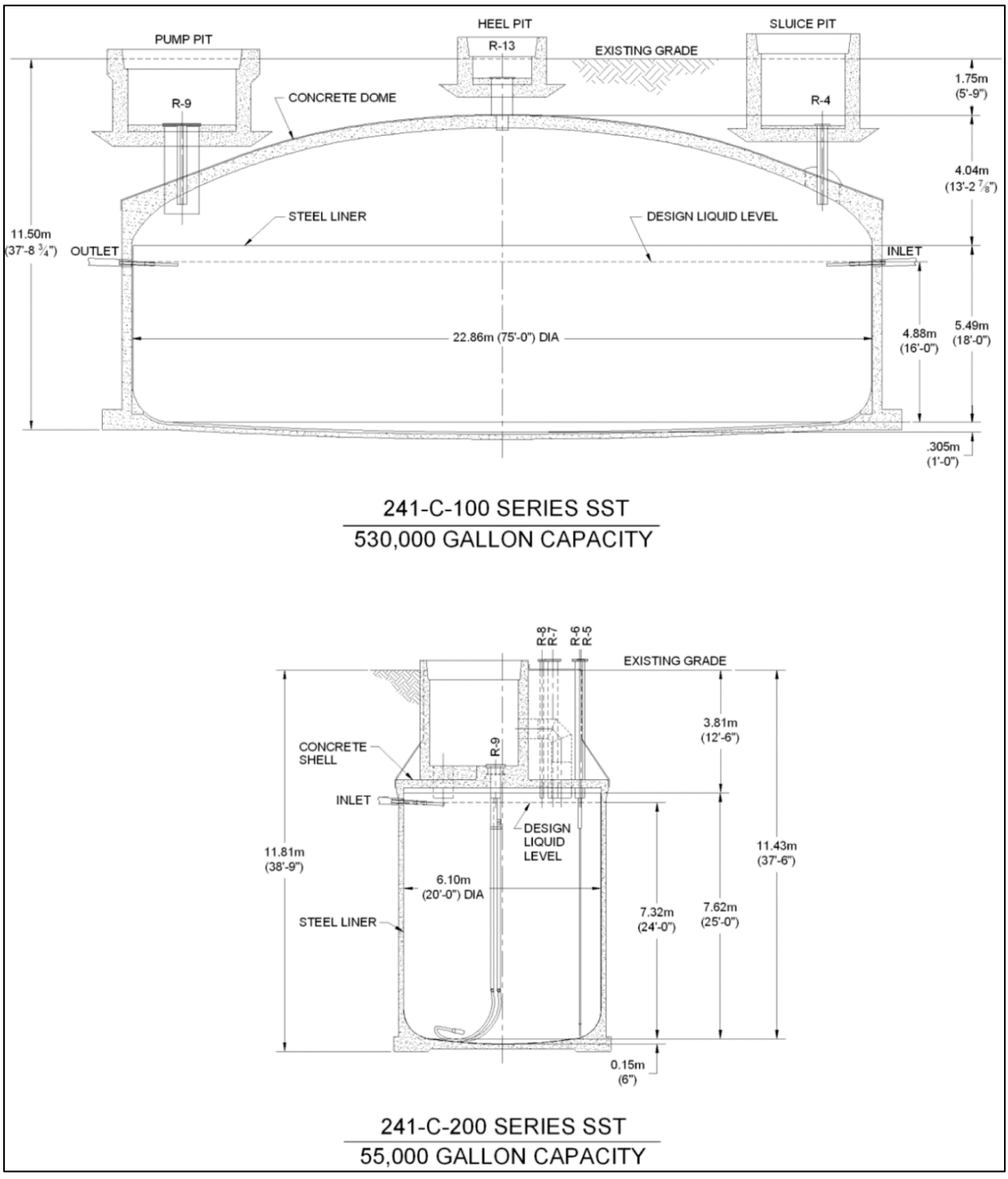
The inlet and outlet lines are located near the top of the liners (Figure 2-16). The 100-series tanks are arranged in four rows of three tanks. The tanks in each row are piped together so that when the first tank fills, it overflows (cascades) into the second tank, and the second into the third. The four smaller 200-series tanks are piped to diversion box C-252 (Figure 2-15).

The SSTs were constructed in place with carbon steel lining the bottom and sides of a reinforced concrete shell. The tanks have concave bottoms (center of tanks lower than the perimeter) and a curving intersection of the sides and bottom (Figure 2-17).

To support the transfer and waste management operations within WMA C, a complex waste transfer system of pipelines (transfer lines), diversion boxes, vaults, and other miscellaneous structures were constructed. Collectively, these are referred to as ancillary structures.

The 244-CR process vault was used to transfer waste solutions from processing and decontamination operations (DOE/RL-92-04, PUREX Source Aggregate Area Management Study Report) and is located south of the tanks. The vault is a two-level, multi-cell, reinforced-concrete structure constructed below grade (DOE/RL-92-04), containing four tanks along with overhead piping and equipment. Two tanks, TK-CR-011 and TK-CR-001, have a capacity of 45,000 gal each. The other two tanks, TK-CR-002 and TK-CR-003, have capacities of 15,000 gal each. This vault was constructed in 1946 and ceased operating in 1988. The CR-151, CR-152, and CR-153 diversion boxes serviced the 244-CR Vault.

Figure 2-16. Waste Management Area C Tanks and Associated Tank Infrastructure.



SST = single-shell tank

The routing of liquid waste from the operations buildings to the tank farms was accomplished using underground transfer lines and diversion boxes. The diversion boxes contain valve assemblies that were used for routing the liquid waste through transfer lines. It is estimated that

there are ~7 mi of waste transfer lines in WMA C with different diameters ranging from 1 to 6 in. (RPP-PLAN-47559, "Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation"). The diversion boxes house jumpers (remote pipeline connectors) that allowed waste to be routed from one transfer line to another. The diversion boxes are below-ground, reinforced-concrete boxes that were designed to contain any waste that leaked from the transfer line connections. The C-151, C-152, C-153 and C-252 diversion boxes generally drained by gravity to catch tank C-301, where waste from processing and decontamination operations was stored and then pumped to SSTs (DOE/RL-92-04). Catch tank C-301 is an underground tank that is 20 ft in diameter and 20.25 ft tall, with a capacity of 36,000 gal.

2.3.2 Sources of the Waste in Waste Management Area C

Because of its long operational history, WMA C received waste generated by multiple operations at the Hanford Site. These processes and the waste types generated are discussed in HNF-SD-WM-TI-740, "Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes", and summarized in the following paragraphs.

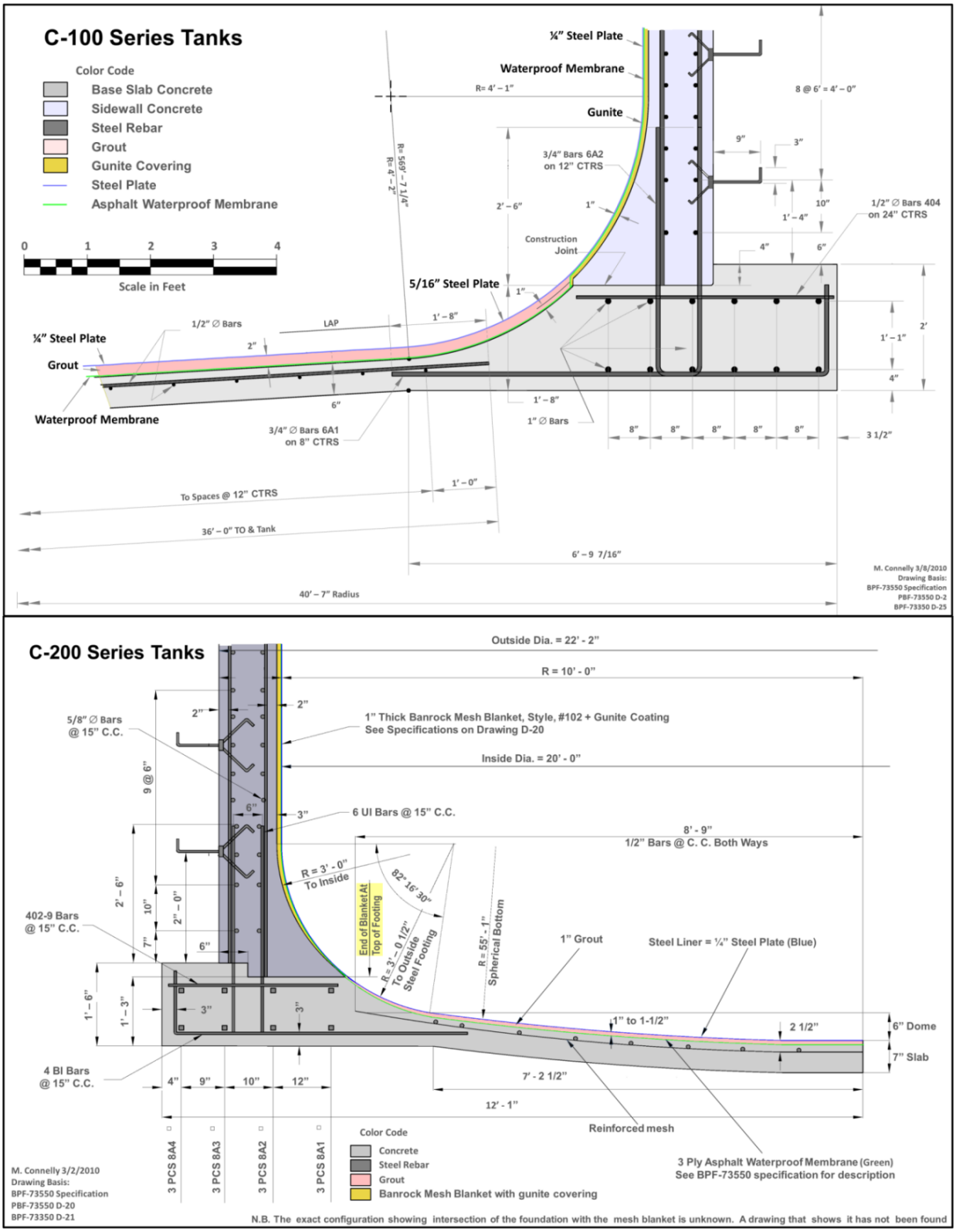
2.3.2.1 Bismuth Phosphate Process at 221-B Plant

The first production process used to separate plutonium from irradiated uranium nuclear reactor fuel was the bismuth phosphate (BiPO4) process. This process operated between 1945 and 1952 in the 221-B and 224-B Buildings (B Plant). As a result of this process, the following waste streams were sent to underground storage tanks for storage or routed through the tanks before being transferred to cribs for ground disposal: coating (cladding) waste (CW) containing the dissolved aluminum cladding; metal waste (MW) containing the uranium and about 90 percent of the fission products; first decontamination cycle (1C) waste containing about 90 percent of the remaining fission products; second decontamination cycle (2C) waste containing essentially all of the remaining fission products; and final plutonium purification/concentration wastes that contained low concentration transuranic wastes.

2.3.2.2 Tri-Butyl Phosphate Uranium Recovery Process at 221-U Plant

Many tons of uranium, along with approximately 90 percent of the fission products from the irradiated reactor fuel, were routed with MW waste to tanks in WMA C. 221-U Plant was modified to perform a uranium recovery mission during the period 1952 to 1957. The uranium recovery (UR) waste (also called Tri-Butyl Phosphate [TBP] waste) routed to the storage tanks consisted of the solvent extraction waste (which could be concentrated in 221-U Plant under certain conditions), combined with the solvent wash waste. The solvent cleanup wash was initially a sodium sulfate solution, but was later replaced by a sodium carbonate solution. The wastes were neutralized to a pH greater than 7 before transfer to the tank farms. This UR waste therefore contained all of the components in the MW (but without the carbonate and with only 1 to 2 percent of the uranium). Further changes in the waste stream consisted of addition primarily of nitrate (added as nitric acid), iron (added as a plutonium reductant), sulfate (from the reductant and sulfate wash), and sodium (from sodium carbonate washes and caustic [sodium hydroxide] neutralization).

Figure 2-17. Corner of Tank Floor with Tank Sides for the C-100 and C-200 Series Tanks.



Source: BPF-73550, "Specifications For Construction of Composite Storage Tanks Bldg. No. 241 Hanford Engineer Works Project 9536."

2.3.2.3 Reduction-Oxidation Operations at 202-S Plant

The Reduction-Oxidation (REDOX) process was developed to replace the BiPO4 process to increase efficiencies and was operated between 1952 and 1966 in the 202-S Building (S Plant). Irradiated fuel elements were declad with caustic and dissolved in nitric acid as was done in the BiPO4 plants. The dissolver product was then adjusted in acid concentration and plutonium valence for solvent extraction. The solvent was Hexone. Aluminum nitrate was added to drive the uranium and plutonium into the solvent phase. The plutonium could then be removed from the solvent by adjusting the valence with a reducing agent, and the uranium could be stripped back into aqueous stream by adjusting the flow ratio of the aqueous to solvent phases.

Under the original REDOX flowsheet, each of the solvent extraction cycles had a waste stream that was routed to the tank farms for storage (after concentration in evaporators in some cases) and combined with the cladding waste as "salt waste" in the 241-S and 241-SX Tank Farms. As the REDOX process matured, several of the intermediate cycle wastes were recycled, thereby reducing the plant chemical consumption and increasing the fission product concentration in the wastes. The fission product concentration (and the associated amount of decay heat) eventually became high enough that the wastes "self-boiled." This reduced the waste tank volume required for storage, but necessitated that the waste tank design incorporate features to promote controlled boiling in the tanks. In the mid-1950s, the cladding waste was routed to storage in separate tanks from the solvent extraction wastes, and a route was installed to utilize the 241-U Tank Farm for storage of some REDOX wastes.

2.3.2.4 Plutonium Uranium Extraction Process at 202-A Plant

The Plutonium Uranium Extraction (PUREX) solvent extraction process eventually replaced REDOX, and operated between 1956-1972 and 1983-1990 in the 202-A Building (PUREX Plant). Aluminum-clad fuels were processed at the PUREX Plant from 1956-1972. Some Zircaloy®-clad fuels were processed between 1967 and 1972.

The PUREX process campaigns, and subsequent campaigns at B Plant to remove fission products from PUREX process waste, produced some of the most complicated combinations of wastes produced at the Hanford Site. This solvent extraction process involved contacting an organic phase mixture of 30 percent volume TBP in normal paraffin hydrocarbon (NPH) with the nitric acid dissolved solution of plutonium and uranium.

The PUREX wastes included both "boiling," i.e., solvent extraction wastes, and "non-boiling" wastes, i.e., the CWs, organic wash wastes (OWWs) and cell drainage. The boiling waste was routed to the A and AX SST farm tanks, and later to DST farms. The sodium carbonate OWWs were originally routed to the boiling waste tanks, but later were routed to non-boiling waste tanks in WMA C for storage, transfer to other tank farms, and subsequent in-farm concentration along with the cladding wastes and cell drainage. All of the thorium wastes (TH) produced in the 1966 and 1971 processing campaigns were routed to non-boiling waste storage in WMA C.

2.3.2.5 Waste Fractionation Operations at B Plant

In 1967, B Plant was reactivated and modified with equipment to "fractionate" the waste, i.e., remove the strontium and cesium and return the remaining waste fraction to the tank farms.

B Plant began removal of ^{137}Cs from stored PUREX waste supernates (PSNs) in 1967 using an ion exchange (IX) system. The REDOX waste supernates (RSNs) were processed for ^{137}Cs removal via IX starting in 1970. The 244-AR Vault was constructed with stainless steel interim waste storage tanks so that the waste currently being produced at PUREX could be stored and processed for ^{90}Sr removal in B Plant without having to neutralize and reacidify the wastes. The first current acid waste (CAW) from PUREX was processed for strontium recovery in B Plant in April 1968. A process for the removal of ^{137}Cs from CAW with a phosphotungstic acid precipitation was developed and first used in B Plant in 1969. The ^{90}Sr in the neutralized and stored PUREX boiling waste (i.e., those boiling wastes produced before 1968) was present in the settled sludge solids in A and AX farm SSTs. These sludges were sluiced to the 244-AR vault, washed, and dissolved in nitric acid. The resultant slurry (PUREX sludge supernate [PSS] derived from washing PUREX sludges in 244-AR vault or 241-A and 241-AX Tank Farm tanks) was settled, and the supernate was transferred to B Plant where the ^{90}Sr was removed via a lead sulfate carrier precipitation process.

A solvent extraction process was used in B Plant to recover, concentrate and purify the ^{90}Sr and rare earths from the CAW and PSS feeds. This process used Di(2-ethylhexyl)phosphoric acid (D2EHPA) and TBP as the extractant in the NPH diluent. The process was pH sensitive, requiring a buffer agent. The presence of relatively high concentrations of various metals, e.g., Fe and Al, in the waste feed necessitated the use of selected chelating agents to prevent the precipitation and/or extraction of these metals.

The B Plant wastes were neutralized and returned to the tank farms. The heat load in the waste determined which tank(s) it was routed to. If the heat load was low (e.g., IX wastes which had been aged before processing, or solvent washes), the waste was routed to tanks that could be used as feed for the In-Tank Solidification (ITS) or Evaporation processes. If the waste had a high-heat load (e.g., the solvent extraction waste), it was routed to tanks that could store boiling wastes for aging before further processing.

2.3.2.6 Pilot Plant Operations at 201-C Hot Semiworks

A relatively small amount of waste was generated at a separations process and equipment development pilot plant (known as the “hot semi-works” or the “strontium semi-works”). The plant was retired in 1967. The 201-C Hot Semiworks (HS) waste streams that originated from this facility are characteristically high in ^{90}Sr.

2.3.2.7 Fission Product Recovery Operations

Ferrocyanide waste scavenging processes were developed at the Hanford Site in the 1950s to provide additional waste storage space while minimizing the construction of additional waste storage tanks. These processes were designed to remove the soluble long-lived fission product ^{137}Cs from liquid wastes. In some cases calcium nitrate was added to precipitate calcium phosphate. In some campaigns, nonradioactive strontium nitrate was added rather than calcium. The treated waste was stirred to ensure thorough mixing and then pumped to receiver tanks in the tank farms. The precipitate containing the scavenged ^{137}Cs and ^{90}Sr was allowed to settle and the supernate was discharged to cribs. When layers of the ferrocyanide sludge built up in the

receiver tanks, they were pumped to other tanks for storage so that the settling depth in the receiver tanks remained maximized.

Scavenging of 221-U Plant waste began with a plant test in 1953 during which the treated waste was routed to tank 241-T-101. Production-scale scavenging began in 1954 and the UR waste was routed to tanks in 241-BY Tank Farm. In 1955, unscavenged UR waste already stored in 200 East Area tanks was routed to the 244-CR Vault for in-farm scavenging. The scavenged ferrocyanide waste from 244-CR Vault treatment of TBP waste (TFeCN) was then routed back to other waste storage tanks for settling, sampling, and decanting to cribs. The primary settling tanks for in-farm scavenged waste were C-108, C-109, C-111, and C-112. In-farm scavenging was completed in 1957.

2.3.2.8 Evaporator Operations

Evaporation was routinely used to reduce overall waste volume in Hanford tanks. The concentrated waste slurries remaining after a portion of the water is evaporated away are referred to as "evaporator bottoms." Salt cakes are the result of these slurries settling and precipitating after being returned to the waste storage tanks. Salt cakes are usually distinguishable from sludges physically and compositionally. Physically salt cakes are lighter in color (white, yellow, or light grey is typical) than sludges, have a visually observable crystal structure, are granular in texture, and are usually very soluble in water. Compositionally, they are mostly made up of the sodium salts of nitrate, nitrite, phosphate, carbonate, and hydroxide.

Different evaporation processes also substantially influenced the composition of the salt cakes. There were four different waste volume reduction methods that relied on evaporation:

- The open-air evaporators, 242-B and 242-T, formed the earliest salt cakes. Their process feeds consisted mostly of bismuth phosphate process supernatants, and later uranium recovery supernatants. These evaporators were operated at relatively high temperatures, which may have contributed to the loss of volatile organic components and the formation of carbonate.
- The in-tank solidification system at 241-BY Tank Farm used an in-tank heater as an open-air evaporator, with a series of tanks connected together in a cooling loop.
- The self-boiling tanks (S, SX, A, and AX Farms) utilized open-air evaporation; however, these wastes were much more alkaline that those from the bismuth phosphate process. This feature of the waste probably contributed to much higher carbonate formation.

Vacuum evaporators (242-S and 242-A) were different than the open-air evaporators in that they operated under a partial vacuum, reducing the amount of heat needed to boil the supernatants. Operation under a partial vacuum also reduced the interaction with the air, inhibiting carbonate formation. Only the 242-A Evaporator remains in use today. Table 2-1and Table 2-2 show waste types and processes that generated wastes transferred to tanks in WMA C Table 2-3 shows the principal types of sludge remaining in WMA C tanks and ancillary structures. The waste consists of a large array of chemicals and radionuclides. Process knowledge-based waste type composition estimates based on reactor fuel irradiation records and process plant records are provided in RPP-19822, "Hanford Defined Waste Model – Revision 5.0."

2.3.2.9 Tank Synopsis

The following section provides a synopsis of the WMA C tank operational history. The data is a summary of the information presented in RPP-ENV-33418, "Hanford C-Farm Leak Inventory Assessments Report," and RPP-15408, "Origin of Wastes in C-200 Series Single-Shell Tanks."

2.3.2.9.1 Tank C-101

Tank C-101 began receiving waste from the 221-B process in March 1946. In May 1946, the tank was declared full (530,000 gal) and began cascading waste to tank C-102. The waste sat undisturbed in tank C-101 until the fourth quarter of 1952. A uranium precipitate formed in the waste, settling to the bottom of the tank as a sludge layer. The supernate and sludge were removed from tank C-101 from the fourth quarter of 1952 through May 14, 1953. Tank C-101 received TBP waste intermittently from 221-U Plant beginning on May 15, 1953. During August 1953, tank C-101 was filled with TBP waste. Tank C-101 was pumped then refilled with TBP supernate until January 1956. Tank C-101 continued to be used through 1957 as the feed tank to the in-farm scavenging process conducted in the 244-CR vault. Tank C-101 received TBP supernate and 242-B Evaporator bottoms wastes from other tanks. Beginning in December 1960 and intermittently until 1962, tank C-101 received 202-A Plant PUREX process cladding removal waste. Tank C-101 was filled and further additions of PUREX cladding removal waste led to the cascade of supernate to tanks C-102 and C-103 in 1962. In the fourth quarter of 1963, tank C-101 received PUREX supernate from tank A-102. Tank C-101 also received PUREX supernate from tank A-103 in the first quarter of 1964. The pumpable liquid was removed from tank C-101 in 1969. Tank C-101 is an assumed leaker. Tank C-101 was interim stabilized via saltwell pumping[19] in November 1983 and waste retrieval was completed in September 2013.

2.3.2.9.2 Tank C-102

Tank C-102 was put into service in October 1946. Initially, tank C-102 received waste via cascade from tank C-101 beginning in May 1946. In 1953, the waste was sluiced out to recover uranium. From the third quarter of 1953 until the first quarter of 1954, tank C-102 received uranium recovery waste. Starting in the third quarter of 1954, tank C-102 received TBP waste. During the second quarter of 1957, the waste in tank C-102 was scavenged and pumped out of the tank. From the third quarter of 1960 until the fourth quarter of 1969, tank C-102 received PUREX cladding waste. Also during the third quarter of 1960, the tank received wastewater. Tank C-102 received thorium waste during the second quarter of 1966. From the second quarter of 1968 until the first quarter of 1969, tank C-102 received PUREX organic wash waste. Tank C-102 is a sound tank. Tank C-102 was interim stabilized in September 1995 and waste retrieval was completed in 2015.

[19] See Section 2.3.3.1 in this Draft WIR Evaluation for explanation of interim stabilization and saltwell pumping.

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Table 2-1. Waste Types Received into Waste Management Area C 100-Series Tanks (1956 through 1978).

Year	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112
1956	TFeCN			CW	CW					OWW	OWW	TFeCN
1957			PSN	CW	CW	PSN/OWW		TFeCN	TFeCN		CW/TFeCN	TFeCN
1958				CW	CW							
1959					CW				CW		CW	
1960	CW	CW	CW		CW			CW			CW	CW
1961		CW					CW	CW			CW	HS
1962		CW					CW		HS		HS	HS
1963	PSN	CW	PSN		PSN	PSN					HS	
1964	PSN	CW					HS		HS		HS	
1965		CW	PSN				HS	HS	HS			
1966		TH/CW	PSN				BNW/HS		HS			
1967		CW					HS					
1968		CW/OWW			PSN							
1969		OWW		OWW	PSN	PSS						
1970			IX	TH/OWW/PSN	PSN/RSN	PSS	IX	OWW/IX	IX	IX		IX
1971			IX	CW/OWW	PSS	PSS						
1972			CW/OWW	CW/OWW	PSS					IX		
1973			Misc	Misc	PSS		Misc	Misc				
1974			Misc	Misc	PSS	BL						
1975			Misc	Misc	PSS	BL						
1976			Misc	Misc	PSS	BL						
1977						BL						
1978						BL						

Note: Waste received from 1946 to 1955 was sluiced and largely removed from the WMA C tanks.

Source: RPP-RPT-42294 “Hanford Waste Management Area C Soil Contamination Inventory Estimates”

Definitions

Colors in table are used to highlight each waste type

BL B Plant strontium processing wastes and miscellaneous wastes

CW cladding (coating) waste from Plutonium Uranium Extraction (PUREX) or Reduction-Oxidation (REDOX) Plants

HS 201-C Hot Semiworks waste

IX cesium denuded waste from ion exchange process in B Plant

Misc Sources may include research waste from Battelle Northwest (i.e., BNW) which is now Pacific Northwest National Laboratory, reactor decontamination waste, etc.

OWW organic wash waste from PUREX Plant

PSN PUREX ”boiling” waste supernate

PSS PUREX sludge supernate derived from washing PUREX waste sludges in 244-AR vault or 241-A and 241-AX Tank Farm tanks

RSN REDOX waste supernate

TFeCN ferrocyanide waste from 244-CR process tank vault treatment of tributyl phosphate waste

TH thorium process waste from PUREX Plant

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Table 2-2. Waste Types in Waste Management Area C 200-Series Tanks.

Waste Type	C-201	C-202	C-203	C-204
Metal waste [20] – addition from B Plant	November 1947 – December 1948			
Metal waste supernate – removal to tank C-106	December 1953			
Metal waste supernate – removal to tank C-104	None	None	None	7,000 gal 11/1954
Metal waste sluicing to 244-CR process tank vault	2/15/1954 – 3/17/1954	1/9/1954 – 1/14/1954	1/15/1954 – 1/28/1954	1/1955 – 2/1955
Hot Semiworks – Plutonium Uranium Extraction process waste (5/1955 – 3/1956) Process equipment and facility flushes for modifications	5/1955 – 11/1955	11/1955 – 5/1956	12/1955 – 11/1956 4/1956 – 11/1956	12/1955 – 11/1956 4/1956 – 11/1956
Supernate removal	—	—	1/1970 – 3/1970	—
Supernate removal	4/1970 – 6/1970			
Supernate removal	—	—	—	7/1977
Supernate removal	10/1980			

Source: RPP-ENV-58782 "Performance Assessment of Waste Management Area C"

2.3.2.9.3 Tank C-103

Tank C-103 went into service during the third quarter of 1946 when it began receiving BP waste via cascade from C-102. In the fourth quarter of 1952, the supernate was transferred to tank C-109 and the sludge was sluiced out for uranium recovery. In the third quarter of 1953, tank C-103 began receiving TBP waste from tank C-101. In the second quarter of 1957, TBP waste was transferred leaving tank C-103 nearly empty. Neutralized PUREX supernate was received from tank A-102 during the third and fourth quarters of 1957 and then transferred to tank BY-103 in 1958. Tank C-103 then remained static until the second quarter of 1960 when transfers of aluminum cladding waste from PUREX were received and held until 1962 then transferred on to BX Tank Farm. Beginning in the second quarter of 1963 and extending through 1968, numerous receipts of PUREX supernate occurred for cesium recovery. During 1969, the majority of the supernate was transferred out of the tank. During 1970 and 1971, tank C-103 received 221-B Plant waste, and PUREX sludge supernate. From 1973 to 1978, tank C-103 received waste transfers from other tanks in WMA C. In 1979, supernate was transferred out of tank C-103 and the tank was declared inactive with approximately 200,000 gal

[20] The term "Metal Waste" refers to the primary waste stream of the Bismuth Phosphate process at B plant, containing the bulk of the original uranium fuel in acid solution. See Section 2.3.2.1.

remaining. Tank C-103 is a sound tank. Tank C-103 was interim stabilized in July 2003 and waste retrieval was completed in 2006.

Table 2-3. Current Waste Types in Waste Management Area C Tanks.

Tank	Waste Type and Waste Code
C-101	C-101 contains only Tri-Butyl Phosphate (TBP) waste.
C-102	Contains TBP, and Metal Waste (MW).
C-103	Contains a combination of waste types, mostly wastes generated by the decladding of Plutonium Uranium Extraction Plant (PUREX) aluminum clad reactor fuel (CWP1).
C-104	Contains MW, PUREX waste from 1963-1967 campaigns (P2), wastes generated by the decladding of PUREX aluminum clad reactor fuel (1969-1972) (CWP2), and Strontium Recovery Waste (1969-1980).
C-105	Contains TBP and CWP1.
C-106	Contains TBP, wastes generated by the decladding of aluminum clad reactor fuel (CW), sludge based on total uranium and modeling of the distribution of uranium isotopes and Low-level waste from B-Plant Strontium and Cesium recovery operations (1967-1976).
C-107, C-108, C-109, C-110, C-111, C-112	Contain a modeled waste template referred to as 1C. After neutralization, the 1C wastes were combined with aluminum cladding wastes (CW) in the 1C waste tank cascades. The major components in 1C/CW waste are Al, Bi, Ce, Cr, Fe, Na, Si, U, F, NO_3.
C-201, C-202, C-203 and C-204	Contain hot semi-works waste.

Source: RPP-ENV-58782 “Performance Assessment of Waste Management Area C ”

2.3.2.9.4 Tank C-104

Tank C-104 was put into service in October 1946. Initially, tank C-104 received BP waste from the fourth quarter of 1946 until the fourth quarter of 1954. By February 1947, the tank was full. Waste was sluiced out in the fourth quarter of 1953. The supernate was sent to the 244-CR vault in 1954 and the tank was declared empty in the first quarter of 1955. 221-U Plant waste was added to the tank in the fourth quarter of 1955. The tank received cladding removal waste from the first quarter of 1956 until the third quarter of 1969. Tank C-104 received supernate from tank C-105 in the first quarter of 1960. It received waste from the 244-CR vault in the second quarter of 1965. The tank received cladding waste and organic wash waste from PUREX from the fourth quarter of 1969 to the third quarter of 1972. During this time waste was sent to and received from various other tanks. From the first quarter of 1956 until the third quarter of 1972, the tank received PUREX cladding removal waste. From the first quarter of 1969 until the third quarter of 1976, the tank received various wastes. The tank received decontamination waste from the second quarter of 1965 until the first quarter of 1974. From the fourth quarter of 1969 until the fourth quarter of 1972, the tank received PUREX organic wash waste. During the third and fourth quarters of 1970, the tank received thorium waste. From the fourth quarter of 1970

until the second quarter of 1976, the tank received PUREX waste. The tank received PUREX supernate from the fourth quarter of 1973 until the second quarter of 1975. The tank was declared inactive in March 1980. Tank C-104 was partially isolated in December 1982 and declared interim stabilized in September 1989 with intrusion prevention completed in February 1991. Tank C-104 is a sound tank. Tank C-104 waste retrieval was completed in 2012.

2.3.2.9.5 Tank C-105

Tank C-105 began receiving BP waste in February 1947. After tank C-105 (530,000 gal) was filled, the waste was sluiced out in 1953 and 1954 leaving virtually no solids in the tank. During July and August of 1954, tank C-105 received TBP waste. Tank C-105 remained filled from August 1954 through February 1956. Once in March and once in April of 1956, TBP waste was transferred from tank C-105 to the 244-CR vault for ferrocyanide scavenging. In August 1956, the tank was utilized as a receiver for PUREX cladding removal waste. Beginning in April 1957, tank C-105 was used to receive PUREX coating removal waste that was then transferred to other SSTs within WMA C and to 241-BY Tank Farm. Tank C-105 was filled and emptied several times from April 1957 through April 1960. Waste was transferred from tank C-105 to tank C-102 in order to use tank C-105 as an emergency spare for waste from A Tank Farm. In the last quarter of 1963, neutralized PUREX supernatant wastes were transferred from tank A-102 to tank C-105 to support sluicing operations testing. Beginning on December 27, 1967, the neutralized PUREX supernate was transferred from tank C-105 to the 221-B Plant. From 1968 through 1978, tank C-105 received additional neutralized PUREX supernatant waste, PUREX sludge supernate, S Plant REDOX neutralized supernate and 221-B Plant cesium IX wastes. After 1978, supernates were removed from tank C-105 and the tank was maintained at a minimum supernate heel. Until the early 1990s, the sludge in this tank generated significant radiolytic decay heat to cause evaporation of water to occur. Water was periodically added to the tank to cool the sludge. Water addition was stopped in the mid-1990s after determining that the radiolytic decay heat generation had declined sufficiently. Tank C-105 is an assumed leaker. Tank C-105 was interim stabilized in 1995. Waste retrieval was completed in 2017.

2.3.2.9.6 Tank C-106

Tank C-106 commenced waste storage service in July 1947, via cascade from C-105. The tank initially received BP waste, continuing until November 1947 when the waste volume reached the tank maximum of 528,000 gal. The tank was emptied in the third quarter of 1953. In the third quarter of 1954, tank C-106 was filled with TBP waste. The tank was pumped before it began to receiving PUREX coating waste in the third quarter of 1957. In mid-1963, tank C-106 was pumped to the heel and then filled with PUREX neutralized waste. In the first quarter of 1969, tank C-106 began to receive PUREX sludge slurry wash water. In the mid-1970s, sludge temperatures rose above 212 °F. As a result, its service as a PUREX sludge slurry receiver was terminated. In the fourth quarter of 1971, vessel ventilation systems were installed to serve tanks C-105 and C-106. Until the third quarter of 1974, no waste was transferred into or out of tank C-106, with the exception of water additions for evaporative cooling. During the third quarter of 1974, tank C-106 began to operate as a receiver for complexed waste from

221-B Plant cesium recovery IX. The last transfer occurred on March 18, 1979. Tank C-106 is a sound tank. Waste retrieval was completed in 2003.[21]

2.3.2.9.7 Tank C-107

Tank C-107 entered service during the second quarter of 1946 when it began receiving first decontamination cycle waste generated from the BP process. In September 1947, tank C-107 was full. In 1952 the BP waste was removed and tank C-107 received uranium recovery/TBP liquid waste. In October 1956, waste was transferred out of tank C-107 for cesium scavenging. During 1957 and 1958, first decontamination cycle waste and numerous line flushes were received. From the fourth quarter of 1961 through the second quarter of 1963, the tank received cladding removal waste from the PUREX Plant. From the fourth quarter of 1964 through the fourth quarter of 1967, tank C-107 received waste primarily from the 201-C Hot Semiworks Facility with additional waste from the 244-CR vault and Site laboratories. In 1970, the tank received waste from tank BX-104, and in 1972 and 1973, the tank exchanged supernatant waste with tank C-104. Supernate was removed from tank C-107 in 1976 and 1977. Finally, tank C-107 received strontium-rich sludge in 1977 and was then declared inactive in 1978. Tank C-107 is a sound tank. Tank C-107 was interim stabilized in September 1995 and waste retrieval was completed in 2014.

2.3.2.9.8 Tank C-108

Tank C-108 entered service in 1947. First-cycle decontamination waste from the BP process began cascading from tank C-107 during the third quarter of 1947. Tank C-108 was filled, and waste began overflowing via the cascade line to tank C-109 during the second quarter of 1948. Supernate was pumped from tank C-108 during 1952. The tank began receiving uranium recovery waste via the cascade line from tank C-107 during 1952. During 1953, the tank was filled and the waste began cascading to tank C-109. After 1953, the tank received no further transfers of uranium recovery waste. Uranium recovery waste from tank C-108 was transferred to tanks C-109 and C-111 for in-tank ferrocyanide scavenging during the first quarter of 1956. A layer of solids is estimated to have settled from the uranium recovery waste in tank C-108. This layer would have been added to another layer of first decontamination cycle waste solids predicted to have settled on the bottom of the tank during its early history. Tank C-108 was used as a primary settling tank from 1956 through 1957, receiving scavenged waste from tanks in the C, B, and BX Tank Farms. During this time, the tank received in-farm ferrocyanide scavenging waste; a portion of this waste remained in the tank in early 1958 following the conclusion of the scavenging campaign. However, most of the ferrocyanide scavenging sludge is predicted to have been removed from the tank in a later transfer. During 1960 and 1961, the tank received supernate (most likely aluminum cladding waste supernate) from tank C-105 and apparently aluminum cladding waste directly from PUREX. During the same period, supernate was transferred from tank C-108 to tanks BY-101 and BY-105. During 1964, supernate was

[21] DOE submitted a waiver request under HFFACO Action Plan Appendix H for tank C-106 (RPP-20658, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106") in 2004. See Section 4.3.3.6, in particular footnote 45, *infra*. Tank C-106 was retrieved in 1999 and in 2003, with an ending nominal volume of 370 ft^3 (measured between 275 and 467 ft^3 with a 95 percent confidence level).

transferred from tank C-108 to tanks in the BX Tank Farm. During 1965 and 1966, the tank received waste from the 201-C Hot Semiworks Facility, and hot semiworks supernate from tank C-107. From 1965 to 1969, supernate was intermittently transferred from tank C-108 to tank C-102. During 1970 and 1973, tank C-108 received supernatant wastes from tanks C-110 and C-104. Records indicate these supernates were likely a mixture of wastes, including PUREX organic wash waste, IX waste, REDOX waste, N Reactor waste, decontamination waste, and laboratory waste. Tank C-108 is a sound tank. Tank C-108 was interim stabilized in March 1984 and waste retrieval was completed in 2013.

2.3.2.9.9 Tank C-109

Tank C-109 was brought into service during 1948 with a cascade from tank C-108 of decontamination cycle waste from the BP process. The waste was transferred to tank B-106 in 1952. The tank was refilled through the cascade line with unscavenged uranium recovery waste in 1953. Beginning in May 1955, unscavenged uranium recovery waste was routed to the 244-CR vault for scavenging. From late 1955 until 1958, tank C-109 was used for settling scavenged ferrocyanide waste in direct transfers from the process vessel. In-farm scavenging was completed in December 1957 and records indicate an additional transfer out of this tank to a crib in the first quarter of 1958. Cladding waste supernate was transferred to tank C-109 from tank C-105 in 1959. In 1959, highly alkaline cladding waste and evaporator bottoms were added to the tank. Waste from the strontium semiworks/hot semiworks was then added at different times to the tank from 1962 to 1965. In 1970, an additional transfer of waste from tank C-110 was received. Tank C-109 is a sound tank. Tank C-109 was interim stabilized in November 1983 and waste retrieval was completed in 2012.

2.3.2.9.10 Tank C-110

Tank C-110 began receiving waste in May 1946, and by August 1946 was filled with first decontamination cycle waste and coating removal waste from the BP process at 221-B Plant. Beginning in August 1946, waste received into tank C-110 overflowed to tank C-111 through the cascade line and then to tank C-112 beginning in November 1946. These tanks were reported as 100 percent full in March 1947. The supernatant waste was transferred from tank C-110 to tank B-106 in July 1952. Beginning in November 1952, tank C-110 was filled with TBP waste. In February 1956, the TBP supernatant waste was transferred from tank C-110 to the 244-CR vault for ferrocyanide scavenging of cesium and strontium. Tank C-110 then received organic wash waste from PUREX Plant from June 1956 through September 1956. In November 1967, supernate was transferred from tank C-110 to the cell 23 evaporator in the 221-B Plant for concentration. From 1970 until 1972, evaporator bottoms waste and IX waste were sent to tank C-110 from tanks BY-104, BX-104 and BX-103. The interstitial liquid was saltwell pumped from tank C-110 in 1976 and 1977. (See Section 2.3.3.1 of this Draft WIR Evaluation.) Additional supernate was transferred to DST AN-103 in 1983. Tank C-110 was removed from service in 1976. The tank was saltwell pumped from November 1991 through January 1992 and again from September 1994 through May 1995. Tank C-110 was interim stabilized in June 1995 after repeated saltwell pumping. Tank C-110 is a sound tank. Tank C-110 waste retrieval was completed in 2014.

2.3.2.9.11 Tank C-111

Tank C-111 entered service in August 1946, with receipt of BP waste via cascade line from tank C-110. In November 1946, tank C-111 was declared full and the waste cascaded into tank C-112. In July and August 1952, supernate was transferred out of tank C-111 to tank B-106. Beginning in November 1952, tank C-111 was an active receiver of TBP waste. Tank C-111 was filled with TBP waste as of January 1953. In January 1956, TBP waste was transferred from tank C-111 to the 244-CR vault for in-farm scavenging. Tank C-111 then served primarily as one of the settling tanks for ferrocyanide waste. In August 1956, ferrocyanide supernate was transferred from tank C-111. Tank C-111 periodically received PUREX organic wash waste and PUREX coating removal waste from September 1956 through April 1957. In April 1957, tank C-111 transferred PUREX organic wash waste and coating removal waste to tank BY-111. Tank C-111 was again used from June 1957 through December 1957 as the settling tank for ferrocyanide waste. Tank C-111 received intermittent transfers of PUREX coating removal waste supernate from tank C-105 in October 1959, March 1960, and November 1960. From July 1962 through June 1964, tank C-111 filled with waste from the 201-C Hot Semiworks Facility. Tank C-111 is a sound tank. Tank C-111 was interim stabilized in March 1984 and the waste retrieval was completed in 2016.

2.3.2.9.12 Tank C-112

Tank C-112 started receiving BP waste in November 1946, via cascade from tank C-111. The tank remained static until the majority of the supernate was transferred to tank B-106 in 1952. The tank received unscavenged uranium recovery waste from the uranium recovery process in 1954. In late 1955, tank C-112 began to be used for settling scavenged ferrocyanide waste. The scavenged supernate was decanted and sent to several cribs, and the ferrocyanide sludge was retained in the tank until the first quarter of 1958 when in-farm scavenging was completed. Small transfers of flush water and cladding waste were received from 1958 through the second quarter of 1961. A small amount of waste from the strontium semiworks/hot semiworks was added to the tank in late 1961 and early 1962. In 1970 and 1975, B Plant ion-exchange waste from tank C-110 and drainage to C-301 catch tank was added to tank C-112. Tank C-112 was emptied of pumpable liquid which was transferred to tank C-103 in 1975 and 1976. Tank C-112 was removed from service in 1976. Tank C-112 is a sound tank. Tank C-112 was interim stabilized in September 1990 and waste retrieval was completed in 2014.

2.3.2.9.13 Tank C-201

Construction of the four C-200 tanks was completed in September 1947. Tank C-201 began to receive BP waste in November 1947 and was 100 percent filled (55,000 gal) by January 31, 1948. Beginning in February 1952, waste was removed from this tank. Tank C-201 was declared empty on March 17, 1954. In May 1955 highly radioactive waste from the solvent extraction process conducted in the 201-C Hot Semiworks Facility was concentrated to recover nitric acid, neutralized by addition of sodium hydroxide solution and transferred to tank C-201. Tank C-201 was reported as being filled on November 30, 1955. Tank C-201 supernate was pumped to tank C-104 between April and June of 1970. Tank C-201 waste retrieval was completed in 2006.

2.3.2.9.14 Tank C-202

Tank C-202 began to receive BP waste in November 1947 and was 100 percent filled (55,000 gal) by January 31, 1948. Beginning in February 1952, waste was removed from this tank. In November 1955, tank C-202 received 201-C Hot Semiworks Facility solvent extraction waste. Tank C-202 was reported as being filled in May 1956. Tank C-202 supernate was pumped to tank C-104 between April and June of 1970. Tank C-202 waste retrieval was completed in 2005.

2.3.2.9.15 Tank C-203

Tank C-203 began to receive BP waste in November 1947 and was 100 percent filled (55,000 gal) by January 31, 1948. Beginning in February 1952, waste was removed from this tank; sluicing operations were completed on January 28, 1954. Tank C-203 was reported to have received some solvent extraction waste from the 201-C Hot Semiworks Facility. In November 1955 tank C-203 also received waste from cold uranium runs conducted as part of startup operations at the PUREX Plant. Supernate was transferred from tank C-203 to tank C-109 between January and March of 1970. Tank C-203 waste retrieval was completed in 2005.

2.3.2.9.16 Tank C-204

Tank C-204 began to receive BP waste in November 1947 and was 100 percent filled (55,000 gal) by January 31, 1948. Beginning in February 1952, waste was removed; sluicing operations were completed in February 1955. Tank C-204 was reported to have received some solvent extraction waste from the 201-C Hot Semiworks Facility. In November 1955, tank C-204 also received waste from cold uranium runs conducted as part of startup operations at the PUREX Plant. Supernate was transferred from tank C-204 on July 10, 1977. Tank C-204 waste retrieval was completed in 2003.

2.3.3 Waste Retrieval Approach for Waste Management Area C

A number of retrieval technologies have been used to complete the retrieval of waste from the WMA C tanks. This section describes waste retrieval technologies deployed for retrieval of the tank waste. Section 4.3 describes the waste retrieval technologies deployed for specific tanks, how those technologies were selected, and the results of the retrievals.

2.3.3.1 Saltwell pumping

The SSTs were taken out of service in 1980. As an interim measure to mitigate potential for leakage from SSTs, a program of “interim stabilization” was carried out (HNF-2358, Single-Shell Tank Interim Stabilization Project Plan). Well screens were installed in each tank to facilitate pumping of supernate and drainable interstitial liquids. The criteria for completion of interim stabilization for each tank were no more than 5,000 gal of supernate, 50,000 gal of interstitial liquid, or the pumping extraction rate of no more than 0.05 gpm.

2.3.3.2 Sluicing (also known as Past Practice Sluicing)

Sluicing was one of the first waste retrieval technologies applied to WMA C tanks, specifically tank C-106. It is a simple process in which a stream of water, similar to the stream from a fire hose, is directed onto the waste surface, breaking the waste into a slurry. The slurry is then pumped out of the tank. This method generates ~1 ft of liquid slurry on the top surface water, which could increase the tank's leakage potential. Sluicing has historically been less effective in tanks with interior obstructions that prevent the jet from reaching some areas. A long-reach manipulator is a mechanical deployment system mounted above the tank that reaches down into the tank to position waste retrieval tools (WHC-SA-2448-FP, "First Generation Long-Reach Manipulator for Retrieval of Waste from Hanford Single-Shell Tanks").

2.3.3.3 Modified Sluicing

The Hanford Site modified sluicing (MS) process is called "modified" to differentiate it from the "past practice" sluicing that was used in the 1950s through 1970s to retrieve selected sludge tanks. All sluicing processes are based on the principle that fine particles can be suspended in a water/brine solution and will then be carried with the fluid so long as there is sufficient turbulence to maintain the solids in suspension. The process is carried out by the use of sluicers that are installed in the tanks through available risers. The sludge waste is pushed by the sluice stream toward a pump, which is installed near the center of the tank. The sludge has somewhat high viscosity and will plug the pump if it is deeply submerged in the waste; therefore, a variable height pump is used. The pump is kept at a relatively shallow submergence of 6 to 12 in. in the waste and pumps the slurry that results from the mixing/ suspending action of the sluicers. The pump is lowered as the waste is retrieved. This process is illustrated in Figure 2-18.

The slurry is pumped to a receiver tank, typically a DST, where the solids are allowed to settle. A pump in the receiver tank transfers clarified supernate back to the sluicers. The supernate is recycled as the sluicing fluid to minimize the volume increase in the DST. Experience in WMA C SSTs has shown that about 90 percent of the sludge waste can be suspended and pumped from a tank using MS, leaving about 10 percent of the waste that is too large and fast-settling to enter the pump or that is located in a position where the sluicers cannot effectively mobilize the waste (RPP-RPT-44139, "Nuclear Waste Tank Retrieval Technology Review and Roadmap").

2.3.3.4 FoldTrack Mobile Retrieval Tool

The FoldTrack Mobile Retrieval Tool (MRT)®[22] is a tracked vehicle with a plow blade that is used as a scraper to push waste agglomerates towards the inlet of the waste transfer pump. In addition, the vehicle is equipped with a pressurized water system including a pressurized water cannon (1,800 psi) and three pressurized water scarifiers (5,000 psi). The water cannon can be used to direct a water stream in front of the vehicle to sluice, to push waste to the transfer pump, and to rinse down the tank walls and other in-tank equipment. The scarifier nozzles can articulate downward and can be used for particle size reduction and waste mobilization. The

[22] The FoldTrack® mobile retrieval tool is manufactured by Non Entry Systems Ltd., UK Patent Application No: 0718573.9.

FoldTrack MRT is hydraulically-driven and is capable of being deployed through a 12-in. diameter riser. The FoldTrack MRT uses hydraulics to align the left and right tracks to form a bulldozer-like vehicle that is ~5 ft long and 30 in. wide (Figure 2-19) (RPP-RPT-44139).

Figure 2-18. Tank C-110 Sluicing Photograph.

The FoldTrack MRT can also be positioned around the transfer pump to be used as a backstop. In this capacity, the vehicle acts as a physical barrier to prevent material from being sluiced past the pump during sluicing operations. The vehicle can also be used to restrict the passable area through the pump screen. The vehicle can be used to physically block a section of screen or facilitate the buildup of material around a section of the pump screen. When passage through the pump screen is reduced and the pumping rate is maintained, the velocity of the material entering the pump increases, enhancing the ability of the pump to entrain larger waste particles (RPP-RPT-44139).

The FoldTrack MRT is designed to be highly mobile in tank waste. Track configuration and vehicle movement are hydraulically driven; forward and reverse drive of the tracks are independent of one another. Independent track mobility allows the vehicle to maneuver over uneven surfaces and obstacles. An integrated plow blade on the front of the vehicle can be raised

and lowered using hydraulic controls. Pressurized water (5,000 psi) nozzles attached to the plow blade are capable of breaking apart large waste particles. Due to the small orifices in the spray nozzles, pressurized water scarifying uses filtered raw water. The water cannon (1,800 psi) also can be raised and lowered with the plow blade. The water cannon also functions as a floor sweep to sluice waste towards the transfer pump (RPP-RPT-44139).

Figure 2-19. FoldTrack® Mobile Retrieval Tool.

The FoldTrack® mobile retrieval tool is manufactured by Non Entry Systems Ltd., UK Patent Application No: 0718573.9.

Hydraulic hoses and pressurized water lines are routed to the vehicle using an umbilical that can support the weight of the vehicle during deployment. The umbilical length is 120 ft and the full length of the umbilical is placed into the tank during waste retrieval operations. The vehicle has sufficient mobility and power to manage the umbilical, but a limited umbilical management system is included in the retrieval system to raise and lower the extra umbilical length when necessary. Hydraulic oil and high-pressure water from a surface-mounted hydraulic power unit (HPU) and high-pressure water skid are connected to the vehicle umbilical using a riser-mounted interface. The HPU and water skid operate off 480 V, 3-phase, 60 Hz power, and 120 V service is necessary for the control console. The control console is used to remotely start and stop the HPU and high-pressure water skid, control the umbilical management system, raise and lower

the plow blade, open and close the vehicle tracks, maneuver the vehicle, and start, stop and change the pressure of the on-board water jetting systems. Local control of the hydraulics and water jetting systems are also provided on the HPU and high-pressure water skid (RPP-RPT-44139).

2.3.3.5 Chemical Heel Retrieval

Chemical heel retrieval methods for use in retrieving waste include acid dissolution, caustic dissolution (also referred to as caustic cleaning), and water dissolution. Chemical treatment processes generally involve batch additions of a chemical solution into the tank. Dissolution occurs following addition of the applicable chemicals. Dissolution progress is monitored by sampling the liquid for certain constituents or chemical properties. When dissolution progress slows, the slurry is removed from the tank using a waste transfer pump. Chemical retrieval methods can be deployed using systems similar to MS; however, instead of using supernate pumped in from a DST, the chemical solution is pumped in from mixing tanks. Recirculation using the waste transfer pump and sluice cannon can be used to agitate the tank contents and enhance the dissolution process by distributing the solution throughout the tank (RPP-RPT-44139).

Acid Dissolution. Use of acid to selectively dissolve waste components has two effects on the waste: (1) it puts the component into solution and (2) removal of the selected component causes the waste particle size to be reduced (e.g., from cobble to sand or from sand to sludge) (RPP-RPT-44139). Numerous studies have concluded that the best acid to dissolve sludge matter without also attacking the tank walls is oxalic acid. Oxalic acid dissolves iron oxide and some other metal oxides but does not work well on aluminum oxides/hydroxides. Acid dissolution systems supplement sluice-based systems. Oxalic acid is introduced into a tank after sluicing to dissolve the remaining insoluble waste.

Caustic Cleaning. Following MS, waste residuals contain high concentrations of insoluble aluminum primarily as aluminum hydroxides. Caustic cleaning (or dissolution) adds strong caustic solutions to the tank to convert the aluminum hydroxides to sodium aluminate. The reactions occur slowly and may take several weeks to reach equilibrium. The resultant sodium aluminate dissolves in water and weak caustic solutions. Retrieval through caustic dissolution uses the following process (RPP-RPT-44139):

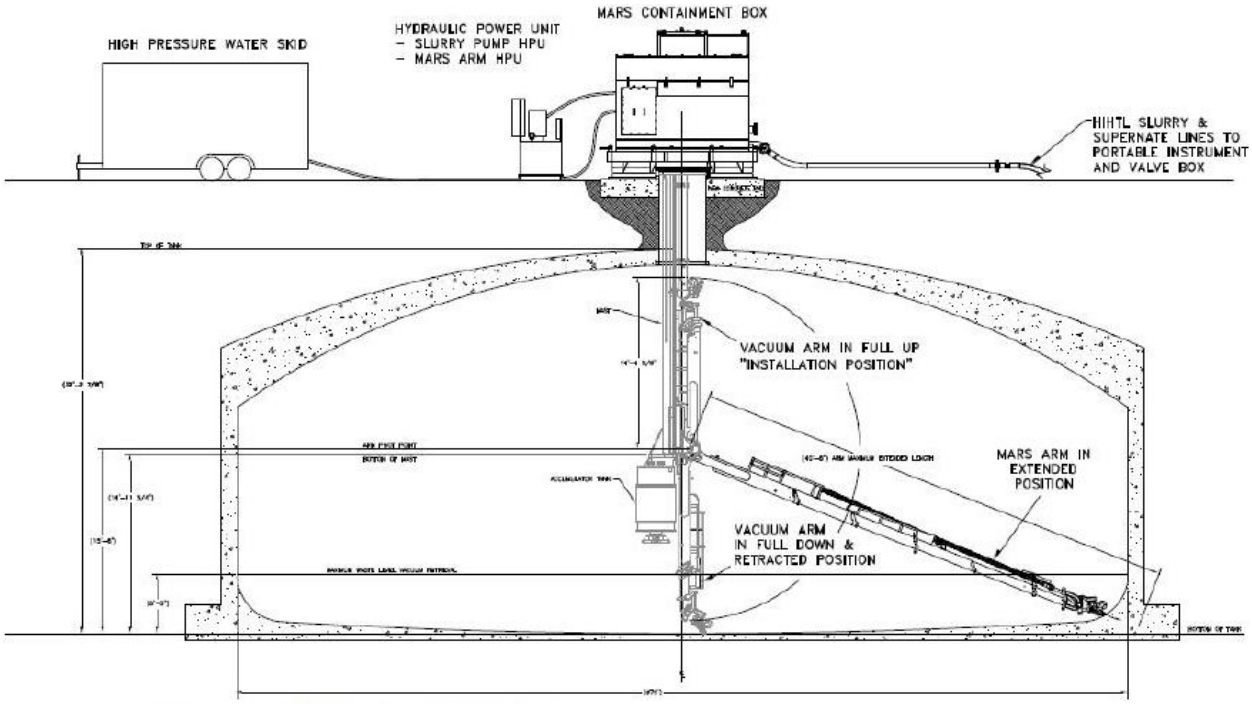
- Wash waste with water to remove phosphates and oxalate that will otherwise precipitate when reacting with the caustic
- Add caustic solution (19 M) to the tank
- Mix the waste and caustic solution
- Wait weeks for the solution to fully react
- Retrieve the soluble aluminum with water additions and conventional slurry pumping or an alternate pump system suitable for removal of liquid volumes.

2.3.3.6 Vacuum-Mode Mobile Arm Retrieval System

The vacuum-mode mobile arm retrieval system (MARS-V) is a telerobotic arm-based retrieval system that uses an educator-driven vacuum for waste retrieval (RPP-RPT-49821, "MARS Vacuum Retrieval System Activity Description"). The MARS-V was developed to clean out tanks using limited liquid addition and maintain a minimum liquid inventory in the tank at all times. With limited liquid additions to the tank, the MARS-V is a suitable technology for sound tanks as well as leaking or suspected leaking tanks. The eductor uses an introduced fluid stream to induce a pressure gradient, thereby creating a suction force. DST supernate is the introduced fluid in the MARS-V. The supernate stream flowing through the dual eductor loop creates suction to collect the waste material and then uses the retrieved material to continue driving the dual eductor loop. A fan nozzle aimed directly at the end-effector screened inlet provides liquid to keep the head flooded, which is necessary in an eductor drive system to maintain suction (RPP-RPT-44139).

A schematic of the MARS-V is shown in Figure 2-20. The MARS-V end-effector includes a pair of recycled supernate fan nozzles (up to 36 gpm and 100 psi) used for fluidizing waste in close proximity to the end-effector. The end-effector is also equipped with two pairs of high-pressure nozzles (up to 9 gpm and 4,950 psi). One pair of high-pressure nozzles is used to break up solid sections or oversized pieces of tank waste for retrieval by the eductor. The other pair is used to back flush the screen in the event the eductor screen becomes plugged (RPP-RPT-44139).

Figure 2-20. Vacuum-Mode Mobile Arm Retrieval System.



Source: Columbia Energy & Environmental Service, Inc.

The retrieval slurry pump system is a submersible hydraulically-driven centrifugal slurry pump that is mounted inside the waste acceptance tank. This pump is a variable speed, hydraulically-driven centrifugal slurry pump capable of controllable pumping up to ~300 gpm. The pump is equipped with a manifold that breaks the discharge stream from the pump into three smaller streams. Two of these streams recirculate to supply the eductor in the end-effector and the supplementary eductor in the waste acceptance tank. The third stream is the return slurry stream to the receiver tank. These streams typically have flow rates between 60 and 100 gpm (RPP-RPT-44139).

The MARS-V includes two HPUs. One supports the operation of the MARS-V arm, constant tension reel, and end-effector subsystems. The second HPU powers the slurry transfer pump system. There are two primary modes for waste retrieval using the MARS-V: (1) an initial mode intended to retrieve the majority of the waste and (2) a mode for hard-to-remove waste retrieval. The initial mode involves extending the arm to within ~3 ft from the edge of the tank. The eductors and fluidization nozzles in the end-effector and in the waste acceptance tank are started. The intake is then submerged into the waste to create a conical depression between 4 and 5 ft in diameter. When the waste level is ~1 ft above the bottom of the tank or as needed, the eductor and fluidization nozzles are stopped and the arm is relocated to retrieve additional waste while creating another conical depression. This scenario is repeated until all waste down to the 1-ft level has been retrieved (RPP-RPT-44139).

A pair of high-pressure nozzles can be used to break up masses of aggregated waste as well as larger particles of waste. The nozzles are used to reduce material to particle sizes of less than 0.375 in. (eductor inlet screen size is 0.4375 in.). The fluidization nozzles are used to assist the eductor in retrieving the resultant waste particles. Should the screen become blocked by particles greater than 0.375 in. or by bridging across a screen opening from multiple smaller particles, high-pressure nozzles are used to remove the blockage. The arm is then used to move the end effector around the bottom of the tank, much like a vacuum cleaner, to retrieve the remaining waste (RPP-RPT-44139).

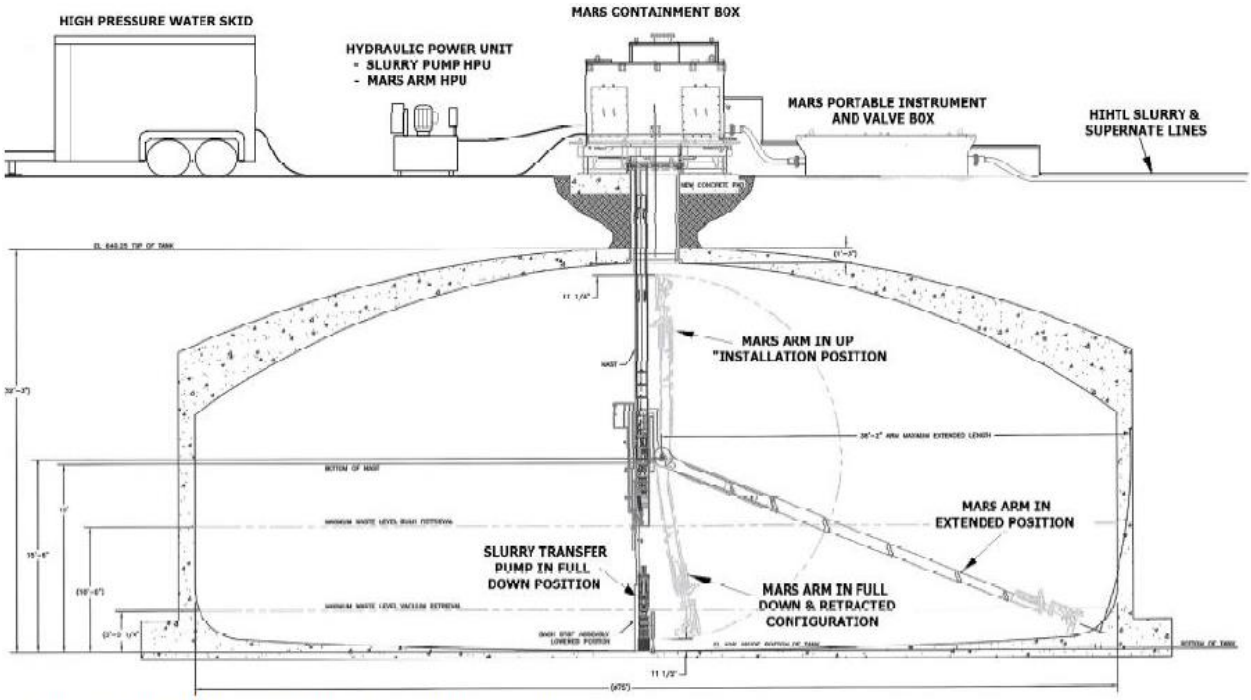
2.3.3.7 Sluice-Mode Mobile Arm Retrieval System

The sluice-mode mobile arm retrieval system (MARS-S) retrieval system mobilizes and retrieves SST waste using spray nozzles in an end-effector at the end of a telescoping arm and a centrally-located centrifugal slurry transfer pump. Waste mobilization is achieved with either recycled supernate or high-pressure water. The spray nozzles direct the resulting waste slurry stream toward the center of the SST where the adjustable-height slurry transfer pump is located. The waste is then pumped to the DST using this pump. The pump initially operates using a pump intake configuration similar to that used in past practice sluicing operations. During final retrieval operations for hard-to-remove waste, a pump backstop assembly is lowered to a position around and under the slurry pump. In this position the backstop assembly supports solid particle size reduction and enhances fluid velocities into the pump intake to improve heavy solids entrainment and transport to the DST. A schematic of the MARS-S is shown in Figure 2-21, and the in-tank components are shown in Figure 2-22 (RPP-RPT-44139).

The MARS-S end-effector includes two types of recycled supernate sprays. Proximity nozzles (up to 32 gpm and 100 psi) are used for fluidizing waste in close proximity to the end-effector.

A water cannon (up to 90 gpm and 100 psi) is used to mobilize waste at a distance. The end-effector is also equipped with high-pressure nozzles (up to 20 gpm and 4,950 psi) to break up solid sections or oversized pieces of tank waste for retrieval. The MARS-S high-pressure water skids (two trailers) provide up to 20 gpm of raw water at up to 4,950 psi via hoses to the containment box (RPP-RPT-44139).

Figure 2-21. Sluice-Mode Mobile Arm Retrieval System Schematic.



Source: Columbia Energy & Environmental Service, Inc.

The MARS-S includes two HPUs. One HPU supports operation of the MARS arm, backstop assembly deployment cylinders, in-tank hose management constant tension reel, and end-effector subsystems. The second HPU powers the slurry transfer pump system. Hydraulic hose bundles connect the HPUs to the MARS-S containment box, and the hose management system routes them to the MARS-S equipment requiring hydraulic fluid power support (RPP-RPT-44139).

There are two primary modes for waste retrieval using the MARS-S. The initial strategy, intended to remove the majority of the waste, involves extending the arm to midway between the center of the tank and the tank perimeter and using the sluice cannon to mobilize waste to the slurry pump. A cone is formed as the MARS-S arm rotates. The width of the cone is expanded as waste retrieval progresses and the arm is extended toward the tank perimeter. This scenario is repeated until all waste has been retrieved down to the 2-ft level (RPP-RPT-44139).

For retrieval of the hard-to-remove waste, the close proximity and high-pressure nozzles are used to break up masses of aggregated waste as well as larger particles of waste around the pump. Once cleared, the backstop is lowered and retrieval using the approach to break up the hard waste is used to the limit of technology. The nozzles reduce material to particle sizes of less than 0.375 in. The fluidization nozzles on the end-effector and backstop assist the pump in retrieving the resultant waste particles (RPP-RPT-44139).

The first-generation MARS-S requires a large tank riser (47-in. nominal diameter) in the center of the tank for deployment (RPP-RPT-44139).

Figure 2-22. Sluice-Mode Mobile Arm Retrieval System In-Tank Components.

Source: Columbia Energy & Environmental Service, Inc.

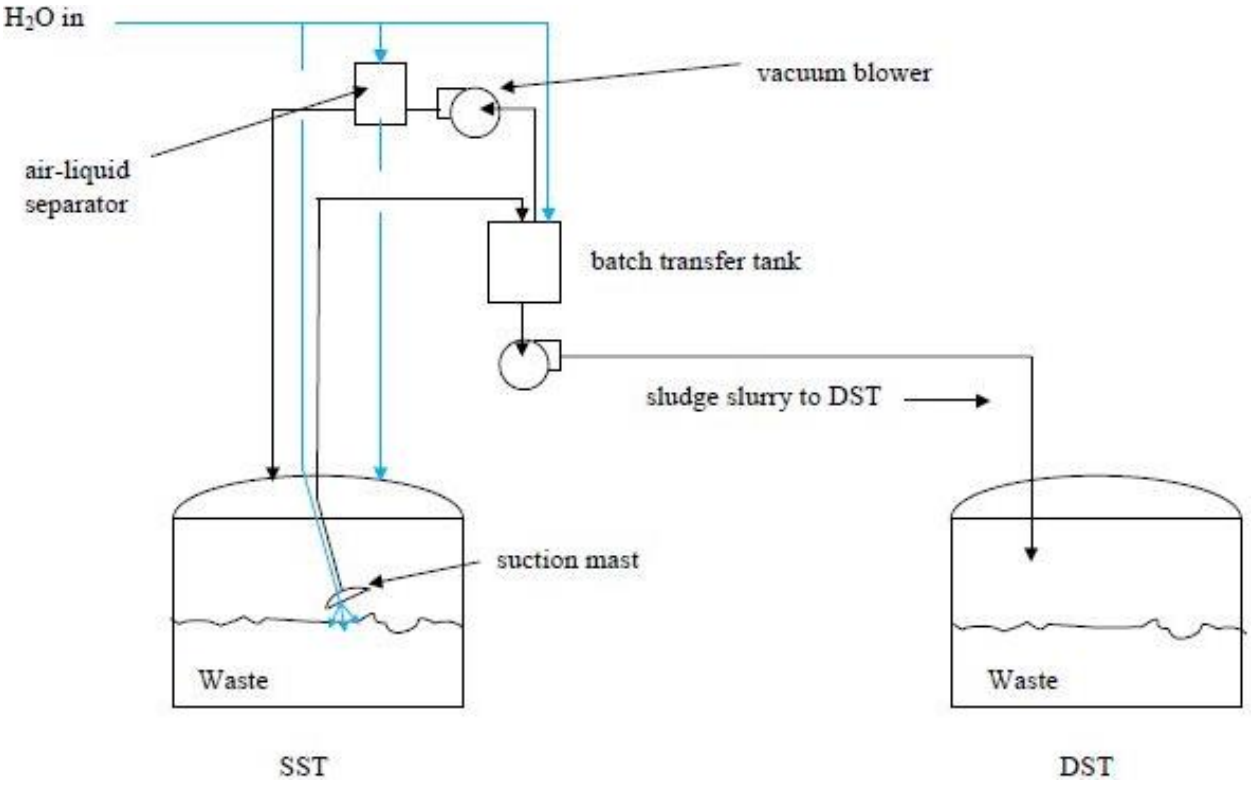
2.3.3.8 Vacuum Retrieval in 200-Series Tanks (VR-200)

The VR-200 vacuum retrieval process was used for waste retrieval in tanks C-201, C-202, C-203, and C-204 (Figure 2-23). The process uses a mast arm capable of in-and-out, back-and-forth, and rotational motion. The arm is inserted into a riser around the perimeter of the tank and used to vacuum the waste through a suction head covered with a protective screen. The vacuum head is equipped with low- and high-pressure water sprays. Vacuum is provided from an above-ground skid equipped with vacuum blowers. Vacuum draws on a 200-gal batch tank in another skid, which in turn pulls vacuum on the mast. When the batch tank is full, the vacuum system is stopped and the batch tank pumped out to the receiving DST (RPP-PLAN-40145, "Single-Shell Tank Waste Retrieval Plan").

Waste was removed from WMA C 200-series tanks to below HFFACO limits using this process, but the retrieval rates were very low. The low rates are believed to have been caused by the small screen size in the mast head that restricted flow of waste particles into the mast and/or

resulted from the length of the vacuum line to the mast head. Operation was also restricted by inadequate cooling for the liquid recirculated through the vacuum blowers. The equipment is more complex and demanding of resources than MS or saltcake dissolution (RPP-PLAN-40145).

Figure 2-23. Simplified Schematic of VR-200 Vacuum Retrieval Process for 200-Series Tanks.



DST = double-shell tank SST = single-shell tank

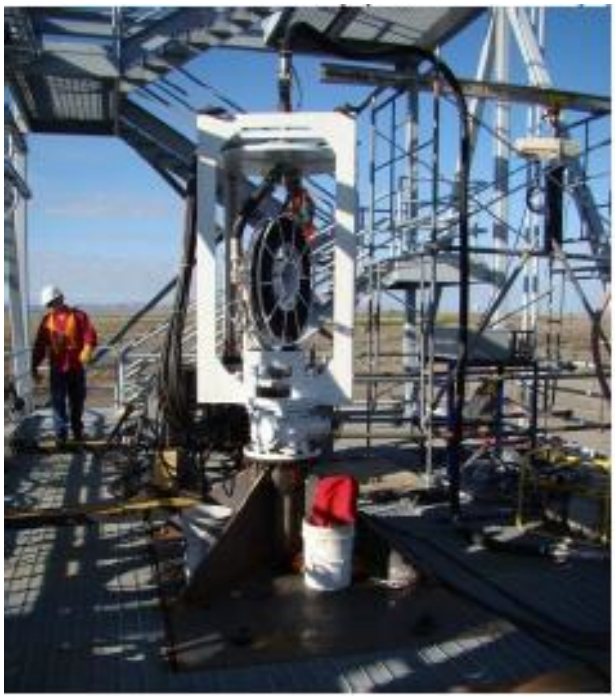
2.3.3.9 Extended Reach Sluicer System

The extended reach sluicer system (ERSS) (Figure 2-24) is an articulating, rotating, and telescoping tool that increases the area of influence of a sluice cannon. The ERSS has a fixed-length mast section that can be rotated in a full revolution (±180°). A hinged elbow connects a telescoping boom to the end of the fixed-length mast. Hydraulics elevate the boom from the vertical position to the horizontal position, which increases the reach of the tool. The elbow allows the boom to be elevated to the horizontal position to direct the sluice stream directly at the tank bottom or up to ~90° horizontally to provide coverage from tank bottom to the tank wall. In addition to elevation, the boom has two telescoping sections that extend the reach of the ERSS to 27 ft from the installed position. An articulating nozzle at the end of the telescoping boom has continuous 360° nozzle rotation and 300° of nozzle elevation. An integrated hose reel manages the supernate hose while the arm is extended and retracted. Two built-in rotary unions accommodate mast and nozzle rotation (RPP-RPT-44139).

The length of the fixed-mast section of the ERSS arm is customizable by the manufacturer to accommodate specific tank requirements. Increasing the installation height to 40 ft reduces the

reach from 22 to 19 ft. The area of influence beyond this reach point is extended by the sluice stream itself, which would be similar to that experienced with conventional (i.e., fixed-length-mast) sluice cannons (100 gpm at 120 psi). An additional enhancement has been the addition of two integrated high-pressure nozzles rated for 5,000 psi filtered water fixed at the articulating head of the sluicer, adding powerful mobilization capabilities (RPP-RPT-44139).

Figure 2-24. Extended Reach Sluicer System (a) Above Riser (b) Below Riser.



(a)

(b)

Source: Washington River Protection Solutions, LLC

Installation of the ERSS requires a minimum 12-in.-diameter riser. The tool can be customized to accommodate different riser lengths; the minimum riser length on the prototype ERSS is 5 ft and is determined by the placement of a hydraulic spider(s) used to stabilize the tool. Larger-diameter risers may be accommodated with additional hardware. The weight of the prototype ERSS is ~4,000 lb (excluding shield box) and the total retracted length of the ERSS prototype is ~35 ft. For an in-pit installation, the pit walls must be 18 in. from the center of the riser to accommodate the hose reel enclosure. Larger shield boxes or new cover plates may also be needed to provide shielding from the riser-mounted equipment, which is not the same size as a conventional sluicer (RPP-RPT-44139).

Similar to waste retrieval with conventional sluice cannons, nozzle positioning is hydraulically driven and requires a surface-mounted HPU, electric power supply (480 V, 3-phase, 60 Hz), a high-pressure filtered water skid, and a control console (RPP-RPT-44139).

2.3.4 Radionuclide Inventory in the Waste Management Area C Facility Components

This section summarizes residual WMA C waste inventory information and describes the methods and assumptions used to estimate the inventories and concentrations of radionuclides in residual waste in the WMA C SSTs and ancillary structures at closure.

The Best-Basis Inventory (BBI) is the official database for tank waste inventory estimates at the DOE Hanford Site. Estimates are based on the best available information to describe in-tank waste contents. This includes sample-based information when available; process knowledge calculations; waste type templates based on sample data; and Hanford Defined Waste (HDW) Model estimates (RPP-19822). The BBI process involves developing and maintaining waste tank inventories comprised of chemical and radionuclide components.[23] A listing of the radionuclides is provided in Table 2-4. The BBI provides waste composition data for safety analyses, performance assessments, risk assessments, and waste retrieval, treatment, and disposal planning.

Development and maintenance of the BBI is an ongoing activity. The tank waste inventories are updated as a result of new sample data, waste transfers into or out of tanks, and advances in process knowledge. The BBI is updated on a quarterly basis to incorporate new data and waste transfer information.

Sample data are not available for every constituent and for every tank. "Best available" information means process knowledge model estimates in these cases. Model-based results are the only available information for many of the radionuclide constituents. Model-based values for tank waste radionuclides are derived from fuel irradiation and plant process records. A previous assessment of limitations to the HDW model provided in HNF-3273, "Hanford Defined Waste Model Limitations and Improvements," showed that tank-specific HDW model estimates and tank sample results can vary by one to two orders of magnitude. A detailed discussion of BBI uncertainties and HDW model limitations is included in DOE/ORP-2003-02, "Environmental Impact Statement for Retrieval, Treatment and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA: Inventory and Source Term Data Package."

When analytical data are not available for a given constituent, waste concentrations are estimated based on waste process information. Waste volume estimates in the BBI are based on waste-level measurements and/or waste transfer information. In addition to standard BBI constituent estimates, after sampling tank residuals, inventories are also developed for additional constituents found in the samples (RPP-23403, "Single-Shell Tank Component Closure Data Quality Objectives").

[23] The BBI includes a standard set of 25 chemicals and 46 radionuclides. Additional constituents are tracked as identified for specific tanks.

Table 2-4. Standard Best-Basis Inventory Radionuclides.

Radionuclides		
^{3}H	^{134}Cs	^{234}U
^{14}C	^{137}Cs	^{235}U
^{59}Ni	^{137m}Ba	^{236}U
^{60}Co	^{151}Sm	^{237}Np
^{63}Ni	^{152}Eu	^{238}Pu
^{79}Se	^{154}Eu	^{238}U
^{90}Sr	^{155}Eu	^{239}Pu
^{90}Y	^{226}Ra	^{240}Pu
^{93}Zr	^{227}Ac	^{241}Am
^{93m}Nb	^{228}Ra	^{241}Pu
^{99}Tc	^{229Th}	^{242}Cm
^{106}Ru	^{231}Pa	^{242}Pu
^{113m}Cd	^{232}Th	^{243}Am
^{125}Sb	^{232}U	^{243}Cm
^{126}Sn	^{233}U	^{244}Cm
^{129}I		

In addition to inventory estimates for the standard constituents tracked in the BBI, the Hanford Tank Waste Operations Simulator (HTWOS) model simulates retrieval operations considering the mobility and composition of waste and retrieval fluids to estimate the waste residual inventories after retrieval. As such, it provides a more rigorous approach to estimate residual inventories compared to estimates based on simple percentage of waste currently in the tanks, and differentiates between soluble and insoluble constituents.

2.3.5 Waste Management Area C Performance Assessment Residual Waste Inventory Estimates

The WMA C PA provides several dose analyses which, together with other analyses and information, are used for comparison to the WIR criteria to demonstrate that the criteria will be met at closure of the WMA C. The first major step in developing the WMA C PA was to determine a best estimate (Base Case) of the expected waste inventory for the tanks and ancillary structures at closure.

The BBI contains inventory estimates for 46 radionuclides. The WMA C PA used a screening analysis which resulted in the number of radionuclides being reduced to 43 in the PA. The screening analysis consisted of the following steps:

- The BBI list contains some very short-lived radionuclides (half-lives less than three years), such as ^{90}Y, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137m}Ba, and ^{242}Cm. These six radionuclides were removed because either they were assumed to decay to negligible concentrations (^{106}Ru, ^{125}Sb, ^{134}Cs, ^{242}Cm) or their parents were already included in the WMA C PA calculations (^{90}Y, ^{137m}Ba). When the parent is included in the WMA C PA calculations, the contribution of the progeny is included in the dose calculation for the parent.
- The next step was to include additional radionuclides needed to complete the uranium decay chain to calculate radon flux. This step identified ^{222}Rn along with intermediate parent ^{230}Th that forms during the decay from ^{234}U. In addition, ^{210}Pb was identified as it is the decay product of ^{222}Rn. The initial mass of all three radionuclides (^{230}Th, ^{222}Rn, and ^{210}Pb) is assumed to be zero at closure.

The 43 radionuclides included for detailed analysis in the WMA C PA are shown in Table 2-5. For the purpose of analysis, the PA assumed a closure date of January 1, 2020. The initial inventory estimates for the WMA C PA were decay corrected to that date.

The residual inventory estimates used in the WMA C PA were determined based on information and conditions as of September 2014. Inventory estimates were developed for (1) residuals in retrieved tanks with post-retrieval sampling; (2) residuals in retrieved tanks without post-retrieval sampling; (3) residuals in tanks undergoing retrieval; and (4) post-retrieval residual inventory estimates for ancillary structures, as discussed below. Additional details on the development of the residual inventories used in the WMA C PA are provided in the PA.

C-103, C-104, C-106, C-108, C-109, C-110, C-201, C-202, C-203, and C-204: In the WMA C PA, inventory estimates for the 10 SSTs for which retrieval operations had been completed and post-retrieval samples obtained were based on the BBI. As of September 2014, waste volume estimates were completed using a camera/computer-aided-design modeling system (CCMS) and post-retrieval residual sampling and analysis was completed for these 10 SSTs.

C-101, C-107, and C-112: The WMA C PA inventory estimates for the three SSTs for which retrieval operations had been completed, but post-retrieval samples had not been obtained as of September 2014, were also based on the BBI and CCMS estimates. However, the basis for waste composition estimates for these tanks varied. For tanks C-101 and C-107, the BBI inventory estimates were based on pre-retrieval sample results, sample-based templates and process knowledge. For tank C-112, the BBI estimates were based on in-process transfer samples representative of bismuth phosphate process first-cycle decontamination waste, and sample and process knowledge templates.

C-102, C-105 and C-111: In the WMA C PA, future residual waste volumes were unknown for the final three SSTs in WMA C for which retrieval was in progress as of September 2014; therefore, residual inventories were estimated in the WMA C PA for these tanks, as follows.

Table 2-5. Estimated Inventory of Radionuclides (in Curies) at Closure of Waste Management Area C (Decay Corrected to January 1, 2020) Used in the Performance Assessment Calculation.

Tank/ Eqpt	Ac-227	Am-241	Am-243	C-14	Cd-113m	Cm-243	Cm-244	Co-60	Cs-137	Eu-152	Eu-154	Eu-155	H-3	I-129	Nb-93m	Ni-59	Ni-63	Np-237	Pa-231	Pb-210	Pu-238	Pu-239
C-101	1.58E-06	9.91E+00	1.43E-03	2.76E-03	1.47E-03	1.86E-05	3.32E-04	1.76E-04	3.61E+02	6.38E-05	2.77E-03	4.69E-04	2.45E-02	5.55E-05	1.83E-05	7.23E-04	5.53E-02	3.45E-04	2.48E-08	0.00E+00	1.13E-01	1.83E+01
C-102	1.93E-02	2.12E+01	7.93E-04	9.88E-04	1.78E-02	6.22E-05	1.28E-03	2.14E-01	8.07E+01	1.26E-04	1.36E-01	2.62E-02	2.15E-05	2.56E-03	1.10E-02	1.62E-01	1.36E+01	5.16E-05	2.12E-03	0.00E+00	1.48E+00	6.49E+01
C-103	6.39E-08	4.83E+00	3.70E-05	6.99E-03	1.49E-02	7.66E-07	1.52E-05	1.83E-02	6.07E+02	2.58E-05	1.41E+00	4.37E-01	3.98E-03	3.00E-03	3.69E-04	1.12E-01	1.86E+01	1.35E-02	1.66E-07	0.00E+00	1.30E+00	4.99E+00
C-104	1.11E-05	8.46E+00	5.25E-03	3.08E-03	5.11E-02	3.64E-03	6.69E-02	4.66E-01	6.22E+02	3.54E-02	1.57E+00	2.29E-01	9.32E-03	4.84E-04	3.16E-02	8.64E-02	9.95E+01	7.97E-02	7.47E-05	0.00E+00	5.89E-01	5.15E+00
C-105	5.17E-07	2.84E+01	6.73E-04	4.86E-02	5.87E-02	9.11E-06	1.56E-04	6.83E-01	5.08E+03	1.12E-04	4.68E-03	6.08E-04	4.08E+00	8.95E-03	1.45E-03	4.41E-01	3.61E+01	1.93E-04	6.57E-07	0.00E+00	7.50E-01	5.28E+01
C-106	1.74E-03	6.38E+01	3.05E-03	8.21E-03	2.13E+00	5.55E-02	7.39E-01	2.23E+00	1.00E+03	2.02E+00	2.25E+01	7.65E+00	4.17E-03	6.31E-04	5.92E+00	1.05E+01	6.53E+01	5.41E-02	2.53E-03	0.00E+00	2.38E+00	1.67E+01
C-107	6.20E-06	3.70E+02	3.86E-02	2.16E-02	2.50E-03	5.02E-04	8.95E-03	9.14E-04	2.32E+03	1.35E-04	5.70E-03	8.66E-04	1.44E-02	4.07E-02	8.45E-02	1.18E-03	1.46E-01	2.08E-04	3.83E-05	0.00E+00	8.05E-01	1.30E+02
C-108	7.78E-07	9.46E-01	9.78E-05	8.18E-03	1.97E-03	1.50E-06	2.96E-05	7.22E-04	8.57E+01	1.07E-04	4.52E-03	6.84E-04	1.94E-02	3.81E-05	4.80E-02	9.30E-04	2.80E+00	2.17E-05	3.02E-05	0.00E+00	4.37E-03	6.68E-01
C-109	3.40E-06	3.71E-01	3.91E-05	7.65E-04	1.37E-03	5.09E-07	9.09E-06	5.02E-04	4.31E+01	7.41E-05	3.13E-03	4.74E-04	3.51E-03	2.65E-05	4.64E-02	6.46E-04	8.78E-01	6.46E-04	2.10E-05	0.00E+00	1.56E-02	4.01E-01
C-110	9.62E-07	4.94E-02	5.54E-06	1.51E-03	3.89E-04	7.22E-08	1.29E-06	1.42E-04	2.02E+01	2.11E-05	8.89E-04	1.35E-04	1.80E-03	2.65E-04	1.32E-02	1.83E-04	4.08E-01	1.09E-03	5.96E-06	0.00E+00	1.56E-02	1.17E+00
C-111	1.82E-05	8.32E+01	1.15E-02	1.04E-01	5.99E-02	1.82E-03	3.26E-02	1.03E-01	7.14E+03	5.38E-02	2.41E+00	3.70E-01	2.58E+00	1.41E-02	9.78E-02	1.40E+00	1.13E+02	3.32E-03	4.99E-05	0.00E+00	1.70E+00	9.45E+01
C-112	4.57E-06	9.42E-01	9.72E-05	1.60E-02	1.84E-03	1.26E-06	2.25E-05	6.75E-04	7.66E+02	1.00E-04	4.22E-03	6.39E-04	1.06E-02	3.57E-05	6.26E-02	8.69E-04	1.08E-01	1.54E-04	2.82E-05	0.00E+00	3.59E-02	5.79E+00
C-201	3.45E-09	2.46E+00	9.76E-04	7.64E-04	5.77E-04	3.10E-03	5.55E-02	2.37E-03	7.01E+00	2.10E-03	9.42E-02	1.45E-02	1.57E-04	4.57E-07	7.46E-04	4.07E-03	8.33E-01	3.42E-03	6.79E-09	0.00E+00	4.42E-01	1.58E+01
C-202	3.51E-09	1.21E+00	4.71E-04	2.03E-04	5.88E-04	1.50E-03	2.68E-02	2.44E-03	6.18E+00	2.14E-03	9.61E-02	1.48E-02	1.60E-04	7.35E-06	7.64E-04	4.16E-03	2.00E-01	2.90E-03	6.93E-09	0.00E+00	3.99E-01	1.43E+01
C-203	2.87E-09	3.16E-02	1.22E-05	1.66E-04	4.80E-04	3.88E-05	6.95E-04	2.15E-03	9.10E+00	1.75E-03	1.50E-02	1.81E-02	1.31E-04	1.47E-05	6.26E-04	3.40E-03	5.54E-02	2.70E-05	5.67E-09	0.00E+00	1.36E-02	4.86E-01
C-204	2.69E-09	3.16E-03	1.22E-06	1.88E-04	4.50E-04	3.87E-06	6.95E-05	1.86E-03	4.13E+00	1.64E-03	5.62E-02	1.13E-02	1.13E-04	3.57E-07	5.84E-04	3.18E-03	1.46E-02	2.16E-02	5.30E-09	0.00E+00	2.76E-04	9.84E-03
C-301	6.62E-05	5.54E+00	1.37E-03	2.04E-03	8.49E-02	5.33E-03	8.60E-02	1.16E-01	1.21E+02	8.31E-02	1.17E+00	3.60E-01	2.09E-03	2.06E-04	2.30E-01	4.14E-01	9.54E+00	2.82E-02	1.01E-04	0.00E+00	7.40E-01	2.13E+01
244-CR vault	1.20E-04	1.01E+01	2.49E-03	3.71E-03	1.54E-01	9.68E-03	1.56E-01	2.11E-01	2.21E+02	1.51E-01	2.13E+00	6.54E-01	3.80E-03	3.75E-04	4.18E-01	7.52E-01	1.73E+01	5.13E-02	1.84E-04	0.00E+00	1.34E+00	3.88E+01
Pipelines	1.02E-04	8.52E+00	2.11E-03	3.14E-03	1.31E-01	8.19E-03	1.32E-01	1.79E-01	1.87E+02	1.28E-01	1.80E+00	5.54E-01	3.22E-03	3.17E-04	3.54E-01	6.37E-01	1.47E+01	4.34E-02	1.56E-04	0.00E+00	1.14E+00	3.28E+01

Tank/ Eqpt	Pu-240	Pu-241	Pu-242	Ra-226	Ra-228	Rn-222	Se-79	Sm-151	Sn-126	Sr-90	Tc-99	Th-229	Th-230	Th-232	U-232	U-233	U-234	U-235	U-236	U-238	Zr-93
C-101	1.96E+00	1.54E+00	2.70E-05	5.90E-07	2.64E-13	0.00E+00	2.80E-04	4.00E+00	5.13E-04	3.29E+03	4.34E-02	1.33E-10	0.00E+00	1.12E-12	1.75E-06	1.71E-07	1.69E-01	7.54E-03	1.93E-03	1.72E-01	3.35E-05
C-102	1.55E+01	4.87E+01	9.00E-04	2.88E-07	3.64E-01	0.00E+00	1.60E-06	9.72E-01	1.83E-04	2.94E+02	3.56E-03	1.06E-02	0.00E+00	2.29E-02	2.83E-02	2.17E+00	1.13E-01	4.27E-03	1.43E-03	9.78E-02	4.22E-03
C-103	1.04E+00	1.80E+00	3.24E-05	1.54E-08	4.70E-05	0.00E+00	2.64E-05	4.30E-01	5.27E-05	6.78E+03	4.48E-02	2.60E-11	0.00E+00	1.99E-04	4.29E-06	5.85E-03	1.36E-02	7.10E-04	3.74E-04	1.64E-02	7.03E-04
C-104	1.55E+00	1.14E+01	1.97E-02	3.24E-07	8.73E-04	0.00E+00	8.56E-03	3.17E+03	8.81E-03	4.89E+03	3.04E-01	8.56E-08	0.00E+00	3.70E-03	3.53E-02	2.18E+00	4.17E-01	1.98E-02	4.85E-03	4.39E-01	6.24E-02
C-105	1.04E+01	1.75E+01	3.14E-04	1.60E-07	2.36E-13	0.00E+00	1.51E-04	2.37E+00	2.93E-04	2.89E+04	7.83E+00	1.25E-10	0.00E+00	1.00E-12	8.62E-06	5.02E-07	2.39E-01	1.02E-02	5.17E-03	2.44E-01	2.77E-03
C-106	3.57E+00	1.84E+01	4.16E-04	5.13E-04	1.32E-04	0.00E+00	9.57E-03	7.82E+03	1.76E+00	4.50E+04	1.64E-01	1.91E-05	0.00E+00	5.60E-04	4.87E-04	1.82E-03	9.40E-04	3.86E-05	1.73E-05	9.02E-04	1.04E+01
C-107	1.42E+01	1.10E+01	1.97E-04	5.95E-07	9.70E-04	0.00E+00	2.70E-04	1.04E+04	4.94E-04	2.42E+04	2.14E+00	1.89E-09	0.00E+00	4.11E-03	2.20E-06	2.15E-07	2.07E-01	9.24E-03	2.31E-03	2.11E-01	1.55E-01
C-108	7.27E-02	7.91E-02	1.01E-06	4.73E-07	3.70E-06	0.00E+00	1.62E-03	6.66E+00	3.91E-04	1.25E+03	4.87E-02	1.50E-09	0.00E+00	1.57E-05	4.50E-07	4.10E-08	3.25E-02	1.82E-03	2.85E-04	4.03E-02	1.22E-01
C-109	4.36E-02	5.09E-01	6.07E-07	3.26E-07	2.06E-12	0.00E+00	1.48E-04	4.65E+00	2.71E-04	2.33E+03	8.77E-03	1.04E-09	0.00E+00	8.72E-12	9.94E-08	9.69E-09	9.35E-03	4.01E-04	9.61E-05	9.53E-03	8.45E-02
C-110	1.27E-01	3.58E-01	1.77E-06	9.27E-08	5.85E-13	0.00E+00	4.21E-05	1.32E+00	2.38E-02	2.62E+03	4.46E-02	2.95E-10	0.00E+00	2.48E-12	1.91E-08	1.86E-09	2.64E-03	1.14E-04	2.93E-05	2.59E-03	2.41E-02
C-111	1.85E+01	3.54E+01	6.54E-04	4.51E-06	6.54E-12	0.00E+00	3.53E-03	6.39E+02	6.72E-03	3.05E+05	2.19E+00	3.56E-09	0.00E+00	2.77E-11	2.22E-05	4.80E-05	7.74E-01	3.37E-02	1.32E-02	7.88E-01	1.81E-01
C-112	6.29E-01	4.91E-01	8.76E-06	4.40E-07	2.78E-12	0.00E+00	1.99E-04	6.25E+00	3.65E-04	2.28E+02	1.69E+00	1.40E-09	0.00E+00	1.18E-11	4.50E-07	4.39E-08	4.23E-02	1.89E-03	4.73E-04	4.32E-02	1.14E-01
C-201	3.40E+00	8.36E+00	1.60E-04	1.00E-09	9.51E-07	0.00E+00	5.49E-05	2.39E+01	1.10E-04	1.71E+02	2.63E-03	1.18E-11	0.00E+00	4.03E-06	2.25E-06	1.14E-05	3.65E-02	1.48E-03	5.23E-04	3.69E-02	1.46E-03
C-202	3.08E+00	7.52E+00	1.45E-04	1.02E-09	9.70E-07	0.00E+00	5.61E-05	2.43E+01	1.13E-04	3.31E+02	2.50E-03	1.20E-11	0.00E+00	4.11E-06	2.00E-06	1.02E-05	3.52E-02	1.42E-03	3.52E-04	3.28E-02	1.49E-03
C-203	1.05E-01	2.58E-01	4.94E-06	8.40E-10	4.48E-07	0.00E+00	4.58E-05	1.99E+01	9.21E-05	1.56E+02	2.32E-03	9.81E-12	0.00E+00	1.90E-06	6.60E-06	3.37E-05	1.13E-01	4.79E-03	8.33E-04	1.09E-01	1.22E-03
C-204	2.12E-03	5.21E-03	9.98E-08	7.86E-10	3.35E-06	0.00E+00	4.29E-05	1.86E+01	8.61E-05	1.03E+02	3.18E-03	9.17E-12	0.00E+00	1.42E-05	4.93E-06	2.51E-05	8.27E-02	3.42E-03	5.13E-04	8.13E-02	1.14E-03
C-301	4.60E+00	1.21E+01	1.30E-03	1.93E-05	5.90E-05	0.00E+00	1.03E-03	5.29E+02	6.80E-02	3.06E+03	3.64E-02	7.21E-07	0.00E+00	2.50E-04	1.96E-03	1.20E-01	2.26E-01	9.56E-03	1.93E-03	2.22E-01	4.07E-01
244-CR vault	8.36E+00	2.19E+01	2.36E-03	3.51E-05	1.07E-04	0.00E+00	1.87E-03	9.62E+02	1.24E-01	5.55E+03	6.62E-02	1.31E-06	0.00E+00	4.54E-04	3.57E-03	2.17E-01	4.11E-01	1.74E-02	3.51E-03	4.04E-01	7.39E-01
Pipelines	7.08E+00	1.86E+01	2.00E-03	2.97E-05	9.08E-05	0.00E+00	1.58E-03	8.15E+02	1.05E-01	4.70E+03	5.61E-02	1.11E-06	0.00E+00	3.85E-04	3.02E-03	1.84E-01	3.48E-01	1.47E-02	2.97E-03	3.42E-01	6.26E-01

1 Values decayed to January 1, 2020.

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C-102: In 2014, the HTWOS model provided the best estimate for concentrations. The initial waste retrieval performance information showed that for tank C-102, waste removal was tracking other similar waste tanks; therefore, a final waste volume of 360 ft^3 and HTWOS model inventory estimates were reasonable to assume at the completion of tank waste retrieval operations.

For tanks C-105 and C-111, the then-current BBI waste concentration estimates were assumed.

C-105: In 2014, initial waste retrieval performance information for tank C-105 indicated that equipment and waste characteristics would limit the performance of the designated retrieval technology (Mobile Arm Vacuum Retrieval System) and that other waste retrieval technologies (e.g., sluicing), or equipment modifications would be required to remove additional waste from the tank. Application of sluicing (particularly hot water sluicing) was expected to result in additional retrieval from tank C-105. The waste types and waste transfer history for tank C-105 are unique but there are some similarities to other WMA C tanks. In an effort to establish a residual waste volume that would be plausible, it was assumed that the quantity of waste remaining in tank C-105 would be similar to the quantity remaining in tank C-112, ~1,700 ft^3 (~12,700 gal).

C-111: In 2014, waste retrieval performance data indicated that significant additional waste removal from tank C-111 was not likely. The waste physical characteristics were such that modified sluicing had not been effective. Additional waste retrieval technologies, caustic and water dissolution, were planned. However, because of the hard, low permeability waste layer remaining in tank C-111, it was considered probable that little or none of the remaining waste would be removed by further waste retrieval operations. Therefore, the BBI provided a reasonable volume estimate for tank C-111.

For these three tanks (C-102, C-105, and C-111), the Base Case estimate for the volume and concentration of residual waste that would remain after retrieval was made in the WMA C PA based on the waste characteristics and retrieval performance to date, as described above.

Ancillary Structures: Although little information is available for the exact composition of waste in ancillary structures, it was assumed to be the same as the average composition of waste in the BBI for WMA C tanks based on process knowledge and operation history. Waste volumes for the C-301 catch tank and the 244-CR process vault were based on measurements; for the Base Case, an assumption was made that 90 percent of the waste would be retrieved.

Although the exact amount of waste remaining in pits, diversion boxes, and pipelines is unknown, a volume estimate for pits and diversion boxes was developed based on their surface area. Operations records show that these structures were well flushed and it is assumed that little or no waste remains except waste adsorbed to surfaces. A volume estimate for pipelines was developed based on the length and size of pipelines in WMA C. For the waste pipelines Base Case, the volume is taken from RPP-PLAN-47559, which assumed the pipelines were only 5 percent full, except for the cascade lines and one transfer line which were assumed to be plugged and therefore completely full.

2.3.6 Updated Residual Waste Inventory Estimates Based on Post-Retrieval Sampling

After the completion of the modeling for WMA C PA, waste from six additional SSTs have been retrieved (C-101, C-102, C-105, C-107, C-111 and C-112). To date, post-retrieval samples have been obtained for five of those tanks (C-101, C-102, C-107, C-111 and C-112).[24] The discussion below provides a comparison of the WMA C PA inventory estimates and the BBI inventory estimates based on post-retrieval samples for those five SSTs.

The tank C-101 2017 radionuclide inventory (Table 2-6) is approximately a factor of 3 greater than the found in the 2014 inventory. All nuclides, with four exceptions (^{244}Cm, ^{243}Cm, ^{241}Am and ^{243}Am), showed increased radioactivity. Of note, ^{99}Tc, ^{90}Sr, ^{237}Np, ^{235}U, and ^{137}Cs Ci quantities increased. The inventory basis for ^{99}Tc, ^{90}Sr, ^{237}Np, ^{235}U, and ^{137}Cs were samples collected from the tanks.

A review of the tables shows that tank C-102 (Table 2-6) had a significantly higher total inventory and subsequently higher Ci quantities of various nuclides. Curie quantities of ^{99}Tc, ^{90}Sr, ^{79}Se, ^{63}Ni, ^{3}H, ^{237}Np, ^{235}U, ^{14}C, and ^{137}Cs were based on sample data and were greater than the inventory issued for the performance assessment. Other nuclides which show increased activity were based on the HDW model and thus are more uncertain than data from samples.

The tank C-107 2017 radionuclide inventory (Table 2-6) is approximately a factor of 2 lower than the 2014 inventory. Of note, ^{99}Tc, ^{90}Sr, ^{241}Am, ^{239}Pu, and ^{137}Cs Ci quantities decreased.

The tank C-111 inventory (Table 2-6) from the 2016 inventory indicates the total Ci are reduced by an order of magnitude. However, some radionuclides were reported as having increased inventories. Nuclides including ^{232}Th, ^{228}Ra, increased significantly. The basis for ^{232}Th is a sample and ^{228}Ra was calculated from ^{232}Th. A daughter of ^{232}Th is ^{228}Ra. The PA reported tank C-111 contributed to the dose in the acute and chronic exposure scenarios for the hypothetical human intruder. Major contributors in various pathways were ^{137}Cs and ^{90}Sr. The decrease in inventory was a factor of 50 and 7 less for each nuclide respectively. Also, ^{239}Pu and ^{241}Am are major contributors to acute and chronic intruder doses after 500 years post closure. The nuclide inventories decreased by a factor of approximately 37 and 11, respectively.

The tank C-112 2017 radionuclide inventory (Table 2-6) is approximately a factor of 30 greater than the 2014 inventory. Of note, ^{99}Tc, and ^{137}Cs Ci quantities decreased, while the Ci quantities of ^{90}Sr, ^{241}Am, and ^{239}Pu increased. The ^{239}Pu increase was negligible; the increase in the total inventory is due almost entirely to ^{90}Sr.

The following paragraph summarizes information provided in RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates." It must be noted that a key difference in inventories for C-102 and C-111 between the 2014 estimates and the 2017 estimates is the actual volume retrieved vs. the assumed volume for the 2014 PA inventory. Tanks C-107 and C-112 used final volume estimates versus preliminary volume estimates in the 2014 PA. Also, the 2014 PA radionuclide inventory estimates for C-101, C-102, C-111 and C-112 were primarily sample based template estimates (based on sample results for other tanks with the same waste types) and model estimates. For tanks C-102, C-105 and C-111, retrieval

[24] DOE anticipates obtaining post-retrieval samples for tank C-105 in the near future. Because more waste was retrieved from C-105 than assumed in the WMA C PA, the WMA C PA analysis remains bounding for C-105.

was in progress and samples had not been obtained for inclusion in the 2014 PA and for C-101 and C-112, laboratory analyses were in progress. Therefore, these analyses were not included in the 2014 PA as well. Many of the 2014 C-107 radionuclide inventories were based on 2001 sample results and the tank C-105 inventory was based on 1995 and 1986 sample results. All 2017 values for these tanks were changed consistent with post-retrieval sample analytical results. Although final post-retrieval samples have not yet been obtained for tank C-105, samples were obtained in 2015, and 2017 BBI values are based on these sample results and the previous estimated waste volume. Table 2-6 compares the PA inventory to the assumed post-retrieval inventory included in the 2017 BBI.

In summary, a comparison of the total tank inventories for the WMA C PA inventory and the post-retrieval sample inventories is provided in Table 2-5. The summed radionuclide inventories for Tanks C-101, 102, 107, 111 and 112 are shown in this table. The data indicate that overall the total inventory of WMA C tanks is lower compared to values used in the PA and the total inventories for the key radionuclides is lower compared to values used in the PA. A comparison of the WMA C PA model results and the post-retrieval sample inventories is conducted in Sections 5.2, 5.3, and 6.5 of this Draft WIR Evaluation. This comparison demonstrates that the residual inventories based on the post-retrieval samples do not significantly change the results of the WMA C PA, which is part of the basis of this Draft WIR Evaluation.

2.3.7 Residual Waste Stabilization

The TC&WM EIS Record of Decision (78 FR 75913, "Record of Decision: Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington") was published on December 13, 2013. It states the following:

> "SST closure operations include filling the tanks and ancillary equipment with grout to immobilize the residual waste. Disposal of contaminated equipment and soil will occur on site. The tanks will be grouted and contaminated soil may be removed. The SSTs will be landfill-closed, which means they will be stabilized, and an engineered modified RCRA Subtitle C barrier put in place followed by post-closure care."

WMA C closure is anticipated to occur during the next decade, at which time the tanks will be filled with grout and the WMA C will be covered with a final closure barrier. However, while the tanks most likely will be filled with grout following retrieval of the waste in the tanks, the final closure barrier may be delayed because of the proximity to nearby SSTs and DSTs just to the east and southeast of WMA C. The following sections summarize information provided in RPP-RPT-44042, "Recharge and Waste Release within Engineered System in Waste Management Area C" and RPP RPT-46879, "Corrosion and Structural Degradation within the Engineered System in Waste Management Area C."

Table 2-6. Comparison of the Waste Management Area C Performance Assessment Inventory and the Post-Retrieval Inventory for Tanks C-101, C-102, C-107, C-111 and C-112. (2 sheets)

	C-101		C-102		C-107		C-111		C-112	
Nuclide	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**
^{227}Ac	1.58E-06	2.01E-06	1.93E-02	2.20E-05	6.20E-06	2.67E-05	1.82E-05	5.92E-06	4.57E-06	2.16E-05
^{241}Am	9.91E+00	5.74E+00	2.12E+01	1.69E+01	3.70E+02	1.32E+01	8.32E+01	7.74E+00	9.42E-01	1.99E+01
^{243}Am	1.43E-03	5.95E-04	7.93E-04	1.22E-03	3.86E-02	1.35E-03	1.15E-02	4.25E-05	9.72E-05	1.55E-04
^{14}C	2.76E-03	3.50E-03	9.88E-04	8.23E-03	2.16E-02	3.15E-02	1.04E-01	3.90E-03	1.60E-02	1.74E-02
^{113m}Cd	1.47E-03	1.87E-03	1.78E-02	5.01E-03	2.50E-03	3.64E-03	5.99E-02	8.06E-04	1.84E-03	2.94E-03
^{243}Cm	1.86E-05	7.73E-06	6.22E-05	1.57E-05	5.02E-04	1.76E-05	1.82E-03	5.53E-07	1.26E-06	2.02E-06
^{244}Cm	3.32E-04	1.38E-04	1.28E-03	2.80E-04	8.95E-03	3.14E-04	3.26E-02	9.88E-06	2.25E-05	3.61E-05
^{60}Co	1.76E-04	2.24E-04	2.14E-01	5.76E-04	9.14E-04	1.33E-03	1.03E-01	2.95E-04	6.75E-04	1.08E-03
^{137}Cs	3.61E+02	1.97E+03	8.07E+01	5.72E+02	2.32E+03	2.17E+02	7.14E+03	1.45E+02	7.66E+02	5.70E+02
^{152}Eu	6.38E-05	8.10E-05	1.26E-04	1.93E-04	1.35E-04	1.97E-04	5.38E-02	4.37E-05	1.00E-04	1.60E-04
^{154}Eu	2.77E-03	3.52E-03	1.36E-01	8.62E-03	5.70E-03	8.31E-03	2.41E+00	1.84E-03	4.22E-03	6.72E-03
^{155}Eu	4.69E-04	5.95E-04	2.62E-02	1.53E-03	8.66E-04	1.26E-03	3.70E-01	2.80E-04	6.39E-04	1.02E-03
^{3}H	2.45E-02	3.11E-02	2.15E-05	8.29E-02	1.44E-02	1.41E-02	2.58E+00	4.66E-03	1.06E-02	5.58E-02
^{129}I	5.55E-05	2.72E-03	2.56E-03	1.60E-03	4.07E-02	2.98E-03	1.41E-02	1.56E-05	3.57E-05	5.70E-05
^{93m}Nb	1.83E-05	4.04E-05	1.10E-02	1.15E-04	8.45E-02	2.14E-01	9.78E-02	4.75E-02	6.26E-02	1.73E-01
^{59}Ni	7.23E-04	9.18E-04	1.62E-01	2.60E-03	1.18E-03	1.72E-03	1.40E+00	3.80E-04	8.69E-04	1.39E-03
^{63}Ni	5.53E-02	5.52E+01	1.36E+01	5.63E+02	1.46E-01	3.00E+02	1.13E+02	3.44E+00	1.08E-01	3.50E+01
^{237}Np	3.45E-04	2.48E-02	5.16E-05	4.03E-03	2.08E-04	2.40E-02	3.32E-03	1.31E-03	1.54E-04	2.16E-02
^{231}Pa	2.48E-08	3.14E-08	2.12E-03	9.90E-08	3.83E-05	5.57E-05	4.99E-05	1.23E-05	2.82E-05	4.51E-05
^{238}Pu	1.13E-01	3.03E-01	1.48E+00	5.38E-01	8.05E-01	9.91E-02	1.70E+00	8.42E-02	3.59E-02	3.66E-01
^{239}Pu	1.83E+01	1.92E+01	6.49E+01	6.30E+01	1.30E+02	1.60E+01	9.45E+01	2.53E+00	5.79E+00	6.27E+00

Table 2-6. Comparison of the Waste Management Area C Performance Assessment Inventory and the Post-Retrieval Inventory for Tanks C-101, C-102, C-107, C-111 and C-112. (2 sheets)

	C-101		C-102		C-107		C-111		C-112	
Nuclide	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**	**WMA C PA Inventory (Ci)**	**Post-Retrieval Inventory (Ci)**
^{240}Pu	1.96E+00	2.06E+00	1.55E+01	5.92E+00	1.42E+01	1.74E+00	1.85E+01	2.75E-01	6.29E-01	6.82E-01
^{241}Pu	1.54E+00	8.50E+00	4.87E+01	2.15E+01	1.10E+01	1.35E+00	3.54E+01	2.15E-01	4.91E-01	1.03E+01
^{242}Pu	2.70E-05	2.83E-05	9.00E-04	2.00E-06	1.97E-04	2.42E-05	6.54E-04	3.83E-06	8.76E-06	1.02E-02
^{226}Ra	5.90E-07	7.49E-07	2.88E-07	1.10E-05	5.95E-07	8.68E-07	4.51E-06	1.92E-07	4.40E-07	7.02E-07
^{228}Ra	2.64E-13	1.43E-12	3.64E-01	2.70E-03	9.70E-04	7.87E-05	6.54E-12	2.85E-06	2.78E-12	1.88E-11
^{79}Se	2.80E-04	4.51E-03	1.60E-06	2.34E-03	2.70E-04	3.94E-04	3.53E-03	8.73E-05	1.99E-04	3.19E-04
^{151}Sm	4.00E+00	5.08E+00	9.72E-01	1.44E+01	1.04E+04	1.51E+04	6.39E+02	2.73E+00	6.25E+00	9.98E+00
^{126}Sn	5.13E-04	7.78E-02	1.83E-04	1.82E-03	4.94E-04	7.21E-04	6.72E-03	1.60E-04	3.65E-04	5.83E-04
^{90}Sr	3.29E+03	9.13E+03	2.94E+02	4.97E+02	2.42E+04	8.38E+03	3.05E+05	4.07E+04	2.28E+02	6.44E+04
^{99}Tc	4.34E-02	7.87E-01	3.56E-03	4.26E-01	2.14E+00	8.83E-02	2.19E+00	4.97E-02	1.69E+00	2.83E-01
^{229}Th	1.33E-10	1.68E-10	1.06E-02	4.87E-10	1.89E-09	2.76E-09	3.56E-09	6.10E-10	1.40E-09	2.23E-09
^{232}Th	1.12E-12	1.43E-12	2.29E-02	2.70E-03	4.11E-03	7.87E-05	2.77E-11	2.85E-06	1.18E-11	1.88E-11
^{232}U	1.75E-06	1.76E-05	2.83E-02	3.58E-05	2.20E-06	1.50E-06	2.22E-05	1.97E-07	4.50E-07	7.19E-07
^{233}U	1.71E-07	1.73E-06	2.17E+00	3.14E-01	2.15E-07	1.47E-07	4.80E-05	1.92E-08	4.39E-08	3.96E-02
^{234}U	1.69E-01	1.70E+00	1.13E-01	1.95E-01	2.07E-01	1.42E-01	7.74E-01	2.90E-02	4.23E-02	6.77E-02
^{235}U	7.54E-03	7.78E-02	4.27E-03	8.40E-03	9.24E-03	6.33E-03	3.37E-02	9.74E-04	1.89E-03	2.20E-02
^{236}U	1.93E-03	1.95E-02	1.43E-03	5.48E-03	2.31E-03	1.58E-03	1.32E-02	6.45E-04	4.73E-04	5.88E-03
^{238}U	1.72E-01	1.73E+00	9.78E-02	2.01E-01	2.11E-01	1.44E-01	7.88E-01	6.65E-03	4.32E-02	4.89E-01
^{93}Zr	3.35E-05	4.25E-05	4.22E-03	1.21E-04	1.55E-01	2.25E-01	1.81E-01	4.99E-02	1.14E-01	1.82E-01

PA = Performance Assessment WMA = Waste Management Area

2.3.7.1 Stabilization of Tank and Selected Components with Grout Fill

After retrieval of the waste, the SSTs and some of the ancillary structures and components (i.e., catch tank C-301, 244-CR vault, and diversion boxes but not pipelines) within WMA C will be filled with grout. Grout is formed from materials such as cement, fly ash, fine aggregate, and water to create a free-flowing material that can be used to fill the tanks after waste retrieval is completed. The grout hardens in the tanks to stabilize the residual waste and provide structural stability for landfill closure of the tank farm.

Pacific Northwest National Laboratory (PNNL) has conducted numerous studies to understand release of ^{99}Tc, chromium, and uranium from residual waste left in the WMA C SSTs (C-103, C-104, C-106, C-108, C-202, C-203, and C-204) after closure using distilled water, as well as water in equilibrium with a young grout and with an aged grout. The results of these studies are provided in Section 5.0 of the WMA C PA. Figure 2-25 shows the conceptual model of an SST shortly after the emplacement of the grout, while Figure 2-26 shows the conceptual model of an aged tank system. The final engineered barrier is not shown in either of these figures.

2.3.8 Engineered Surface Barrier

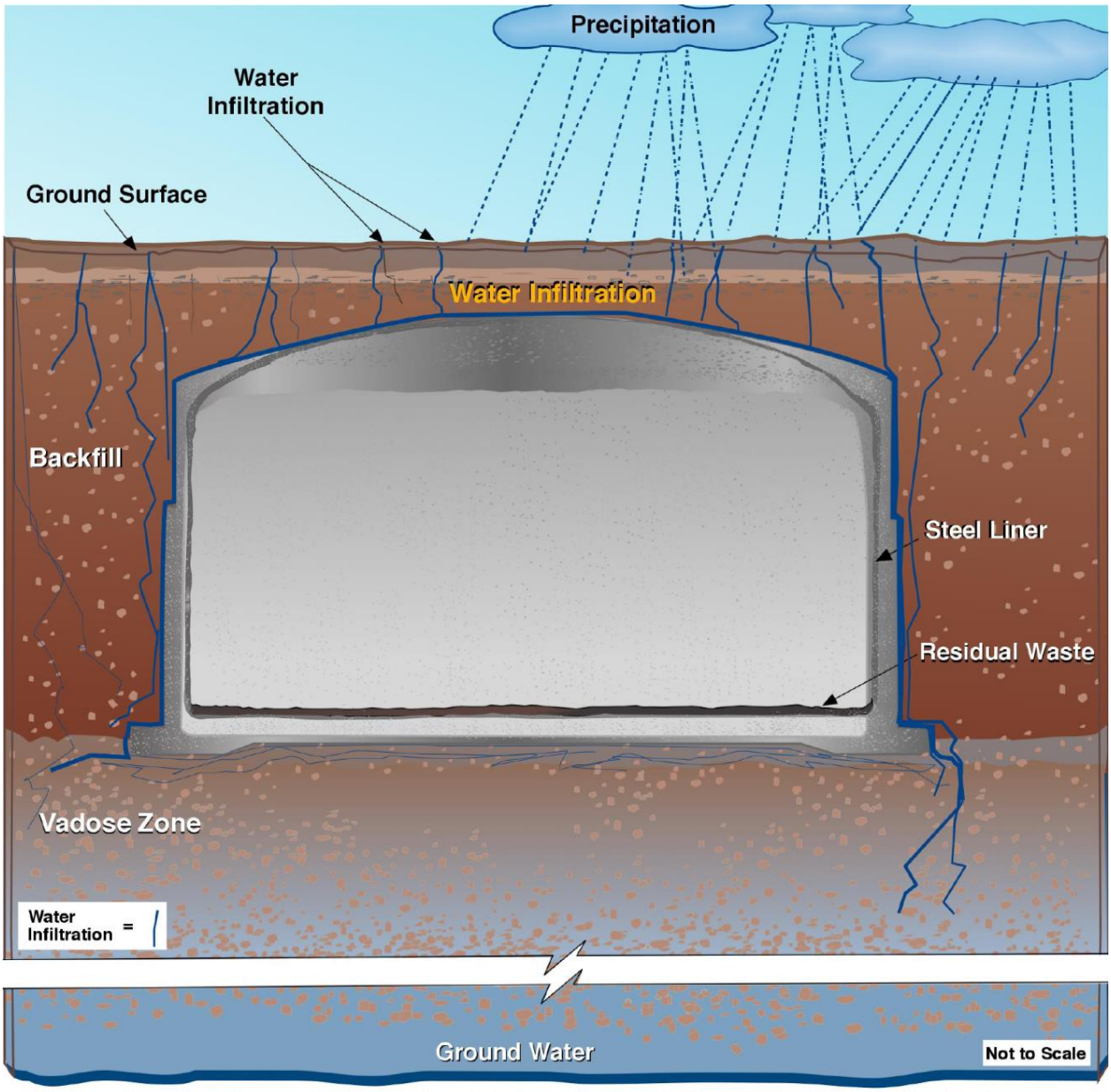
After the tanks and ancillary structures have been grouted, the closure plan approach will be to construct an engineered surface barrier over the WMA C. DOE/RL-93-33, Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Area, provides the baseline design of a modified RCRA Subtitle C barrier. The surface barrier does not currently exist, but the barrier will be designed to prevent direct contact exposure to the waste and include a vegetated surface layer of fine-grained soils to retain moisture and encourage evapotranspiration, thereby minimizing infiltration and vadose zone transport of contaminants to groundwater. The RCRA-compliant barrier generally consists of a layer of clay, geo-membrane material, and sand and gravel. The RCRA-compliant barrier will be modified by the addition of ~15 ft of soil to provide shielding from radioactive material and to deter intrusion. Prior to barrier construction, specific closure barrier designs will be evaluated and the most appropriate closure barrier design will be selected for construction.

Figure 2-27 provides the generic modified RCRA Subtitle C barrier baseline design from DOE/RL-93-33. The expected performance of this design configuration is used in building the fate and transport model. The performance of the barrier with regard to recharge comes from the upper 1 m of the barrier which contains the silt loam layer. This layer collects and holds the precipitation that falls over the site during the winter months; then, during the summer months, evapotranspiration takes place that removes the stored precipitation from an assumed silt loam layer. If the silt loam layer is thick enough, the barrier will continue to perform even after fires have burned off the vegetation (PNNL-18934, “The Effects of Fire on the Function of the 200-BP-1 Engineered Surface Barrier”) and extreme precipitation events (PNNL-14143, “The Hanford Site 1000-Year Cap Design Test”).

For a degraded surface barrier, a range of potential recharge rates can be envisioned. PNNL-14744, “Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment,” investigated the possibility of the most likely natural failure mechanisms (i.e., bioturbation of the silt loam layer, wind erosion, and accretion of windblown sand). With

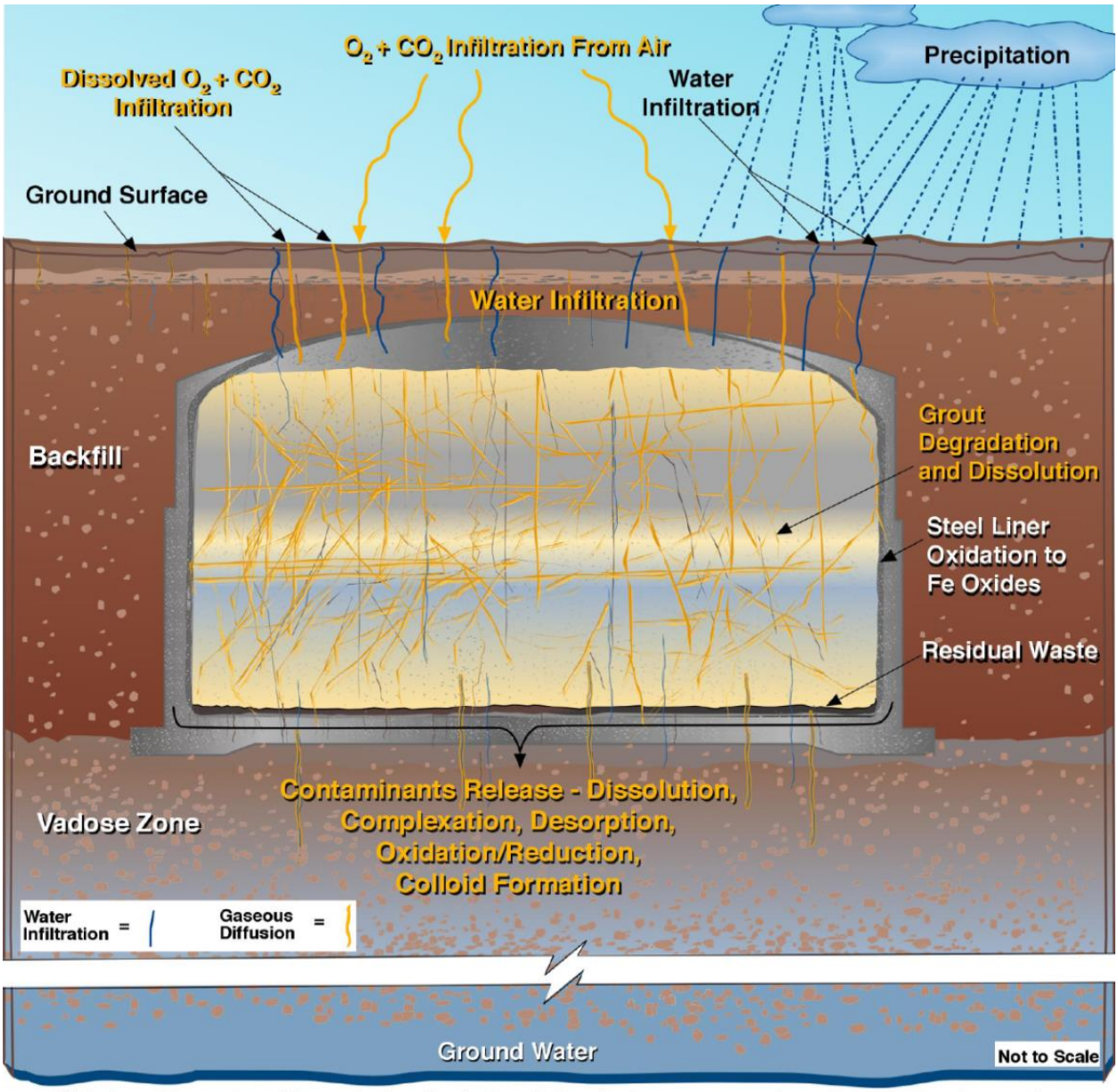
appropriate design considerations, PNNL-14744 argues that the failure possibility of these natural systems is quite low, and the emplaced silt-loam soils will continue to perform for as long as they remain in place. Based on these arguments, PNNL-14744 concludes that the long-term effectiveness of the surface barrier would continue to limit recharge rates to less than 0.1 mm/yr for thousands of years.

Figure 2-25. Conceptual Model of Tank Filled with Cementitious Grout.



This is a schematic to illustrate infiltration of precipitation which is typically through slow gravitational drainage.

Figure 2-26. Conceptual Model of Cementitious Grouted Tank Aging.



This is a schematic to illustrate the physical and chemical processes acting on grouted tank over time

These arguments are further buttressed by the monitoring of the Hanford Barrier documented in PNNL-18845, "200-BP-1 Prototype Hanford Barrier – 15 Years of Performance Monitoring," which reports 15 years of data collection on the following:

- Water-balance monitoring, consisting of precipitation, runoff, soil moisture storage, and drainage measurements with evapotranspiration calculated by difference
- Stability monitoring, consisting of asphalt-layer-settlement, basalt-side-slope-stability, and surface-elevation measurements

- Vegetation dynamics
- Animal use.

The 200-BP-1 prototype Hanford Barrier was installed in 1994 over the 216-B-57 crib.

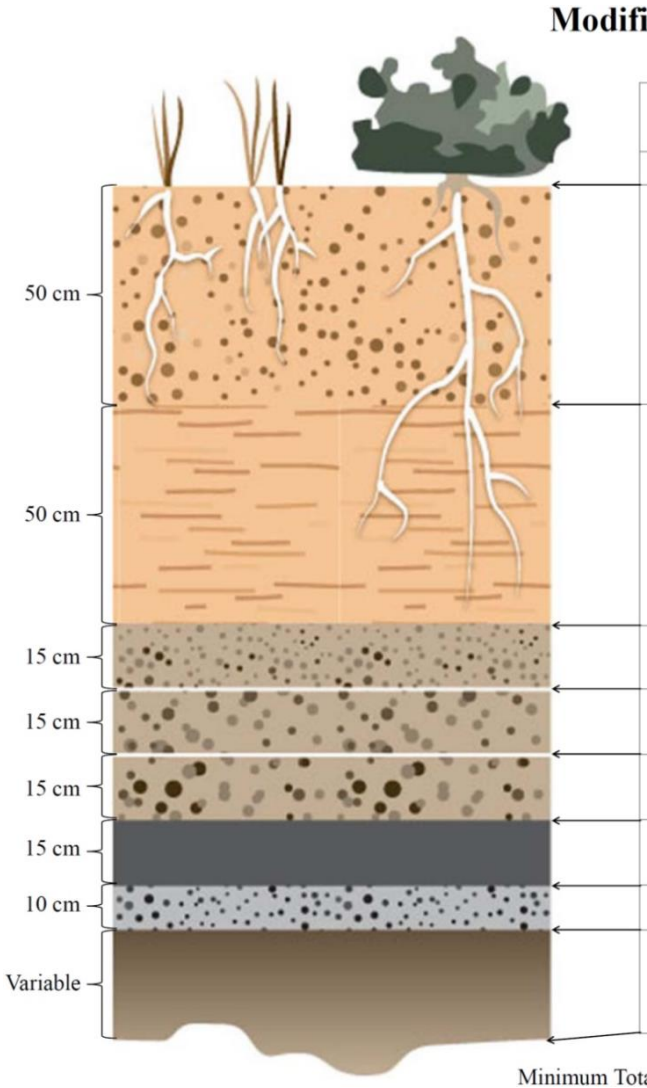
The modified RCRA-compliant closure barrier being considered for WMA C will be designed to meet or exceed the regulatory requirements for applications at Category 1 LLW and Category 3 LLW (NRC Class C waste) facilities. The barrier design criteria are expected to be similar to that described in DOE/RL-93-33 for the Modified RCRA Subtitle C barrier, which are summarized in Table 2-7.

Erosion Protection. Water and wind erosion surface barrier material can impact the integrity of a surface barrier. The low precipitation, the low intensity of precipitation events, and the absence of surface run-on features at the Hanford Site all support the assumption that water erosion will not be a significant factor at WMA C. Wind erosion, however, has been observed at the Hanford Site, primarily in exposed sandy areas and in the sand dunes to the southeast of WMA C.

DOE/RL-99-11, 200-BP-1 Prototype Barrier Treatability Test Report, evaluates the potential for wind erosion for surface barriers. DOE/RL-99-11 calculates that the worst-case potential erosion rate would be to lose 15 cm of silt loam in 500 years. The analysis method was derived for agricultural soils and did not consider the benefits of the pea gravel admix. Extensive wind tunnel studies performed at the Hanford Site show that a mixture of fine-grained soil and pea gravel significantly reduced erosion due to wind forces. Soil/pea gravel armoring can reduce erosion rates from 96.5 percent to more than 99 percent at wind speeds of 45, 56, and 67 mi/hr (PNL-8478, “Soil Erosion Rates Caused by Wind and Saltating Sand Stresses in Wind Tunnel”; WHC-EP-0673, “Permanent Isolation Surface Barrier Development Plan”). With the lower reduction value (96 percent), the wind erosion potential would be 15 cm in 12,500 years. The experience at the Prototype Hanford Barrier (Wing and Gee 1994, “Quest for the Perfect Cap”) suggests that wind erosion will be negligible within months after the barrier surface is vegetated. Therefore, for all intents and purposes, wind erosion of the silt loam should be minor and is assumed to be so for the WMA C vegetated, closure surface barrier.

The engineered barrier system surface will be seeded and fertilized to promote plant growth. Vegetation will minimize erosion and accelerate removal of water from the water storage layer through transpiration. Long-term considerations include periods of drought or fire so erosion and hydrologic modeling studies have assumed a poor stand of vegetation. The vegetation will consist of local plant species based on vegetation studies performed for Hanford Site disturbed areas.

Figure 2-27. Generic Modified RCRA C Baseline Design from DOE/RL-93-33.



Layer Number	Thickness cm (in)	Layer Description	Function
0	N/A	Cover Vegetation	Mixed perennial grasses to enhance transpiration
1	50 (20)	Silt loam with pea gravel admix	The topsoil material was identified for optimal water retention properties and should provide a good rooting medium for cover vegetation. The pea gravel is designed to minimize wind erosion of the silt loam without significantly affecting its moisture retention capabilities. **(thickness may be increased to provide [additional] protection against inadvertent intruder [DOE/RL-93-93, Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Area])**
2	50 (20)	Compacted topsoil	Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity. Compaction of this layer is intended to retard the rate of infiltration of soil moisture. The extended residence time of moisture in Layer 2 will increase the amount of moisture removed by evapotranspiration **(thickness may be increased to provide [additional] protection against inadvertent intruder [DOE/RL-93-93])**
3	15 (6)	Sand Filter	This layer is part of a two-layer graded filter designed to prevent the migration of topsoil particles into Layer 5.
4	15 (6)	Gravel Filter	Same as Layer 3.
5	15 (6)	Lateral drainage aggregate	The lateral drainage layer will intercept and divert moisture along a 2% slope to the margin of the cover for collection and/or discharge.
6	15 (6)	Asphaltic concrete with spray applied asphalt coating	This layer will function as a hydrologic barrier and as a biointrusion barrier.
7	10 (4)	Asphalt base course	The function of the material in this layer is to provide a stable base for placing and supporting the asphalt layer.
8	Variable	Grading Fill	This layer will provide a smooth, level subgrade for construction of the overlying layers. **(thickness may be increased to provide [additional] protection against inadvertent intruder [DOE/RL-93-93])**

Minimum Total Thickness = 1.7 m

Reference: DOE/RL-93-33, Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Area.
RCRA = Resource Conservation and Recovery Act of 1976

Table 2-7. Summary of Design Criteria for the Modified RCRA Subtitle C Barrier.

1	Minimize moisture infiltration through the barrier.
2	Design a multilayer barrier of materials that are resistant to natural degradation processes.
3	Design a durable barrier that needs minimal maintenance during its design life.
4	Design a barrier with a functional life of 500 years.
5	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).
6	Prevent burrowing animals from accessing and mobilizing contamination.
7	Ensure that the top of the waste is at least 16 ft below final grade or include appropriate design provisions to limit inadvertent human intrusion.
8	Facilitate drainage and minimize surface erosion by wind and water.
9	Design the low-permeability layer of the barrier to have a permeability less than or equal to any natural subsoil present.
10	Design the barrier to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).
11	For frost protection, the lateral drainage layer and the low-permeability asphalt layer must be located at least 2.5 ft below final grade.

RCRA = Resource Conservation and Recovery Act of 1976

Post-Closure Inadvertent Intrusion Protection. DOE/RL-93-33 includes design criteria 4 and 7 listed in Table 2-7 as part of the design of the Modified RCRA Subtitle C barrier to meet safety requirements comparable to the requirements of 10 CFR 61.42 for the protection of individuals from inadvertent intrusion, and requirements in Chapter IV of DOE M 435.1-1, including requirements that are analogous to requirements for licensed facilities set forth in Title 10, CFR, Part 61, Subpart D, § 61.52, Land disposal facility operation and disposal site closure (10 CFR 61.52) for the protection of the inadvertent intruder. Additionally, to further deter the inadvertent intrusion of humans into the waste, a marker system will be used to warn future generations of the dangers of the buried waste. Permanent markers that identify the potential exposure hazards will be installed at all corner boundaries of the closed facility. DOE is expected to maintain active control of the Hanford Site (using fences, patrols, alarms, and monitoring instruments). Site information will be provided on an Internet website, U.S. Geological Survey maps, libraries, and other information repositories that would be readily available to the public. Land-use restrictions and institutional controls will be placed on the closed WMA C facility and its adjacent buffer zone to preclude development at the site.

The closed WMA C facility will clearly delineate the boundaries of the surface barrier by providing a distinct contrast with the surrounding terrain. The side slopes are engineered structures that will be obvious that the structure had been built by humans. These distinct side slopes in combination with warning signs are intended to minimize the risk of human intrusion.

As discussed above, the WMA C engineered surface barrier system also contains a bio-intrusion layer consisting of gravel. The function of this layer is to prevent small burrowing animals and

rodents from penetrating the underlying barrier components and the waste material. Barrier studies at the Hanford Site have shown that a thin layer of gravel is effective in preventing animals and rodents from penetrating underlying waste materials (WHC-EP-0673). The bio-intrusion material will consist of gravel screened from the local available alluvium at the Hanford Site. The alluvium gravels at the Hanford Site are composed of granite, quartz, and other durable minerals that make it ideally suited for long-term applications.

3.0 WIR CRITERIA

Section Purpose

The purpose of this section is to provide the evaluation criteria from DOE M 435.1-1 for a potential WIR determination for the residuals, tanks and ancillary structures in the WMA C at closure at the Hanford Site.

Section Contents

This section provides an overview of the WIR criteria contained in DOE M 435.1-1.

Key Points

- Applicable criteria appear in DOE M 435.1-1, *Radioactive Waste Management Manual*.

3.1 DOE M 435.1-1

DOE M 435.1-1 states, in relevant part, that waste that is determined to be incidental to reprocessing is not HLW, and shall be managed under DOE regulatory authority in accordance with the requirements for LLW. In accordance with DOE M 435.1-1, DOE may determine that waste is incidental to reprocessing of SNF where an evaluation shows that the waste meets the following criteria. The wastes:

1. Have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical; and
2. Will be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR 61 Subpart C; and
3. Are to be managed, pursuant to DOE authority under the AEA, and in accordance with the provisions of Chapter IV of DOE M 435.1-1, provided the waste 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[.] [25]

As will be demonstrated in the next three sections of this Draft WIR Evaluation, DOE has evaluated the WMA C stabilized tanks, residuals and ancillary structures, at closure of the WMA C, against these criteria, and, for the reasons presented, this Draft WIR Evaluation shows that the tanks and ancillary structures and waste residuals meet the applicable criteria and can be managed as LLW.

[25] This provision in DOE M 435.1 also includes the following language: "or will meet alternative requirements for waste classification and characterization as DOE may authorize." DOE is not using or relying upon this language in this document to any degree whatsoever.

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4.0 WASTE HAS HAD KEY RADIONUCLIDES REMOVED TO THE MAXIMUM EXTENT TECHNICALLY AND ECONOMICALLY PRACTICAL

Section Purpose

This section demonstrates that the WMA C residual waste, tanks, and ancillary structures, upon completion of waste removal activities, will have had key radionuclides removed to the maximum extent technically and economically practical in accordance with DOE M 435.1-1.

Section Contents

Section 4.2 identifies the key radionuclides for this Draft WIR Evaluation. Section 4.3 describes the processes used to remove the key radionuclides to the maximum extent technically practical. Section 4.4 provides a cost/benefit analysis demonstrating that no further retrieval is economically practical. Section 4.5 summarizes and concludes that, at closure, the key radionuclides will have been removed to the maximum extent that is technically and economically practical.

Key Points

- The list of key radionuclides for WMA C identifies the radionuclides that could reasonably be expected to exist in the WMA C waste tanks and ancillary structures and that contribute significantly to the radiological risk to workers, the public and the environment, taking into account scientific principles, knowledge, and expertise.
- The list of key radionuclides for WMA C includes all radionuclides important to meeting the performance objectives in 10 CFR 61 Subpart C and all radionuclides in Tables 1 and 2 of 10 CFR 61.55.
- Waste retrieval methodologies to date have removed key radionuclides to the maximum extent technically practical.
- Waste retrieval methodologies to date have removed key radionuclides to the maximum extent economically practical.

4.1 BACKGROUND

The first criterion in DOE M 435.1-1 states that to determine whether waste is incidental to reprocessing using the evaluation method, the wastes:

> "Have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical[.]"

Section 4.2 below discusses the identification of the key radionuclides. Section 4.3 discusses their removal to the limits of the best available technologies. Section 4.4 provides a cost/benefit analysis of additional retrievals beyond what has been completed. Section 4.5 provides a summary of the removal of key radionuclides, and a conclusion statement for this section.

4.2 KEY RADIONUCLIDES

DOE views key radionuclides to be those that, using a risk-informed approach, contribute most significantly to radiological dose to workers, the public, and the environment. As noted in Section II.B of DOE G 435.1-1:

> "Although key radionuclides are not defined by the NRC in either the Denial of Petition for Rulemaking or the letter from R. Bernero to J. Lytle, dated March 2, 1993, it is generally understood that key radionuclides applies to those radionuclides that are controlled by concentration limits in 10 CFR 61.55. Specifically these are: long-lived radionuclides, ^{14}C, ^{59}Ni, ^{94}Nb, ^{99}Tc, ^{129}I, ^{241}Pu, ^{242}Cm, and alpha emitting transuranic nuclides with half-lives greater than five years and; short-lived radionuclides, ^{3}H, ^{60}Co, ^{63}Ni, ^{90}Sr, and ^{137}Cs. In addition, key radionuclides are those that are important to satisfying the performance objectives of 10 CFR Part 61, Subpart C."

To identify the key radionuclides applicable to WMA C waste residuals, this draft WIR Evaluation considers those identified in the WMA C PA [26](i.e., those important to satisfying the performance objectives of 10 CFR Part 61, Subpart C), as well as those derived from 10 CFR 61.55.

4.2.1 Performance Assessment Radionuclides

DOE has included in the list of key radionuclides those that may be important to meeting the performance objectives of 10 CFR 61 Subpart C, because they contribute to the dose to workers, the public, and/or the inadvertent intruder based on the WMA C PA.

Radiological constituents of potential concern were identified for the WMA C PA using two types of screening evaluations: (1) one that considered inventory-related information including radionuclide half-lives, the ingrowth of constituents from chain decay, and activity level (discussed in Section 2.0 of the WMA C PA), that resulted in 43 radionuclides for consideration in the WMA C PA (Table 2-5), and (2) another that considered information on the groundwater pathway including travel times to the accessible environment and constituent-specific mobility, as discussed in the following sections.

[26] A performance assessment is a multi-disciplined assessment (e.g., geochemistry, hydrology, materials science, and health physics) which uses a variety of computational modeling codes to evaluate groundwater concentrations and doses at various points of assessment over time. In doing this assessment, DOE evaluates the impact of natural features (e.g., hydrology, soil properties, groundwater infiltration) and engineered barriers (e.g., closure cap, fill grout, waste tank design) on the release of radionuclides, to estimate, among other things, the potential dose to a hypothetical member of the public and a hypothetical inadvertent intruder. The results of the WMA C PA, as reported here, should not be considered limits or thresholds. As required by DOE M 435.1-1, maintenance of the WMA C PA will include future performance assessment revisions or special analyses to incorporate new information, update model codes and reflect analysis of actual residual inventories.

4.2.1.1 Key Radionuclides Based on the Groundwater Pathway

In the WMA C PA, of the list of radionuclides in the WMA C residuals, seven radionuclides (^{60}Co, ^{3}H, ^{93m}Nb, ^{222}Rn, ^{99}Tc, ^{79}Se, ^{129}I) were sufficiently mobile to arrive at groundwater during the 1,000-year compliance period following closure of the WMA C, and seven others (e.g., ^{126}Sn, ^{14}C, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) were sufficiently mobile to arrive at groundwater during the sensitivity/uncertainty analysis time frame (1,000 to 10,000 years after WMA C closure). The other radionuclides in the WMA C residual inventory were not included in further groundwater impact analyses because they would not reach the water table within the groundwater evaluation time frames.

The WMA C PA dose analysis for the groundwater pathway results in a highest total dose within the compliance time period of 4×10^{-4} mrem/yr resulting from release of ^{99}Tc (Figure 4-1). The highest total dose from the groundwater pathway within the sensitivity/uncertainty analysis time period is 0.10 mrem/yr, also resulting from release of ^{99}Tc. Based on the WMA C PA analysis for the groundwater pathway, ^{99}Tc is identified as a key radionuclide, although the dose attributable to ^{99}Tc is well below the 25 mrem/year dose to a member of the public specified in the performance objective in Chapter IV.P.(1) of M 435.1-1 and 10 CFR 61.41. Additional contributors to the total dose at long times are ^{79}Se, ^{129}I, ^{126}Sn, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U and their progeny as shown in Figure 4-1; although these radionuclides, individually and in combination, result in doses significantly below the 25 mrem/year performance objective, ^{234}U, ^{238}U and ^{129}I are considered by DOE to be key radionuclides since they contribute, along with ^{99}Tc, 95 percent of the total dose from the groundwater pathway.

4.2.1.2 Key Radionuclides Based on the Air Pathway

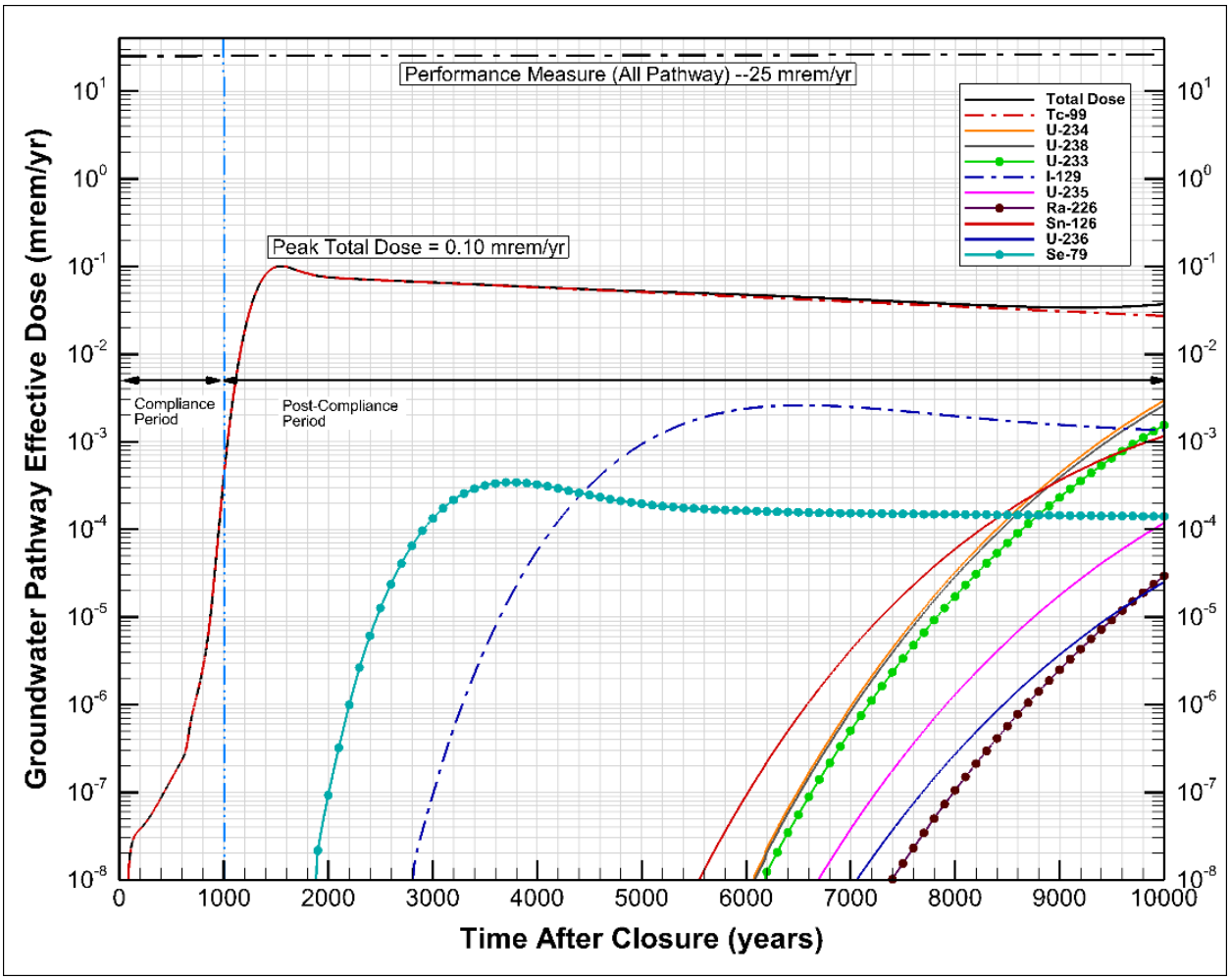
In the WMA C PA, the atmospheric release is modeled for those radionuclides that can partition into the gas phase from the dissolved phase (in water). These radionuclides are ^{14}C, ^{3}H, ^{129}I, and ^{222}Rn. For the radionuclides that are included in the air pathway performance objective, an air transport calculation is performed to calculate the concentration at a receptor located 100 meters downwind from the WMA C fence line.

Doses from radionuclides that may potentially be released in gaseous form are presented in Figure 4-2 along with the 10 mrem/yr air pathway dose performance objective from DOE M 435.1. Doses are very small, orders of magnitude below the dose performance objective, at all times. The peak dose of 2×10^{-3} mrem/yr occurs within two years of closure, with ^{3}H being the primary dose contributor. At around 100 years, ^{129}I takes over as the primary dose contributor as ^{3}H dose declines due to its short half-life. Iodine-129 persists within the tank due to its long half-life and retention in the grout (from sorption), leading to a slow continuous diffusive flux. By ~500 years the ^{129}I dose reaches a steady value of 9×10^{-6} mrem/yr, indicating that the concentration gradient in the air phase from the tank to the surface has reached a steady state.

The radon flux at the surface of WMA C is also assessed in the WMA C PA. The relative magnitude of the fluxes are the result of the initial residual inventory of ^{226}Ra and the amount of uranium inventory that decays to form ^{226}Ra and then to ^{222}Rn. The radon flux increases with time resulting from ingrowth due to decay of ^{234}U and ^{238}U inventory. The peak radon flux for

the 1,000-year compliance period is ~2 × 10^{-4} pCi/m^2/sec. At 10,000 years the peak radon flux is several orders of magnitude below the performance objective. Due to the low doses from the atmospheric pathway, only ^{3}H was considered a key radionuclide from the WMA C PA air pathway. H-3 provides over 95 percent of the dose from the air pathway.

Figure 4-1. Waste Management Area C Performance Assessment Results of the Groundwater Pathway Dose Analysis at the Maximum Point of Concentration.

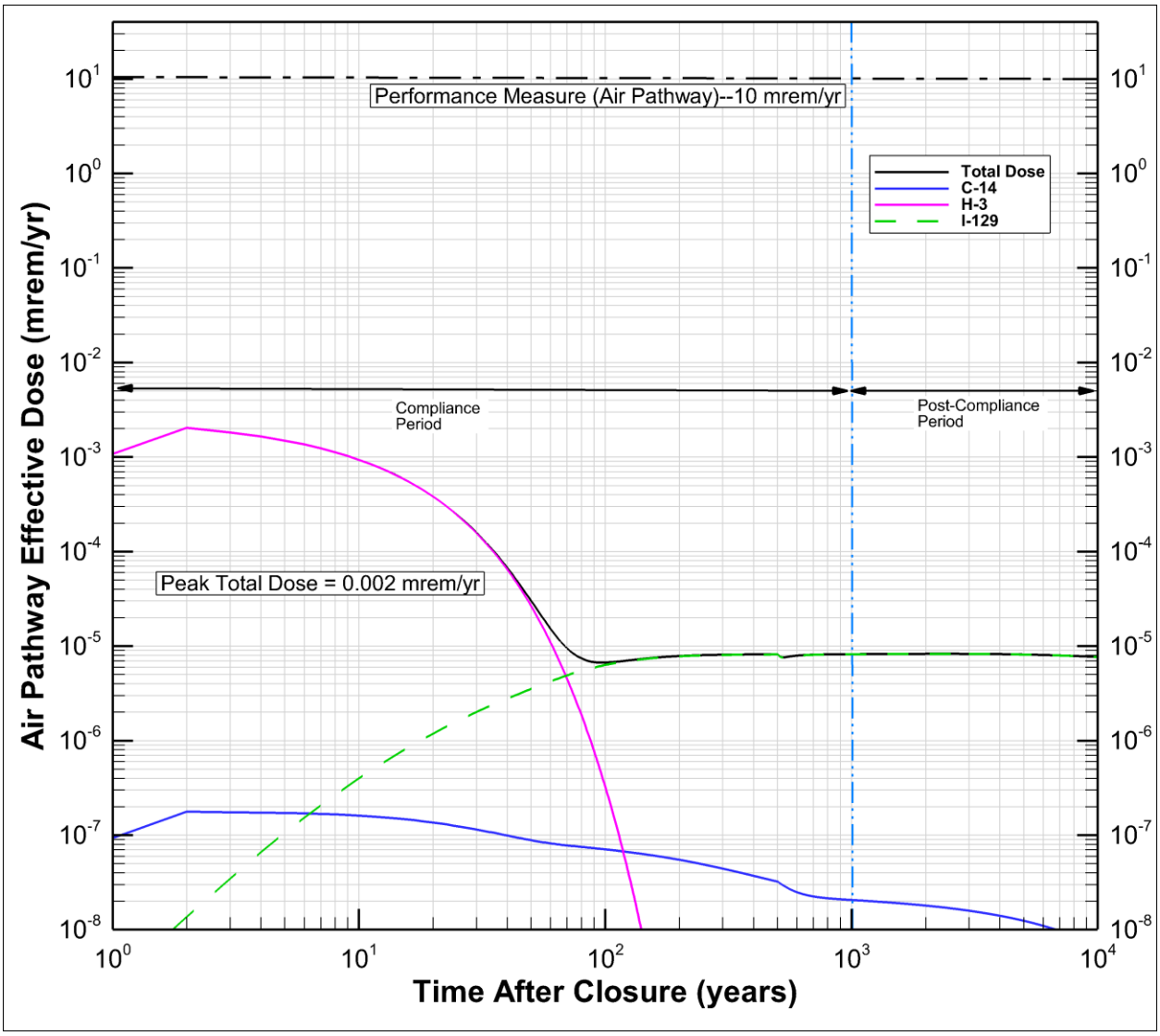


4.2.1.3 Key Radionuclides Based on the Intruder Pathway

The WMA C PA intruder scenario for acute dose is dominated by ^{137}Cs and ^{239}Pu, while the intruder scenarios for the chronic doses are dominated by ^{90}Sr, ^{137}Cs, and ^{239}Pu. The total dose generally shows a steep decline, compared to the timescales evaluated in the WMA C PA, due to short half-lives of ^{90}Sr and ^{137}Cs but becomes stable once long-lived ^{239}Pu becomes the dominant dose contributor as illustrated in Figure 4-3 for the acute exposure scenario. The dominant exposure condition for the assessment was the acute scenario, which had higher doses than the chronic exposure scenarios at 100 years after closure. At longer times (greater than ~500 years after closure), the acute scenario also produced higher calculated doses for the intrusion into waste transfer pipelines, mainly because long-lived ^{239}Pu plays a more important role in the dose

calculation. Based on the WMA C PA intruder analysis, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{241}Am and ^{240}Pu which provide over 95 percent of the intruder dose, are identified as key radionuclides.

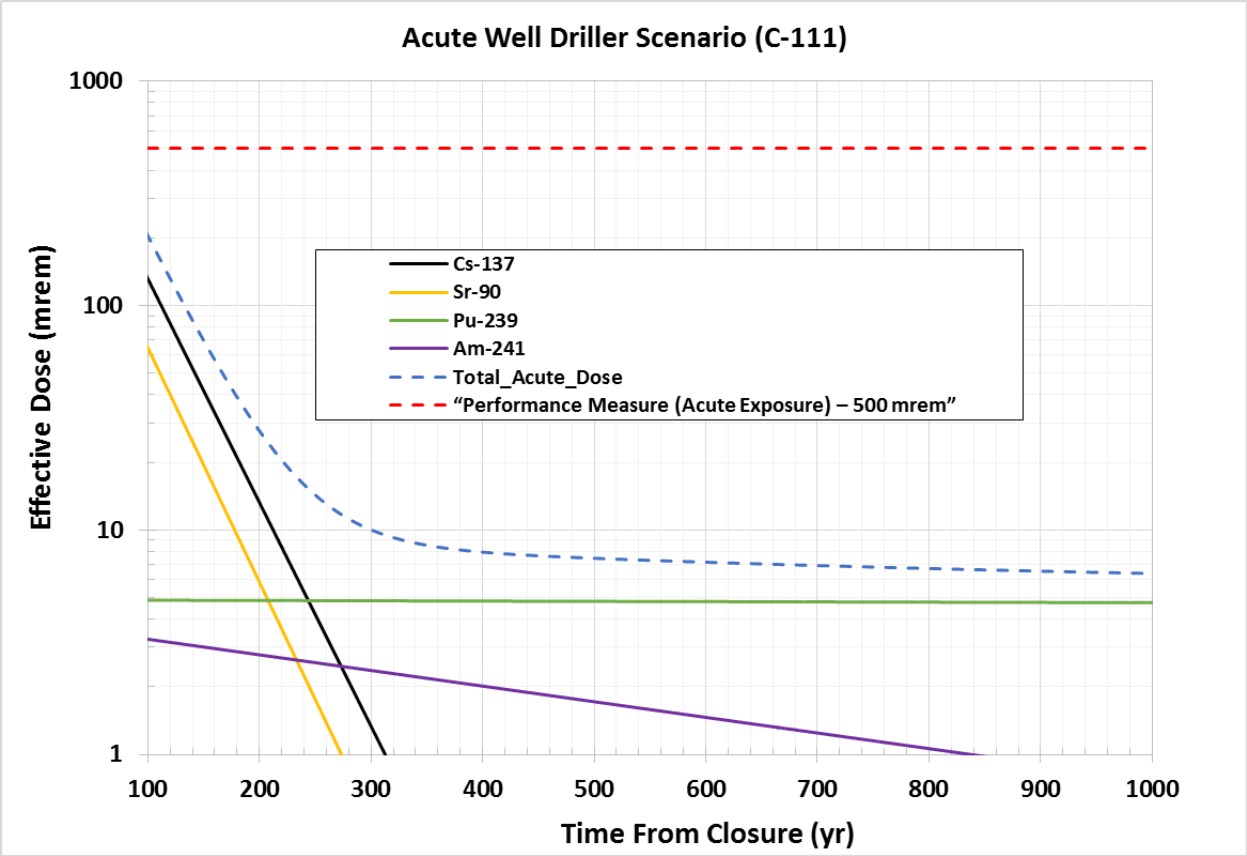
Figure 4-2. Waste Management Area C Performance Assessment Results of the Air Pathway Dose Analysis.



4.2.1.4 All-Pathways Dose

The WMA C PA all-pathways dose is a combination of dose from the groundwater pathway and air pathway. The receptor is considered to be a reasonably maximally-exposed individual and assumed to be located along the centerline of the air pathway plume and getting water from the well located at the highest concentration point in the aquifer at the 100 m boundary. The groundwater concentrations are used as the concentrations at the wellhead. This approach has been taken to maintain consistency between the groundwater protection performance objectives and the all-pathways dose performance objective, but does not take account of any dilution that may occur in the well as it is pumped.

Figure 4-3. Waste Management Area C Performance Assessment Effective Dose for the Well Driller Acute Exposure Scenario for Tank C-111 Residual Waste.

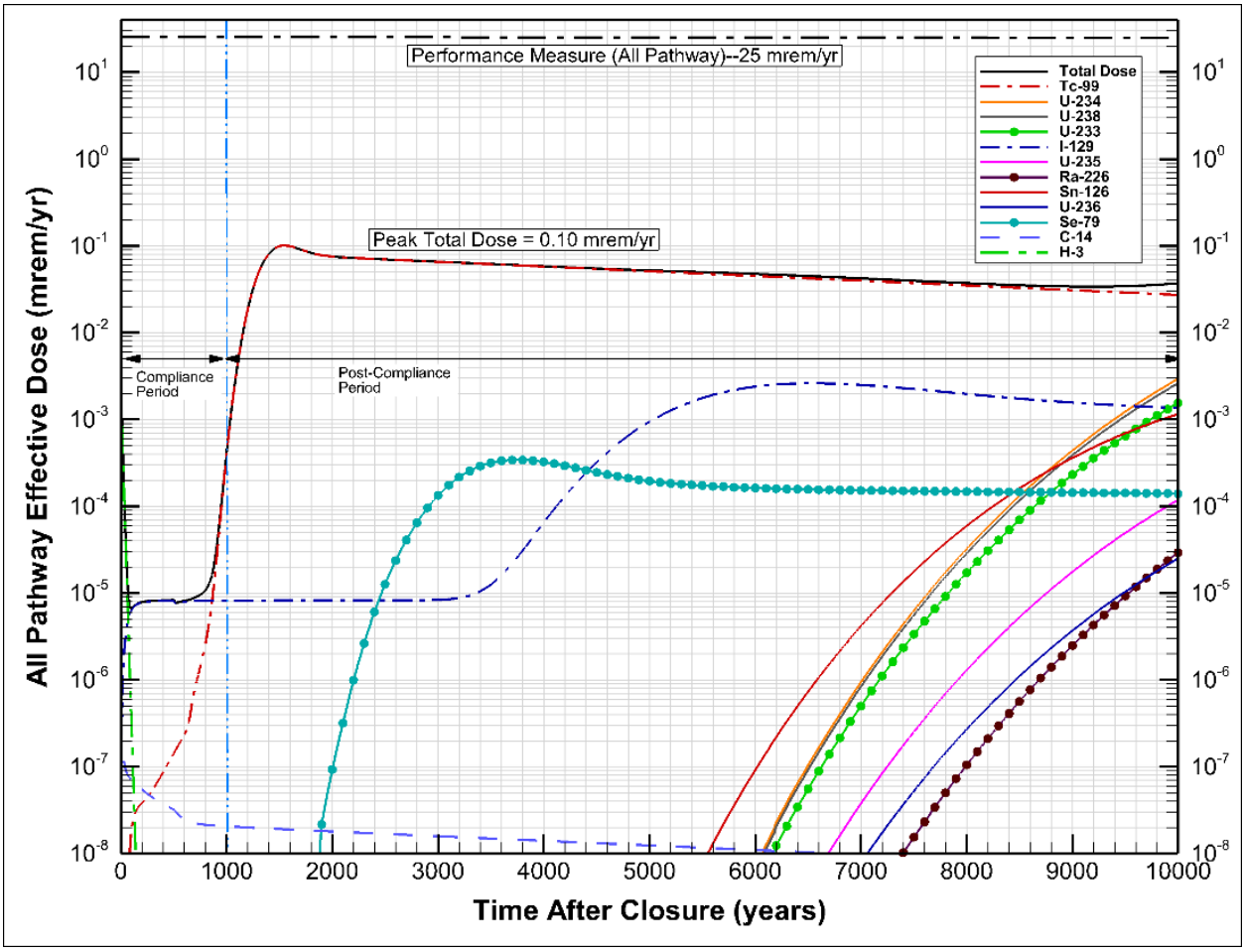


The all-pathways dose results for the groundwater and the air pathway are presented in Figure 4-4 for all radionuclides that produced a dose result within 10,000 years after closure of the WMA C. The DOE M 435.1-1 compliance time and compliance dose are also shown on the figure for comparison. The peak dose summed over all radionuclides within the compliance time period is 2×10^{-3} mrem/yr, primarily from ^{3}H release. Within the compliance time period the early dose is due to contribution of ^{3}H and ^{129}I from the air pathway, but after ~800 years the dose is dominated by ^{99}Tc contribution from the groundwater pathway. Within the sensitivity / uncertainty analysis time period (1,000 to 10,000 years after WMA C closure), the peak dose summed over all radionuclides is 0.10 mrem/yr, which occurs ~1,500 years after closure.

The dose resulting from exposure along the groundwater pathway is by far the dominant dose in the sensitivity/uncertainty analysis time period (1,000 to 10,000 years after WMA C closure) and is presented separately in Figure 4-4 along with the major dose-contributing radionuclides. The highest total dose from the groundwater pathway within the compliance time period is 4×10^{-4} mrem/yr and within the sensitivity/uncertainty analysis time period is 0.10 mrem/yr resulting from the release of ^{99}Tc. Additional contributors to the total dose at long times are ^{79}Se, ^{129}I, ^{126}Sn, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U and their progeny as shown in Figure 4-4; although these radionuclides, individually and in combination, result in doses significantly below the 25 mrem/year performance objective, ^{234}U, ^{238}U and ^{129}I were considered by DOE to be key

radionuclides since they contribute, along with ^{99}Tc, over 95 percent of the total dose from the all-pathways scenario.

Figure 4-4. Waste Management Area C Performance Assessment All-Pathways Dose Results that Includes Air and Groundwater Pathway Contributions at the Maximum Point of Concentration.



4.2.2 10 CFR 61.55 Radionuclides

In addition to those radionuclides identified as key radionuclides in the WMA C PA, DOE considers the radionuclides listed in 10 CFR 61.55 to be key radionuclides. These are specified in two separate tables within 10 CFR 61.55, and listed in Table 4-1 and Table 4-2. The concentration limits for these radionuclides are discussed in Section 6.0 of this Draft WIR Evaluation.

Table 4-1. Radionuclides in 10 CFR 61.55 Table 1.

Radionuclides (long lived)
^{14}C
^{14}C in activated metal
^{59}Ni in activated metal
^{94}Nb in activated metal
^{99}Tc
^{129}I
Alpha-emitting transuranic nuclides with half-life >5 years
^{241}Pu
^{242}Cm

Source: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

Table 4-2. Radionuclides in 10 CFR 61.55 Table 2.

Radionuclides (short lived)
Total of all nuclides with <5 year half-life
^{3}H
^{60}Co
^{63}Ni
^{63}Ni in activated metal
^{90}Sr
^{137}Cs

Source: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

4.2.3 Key Radionuclides Summary

Key radionuclides were identified from the WMA C PA analyses and are provided in Table 4-3. In addition, radionuclides and their associated limits specified in 10 CFR 61.55 were evaluated in Section 6 of this WIR. As demonstrated in Section 6, the stabilized WMA C wastes at closure are anticipated to meet concentration limits for Class C LLW as set out in 10 CFR 61.55. In fact, the concentrations of these radionuclides are at least two orders of magnitude less than their associated limits in 10 CFR 61.55. Nevertheless, the 10 CFR 61.55 radionuclides in the WMA C residuals, tanks and ancillary structures at closure are considered to be key radionuclides in this Draft WIR Evaluation, consistent with DOE G 435.1-1.

Table 4-3. Key Radionuclides for this Evaluation.

Radionuclide[a]	10 CFR 61.55 Long-Lived Radionuclides	10 CFR 61.55 Short-Lived Radionuclides	Radionuclides Important to Performance Assessment
^{3}H		X	X
^{14}C	X		
^{60}Co		X	
^{59}Ni	X		
^{63}Ni		X	
^{90}Sr		X	X
^{99}Tc	X		X
^{129}I	X		X
^{137}Cs		X	X
^{234}U			X
^{238}U			X
^{237}Np	X		
^{238}Pu	X		
^{239}Pu	X		X
^{240}Pu	X		
^{241}Pu	X		
^{242}Pu	X		
^{241}Am	X		
^{243}Am	X		
^{243}Cm	X		
^{244}Cm	X		

Nb-94 and ^{242}Cm are listed in 10 CFR 61.55 Table 2; however, these radionuclides do not exhibit significant activity in the tanks and are therefore not considered key radionuclides in this Draft WIR Evaluation.

4.3 REMOVAL OF KEY RADIONUCLIDES TO THE MAXIMUM EXTENT TECHNICALLY AND ECONOMICALLY PRACTICAL

The first criterion in DOE M 435.1-1, Chapter II(B)(2)(a) is that the wastes "have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical."

Removal to the maximum extent "technically and economically practical" is not removal to the extent "practicable" or theoretically "possible."[27] Nor does the criterion connote removal which may be notionally capable of being done. Rather, the adverbs "technically" and "economically" modify and add important context to that which is contemplated by the criterion. Moreover, a "practical" approach as specified in the criterion is one that is "adapted to actual conditions" (Fowler 1930); "adapted or designed for actual use" (Random House 1997); "useful" (Random House 1997); selected "mindful of the results, usefulness, advantages or disadvantages, etc., of [the] action or procedure" (Random House 1997); fitted to "the needs of a particular situation in a helpful way" (Cambridge 2004); "effective or suitable" (Cambridge 2004). Therefore, the evaluation as to whether a particular key radionuclide has been or will be removed to the "maximum extent that is technically and economically practical" will vary from situation to situation, based not only on reasonably available technologies but also on the overall costs and benefits of deploying a technology with respect to a particular waste stream. The "maximum extent that is technically and economically practical" standard contemplates, among other things: consideration of expert judgment and opinion; environmental, health, timing, or other exigencies; the risks and benefits to public health, safety, and the environment arising from further radionuclide removal as compared with countervailing considerations that may ensue from not removing or delaying removal; life cycle costs; net social value; the cost (monetary as well as environmental and human health and safety costs) per curie removed; radiological removal efficiency; the point at which removal costs increase significantly in relationship to removal efficiency; the service life of equipment; the reasonable availability of proven technologies; the limitations of such technologies; the usefulness of such technologies; and the sensibleness of using such technologies. What may be removal to the maximum extent technically and economically practical in a particular situation or at one point in time may not be that which is technically and economically practical, feasible, or sensible in another situation or at a prior or later point in time. In this regard, it may not be technically and economically practical to undertake further removal of certain radionuclides because further removal is not sensible or useful in light of the overall benefit to human health and the environment.[28]

4.3.1 Removal of Key Radionuclides to the Maximum Extent Technically Practical

4.3.1.1 Introduction and Background

Retrieval of waste and removal of key radionuclides from the tanks and applicable ancillary structures at WMA C has been performed using a variety of methods and advanced technologies,

[27] In evaluating whether key radionuclides have been removed to the maximum extent that is "technically and economically practical", DOE has considered the guidance in DOE Guide 435.1-1 as well as the plain meaning of the phrase "technically and economically practical." DOE's evaluation also reflects a risk-based approach, and is consistent with the NRC Policy Statement concerning WVDP decommissioning criteria for waste to remain at the WVDP (NRC 2002), NRC staff guidance for NRC consultation activities related to DOE waste determinations (NRC 2007), and the approach taken pursuant to the similar criterion in Section 3116(a) of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (see e.g., Basis for Section 3116 Determination for the Idaho Nuclear Technology and Engineering Center Tank Farm Facility (DOE 2006)).

[28] As a general matter, such a situation may arise if certain radionuclides are present in such extremely low quantities that they make an insignificant contribution to potential dose to workers, the public, and the hypothetical human intruder.

through a series of campaigns and steps, as described more fully in the ensuing sections of this Draft WIR Evaluation.[29] As waste retrieval efforts progressed, DOE applied lessons learned and developed enhanced technologies, with an emphasis on removing waste and key radionuclides. Importantly, the tanks in the WMA C contained a variety of wastes from different sources, and contained different radionuclides, chemical constituents, and physical properties which vary from tank to tank, as explained in Section 2.3.2. Accordingly, DOE also tailored the technological approaches used to address the physical, chemical and radionuclide properties of the waste to be removed and enhance retrieval performance. These waste retrieval technologies are discussed in more detail in Sections 2.3.3 and 4.3.3.

DOE initiated tank waste retrieval activities from single-shell tanks at the WMA C in 1998 according to the requirements of the HFFACO (RPP-20577, "Stage II Retrieval Data Report for Single-Shell Tank 241-C-106"). Those waste retrieval activities employed technologies intended to remove the waste as quickly and safely as possible while minimizing the risk to workers, human health, and the environment. The retrieval technologies are discussed in more detail in Sections 2.3.3 and 4.3.3 of this Draft WIR Evaluation. Waste retrieval used one or more retrieval technologies, applied either simultaneously or serially in each tank, as explained in more detail in Section 4.3.3 of this Draft WIR Evaluation. DOE's approach concerning waste retrieval was premised on the concept of achieving the limits of a retrieval technology for a specific tank and then determining what other technologies may be used to achieve additional waste removal, if needed, so as to remove waste and key radionuclides to the maximum extent technically practical.

Sections 4.3.2.1.1 to 4.3.2.12.1 describe the retrieval technologies deployed for each of the 100-series tanks, how those technologies were selected, the results of the retrieval activities, and the process for making the determination that a given technology has reached the limits of retrieval. Section 4.3.3 discusses these aspects of retrieval in the 200-series tanks. The selection of waste retrieval technologies for WMA C tanks was based generally upon the following: (RPP-PLAN-40145)

- Which technologies have been available at the time retrievals were performed
- Known or assumed soundness of the tank being retrieved
- Available tank access
- Impact of the technology on available DST storage space
- Expected effectiveness of the technology given a specific waste type.

[29] Retrieval of the waste serves to remove radionuclides – including the key radionuclides described in Section 4.2 – from the tanks. DOE Guide 435.1-1, at II-22, recognizes that removal of key radionuclides may be accomplished by physical removal processes. See also NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations*, at Sections 2.4.3 and 3.3.1. In DOE's view, selective removal of only key radionuclides from the tanks at WMA C is not practical, sensible or useful, because, among other things, the SSTs in WMA C contain a mixture of wastes with differing radionuclide, chemical and physical properties that vary from tank to tank, and selective removal of only key radionuclides from the SSTs would not be consistent with the HFFACO and Consent Decrees.

DOE recognizes that removal of waste containing key radionuclides to the maximum extent "technically practical" must take into account the technical limit of mature, available, and proven retrieval technologies (i.e., the limit of technology), and any associated risks, using a risk-informed approach.[30] Section 4.3.1 describes the concept of the limit of technology in more detail. Essentially, the limit of technology is reached when the amount of waste removed during an operating period approaches zero, and it is apparent that it is no longer technically practical to continue. As discussed further in Section 4.3.2 of this Draft WIR Evaluation, when the limit of technology is reached, continued retrieval also is not economically practical because the benefit of retrieval – reduction of radiological risk to workers, the public, and the environment – remains static as well. While the cost of retrieval operations remains constant for each operating period, the dose is not effectively reduced to workers, the public, potential public receptors in the future, or the hypothetical human intruder.[31]

The risk/dose analysis provided in the WMA C PA demonstrates further that key radionuclides have been removed to the maximum extent technically practical by the retrieval activities conducted thus far under the HFFACO and Consent Decrees. The residual waste in the WMA C tanks provide risk/dose to the public that are well below the limits in the performance objectives and performance measures set forth in DOE M. 435.1-1, Chapter IV.P and 10 CFR Part 61, Subpart C, as discussed in Section 5.0.[32] The WMA C PA analyses were based on the WMA C waste residual inventory as of September 2014. However, as discussed in Section 2.3.6, after the completion of the modeling for WMA C PA, wastes from six additional SSTs have been retrieved (C-101, C-102, C-105, C-107, C-111 and C-112)[33] and the post-retrieval samples have been obtained for C-101, C-102, C-107, C-111 and C-112. The post-retrieval data indicate that the overall inventory in WMA C tanks has been reduced and the total inventories for the key radionuclides have also been reduced. A comparison of the WMA C PA model results and post-retrieval sample inventories is conducted in Sections 5.2, 5.3, and 6.5 of this Draft WIR Evaluation. This comparison demonstrates that the residual inventories based on the post-retrieval samples do not significantly change the results of the WMA C PA.

It is important to note that DOE M 435.1-1 does not set any numerical criteria associated with removal of key radionuclides to the maximum extent that is technically and economically practical. Although in different ways both the HFFACO and Consent Decrees employ a 360 ft^3 volume standard – under the Consent Decrees as a residual goal and under the HFFACO as a retrieval requirement – DOE has complied with both in retrieving waste from the WMA C tanks.

Among other things, the HFFACO has established enforceable milestones for retrieval of tank waste. HFFACO Milestone M-045-00 states that SST closure will follow retrieval of as much tank waste as technically possible with residual waste volumes in 100-series SSTs not to exceed

[30] See DOE G 435.1-1, at II-22 to II-23.

[31] The same considerations may be used in reaching a decision to forego deployment of additional technologies, if the benefit of developing or deploying them appears to be minimal.

[32] DOE M. 435.1-1, Chapter IV. P. sets forth safety requirements, performance objectives and performance measures comparable to the performance objectives in 10 CFR Part 61, Subpart C for NRC licensees.

[33] Retrieval has recently been completed in tank C-105, but final sampling and volume analysis have not yet been completed, and are anticipated in the near future. Because more waste was retrieved from C-105 than assumed in the WMA C PA, the WMA C PA analysis remains bounding for C-105.

360 ft^3 or the limit of waste retrieval technology, whichever is less, and the residual waste volumes in 200-series SSTs not to exceed 30 ft^3 or the limit of waste retrieval technology, whichever is less. Tanks C-201, C-202, C-203, C-204, C-103, and C-106 were retrieved under the requirements of HFFACO Milestone M-045-00.

As described previously, Ecology filed suit against DOE in 2008 based on allegations that DOE "had missed or was certain to miss" certain HFFACO milestones, including tank retrieval milestones. In the 2010 Consent Decree, DOE was required, among other things,[34] to retrieve the ten remaining WMA C tanks by September 30, 2014, but due to a combination of factors, DOE was unable to complete this milestone. In the Amended Consent Decree of March 11, 2016, DOE was required to retrieve waste from the remaining WMA C tanks by March 31, 2024.

Under the 2010 Consent Decree, [35] two waste retrieval technologies are planned for deployment, and then each is to be operated to the "limits of technology" in "an effort to obtain a waste residue goal of 360 cubic feet of waste or less for each tank." The Consent Decree requires that a third waste retrieval technology be deployed if the volume goal is not achieved using the first two technologies, unless DOE requests to forego implementation of the third technology and Ecology agrees. Waste in Tanks C-101, C-102, C-104, C-105, C-107, C-108, C-109, C-110, C-111, and C-112 have been physically retrieved in compliance with the Consent Decree process.[36]

4.3.2 Limit of Technology

Although neither DOE M 435.1-1 nor the HFFACO prescribes a basis for determining when a technology has reached the limit of its capability to retrieve waste, the Consent Decree defines "limits of technology" to mean "that the recovery rate of that tank retrieval technology for that tank is, or has become, limited to such an extent that it extends the retrieval duration to the point at which continued operation of the retrieval technology is not practicable, with the consideration of practicability to include matters such as risk reduction, facilitating tank closures, costs, the potential for exacerbating leaks, worker safety, and the overall impact on the tank waste retrieval and treatment mission." In general, DOE considered three types of data to demonstrate reaching the limit of a given retrieval technology, and determine when the end of retrieval was reached.[37]

1. In-tank photos/videos to observe and record the waste surface contours, form, and characteristics;
2. Retrieval performance efficiency based on daily material mass balance calculations;

[34] For example, the 2010 Consent Decree also included milestones for nine additional SST tank retrievals and established nineteen other milestones for construction and startup of the Waste Treatment and Immobilization Plant.

[35] Neither the retrieval goal nor the "limits of technology" retrieval process of the 2010 Consent Decree was changed by either the Amended Consent Decree (March 11, 2016) or the Second Amended Consent Decree (April 12, 2016).

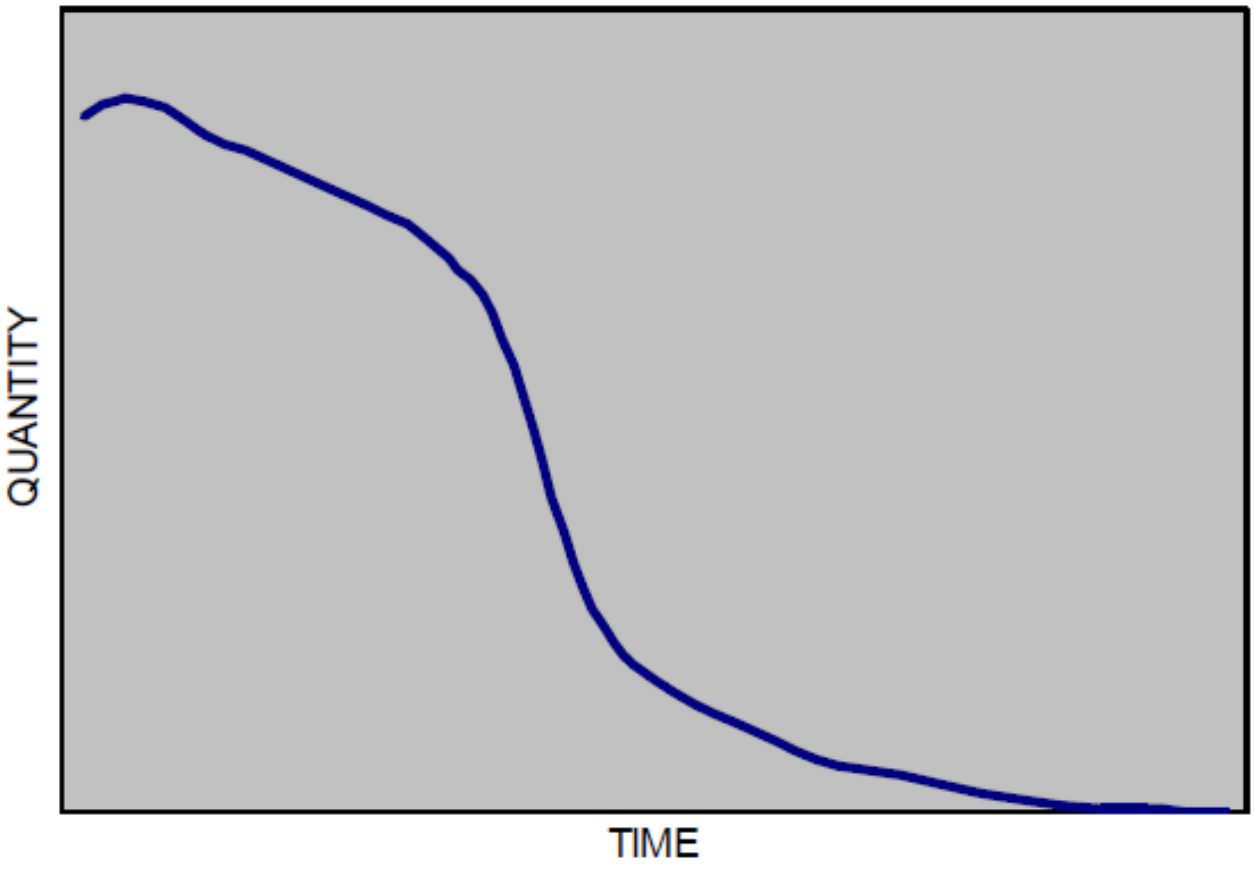
[36] For Tank C-105, the last 100-series tank from which waste was retrieved, the final sampling, analysis, and submittal of completion of retrieval certification documents will occur in the near future.

[37] The decision process is described for each tank in the Retrieval Data Reports, which are submitted for tanks retrieved under both the HFFACO and the Consent Decrees. See Section 4.3.2. Retrieval Completion Certification Reports submitted to Ecology for tanks covered by the Consent Decrees also include this information.

3. Retrieval performance data trends to demonstrate that a consistent pattern was present and indicating that as much waste has been removed as practical.

Figure 4-5 illustrates the general concept of diminishing returns over time as a waste retrieval activity progresses towards its limit. The limit of technology model (Figure 4-5) shows that during the early part of a hypothetical campaign, efforts are focused on optimizing the efficiency of the technology. During the middle period, the operational parameters are in place and relatively large volumes of waste are removed efficiently. In later stages, the small volume of waste remaining causes the retrieval operation to use additional fluid to mobilize the remaining waste and thus more operating time is required in relation to the volume of waste recovered. In the final days, the quantity of waste recovered approaches zero (using the same volume of retrieval fluids), indicating that retrieval efficiency has diminished to the point where only a negligible amount or no waste can be retrieved using the technology.

Figure 4-5. Limit of Technology Model.



4.3.3 Tank Retrieval Technologies and End-State for 100-Series Tanks

4.3.3.1 Tank C-101

4.3.3.1.1 Waste Retrieval Operations

MS was the first retrieval technology selected and employed in tank C-101, as described in RPP-22520, "241-C-101 and 241-C-105 Tanks Waste Retrieval Work Plan." A high-pressure water system was identified as the second technology as is described in RPP-22520. MS operations using the ERSS started on December 10, 2012. High-pressure water deployment was initiated on July 25, 2013 to break up remaining wastes. The two technologies were operated alternately or together until September 11, 2013. Both the MS and high-pressure water retrieval technologies were performed in tank C-101 to the point where further operation of the combined technologies would not reduce risk significantly while continuing to cause exposure to workers, increase costs, and delay the initiation or completion of other retrieval activities. Consequently, DOE-ORP concluded that the MS and high-pressure water retrieval steps had reached the limit of technology (RPP-RPT-58386, "Retrieval Data Report for Single-Shell Tank 241-C-101").

DOE-ORP prepared RPP-55849, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-101," documenting that retrieval operations undertaken on tank C-101 using MS with DST supernate and high-pressure water technologies deployed by two ERSS assemblies have been completed to the limit of technology, and that further retrieval is not practicable as that term is used in Appendix C, Part 1 of the Consent Decree.

4.3.3.1.2 Limit of Technology.

As stated in RPP-22520, "There is no limit of technology definition for an ERSS or MARS-V waste retrieval process. A limit of technology definition will not be developed until sufficient ERSS and MARS-V retrieval operations have been performed to enable development of a justifiable definition. Until an ERSS and MARS-V limit of technology definition is developed the same value used for modified sluicing in RPP-50910 is applied to ERSS and MARS-V retrieval operations. Also for ERSS and MARS-V, data for retrieval performance measurement used to show the limits of technology have been met will be used after implementation of one or both low pressure sluicing and high pressure water operations (each technology will not be evaluated separately for its limit of technology)."

In accordance with RPP-50910, DOE provided documentation to Ecology as to how meeting the following two criteria constitutes reaching the limit of technology for retrieval of waste from a Hanford Site SST using MS with only DST supernate or water as the sluicing medium.

1. The concentration of SST waste in the retrieved slurry sent to the DST is within or bracketing a 0 to 0.6 vol. percent range for three operating periods. Bracketing refers to two successive data points, one of which is below 0 and the next near or above 0.6, which average less than 0.6 vol. percent. An operating period is a period over which retrieval performance is measured. An operating period is normally one operating day, but as a minimum must be greater than or equal to eight hours in duration and consist of at least 10,000 gal of slurry transferred from the SST.

2. The DOE Office of River Protection (ORP) and the Tank Operations Contractor (TOC) have provided documentation to Ecology that demonstrates that all reasonable efforts were attempted to enhance effectiveness of the installed modified sluicing retrieval system in order to increase waste removal from all quadrants of the tank under consideration.

MS using the ERSSs was performed in tank C-101 beginning on December 10, 2012. When MS alone did not appear effective in retrieving more material, high-pressure water was introduced to facilitate breakup of larger waste chunks. High-pressure water was alternated with, or operated concurrently with, additional MS to mobilize and remove any waste pieces and fines. Retrieval was completed on September 11, 2013 (RPP-RPT-58386).

Figure 4-6 shows the volume of slurry transferred from tank C-101 to tank AN-101, a DST in another tank farm. The volume of waste retrieved is estimated from the increase in the waste volume in DST AN-101 after accounting for water additions and adjusting for void space in the bulk tank C-101 waste.

Table 4-4 displays the volume percent of solids in the retrieved bulk waste for the amount of slurry transferred for the last three months of the tank C-101 retrieval operation. Table 4-4 shows that starting in mid-August 2013, the volume percent of solids in the slurry had decreased to ~0.02 percent; therefore, the concentration of SST waste in the retrieval slurry sent to the DST is within or bracketing a 0 to 0.6 vol percent range for three operating periods, effective September 11, 2013. Thus, the first criterion of RPP-50910 was met for the combination of MS and high-pressure water retrieval operations.

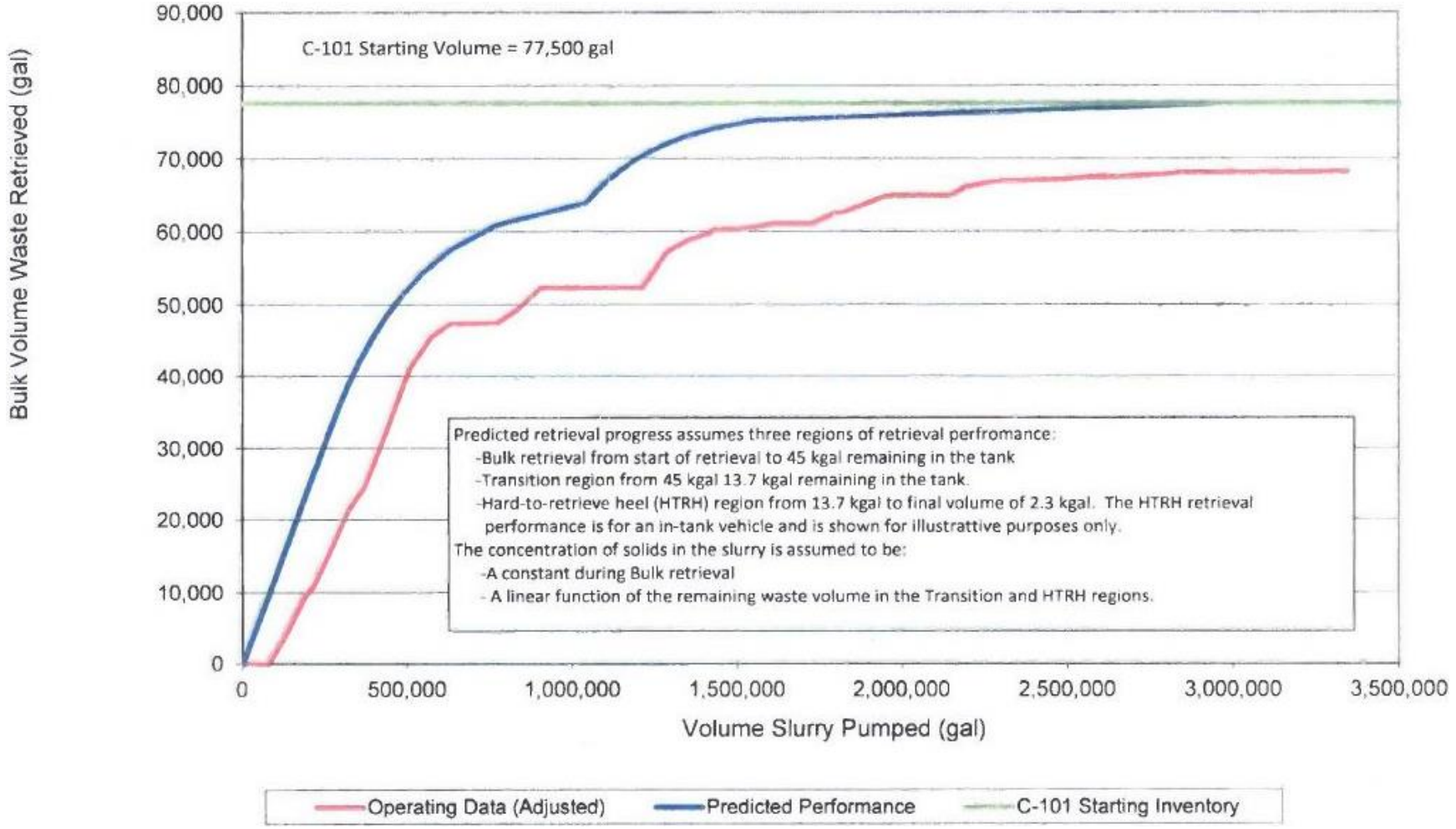
The second criterion associated with the limit of technology definition from RPP-50910 requires a demonstration that all reasonable attempts were made to enhance the effectiveness of the installed MS system in order to increase waste removal from all quadrants of the tank under consideration. At the end of MS in tank C-101, waste had been mobilized and largely removed from the areas under the sluicers and the center of the tank. In these areas, the tank bottom was either exposed or covered by loose solids. Most of the solids that still remained were in the areas near the tank wall. Attempts were made to spray the tank wall and stiffener rings, and the liquid was able to reach these areas; the same operation was also performed using high-pressure water. Little to no reduction in the waste on the wall and stiffener rings was observed, even in the areas closest to the sluicer.

Per the Consent Decree, the limits of technology "means that the recovery rate of that retrieval technology for that tank is, or has become, limited to such an extent that it extends the retrieval duration to the point at which continued operation of the retrieval technology is not practicable, with the consideration of practicability to include matters such as risk reduction, facilitating tank closures, costs, the potential for exacerbating leaks, worker safety, and the overall impact on the tank waste retrieval and treatment mission."

- The MS technology/high-pressure water retrieval effectively removed the bulk of the sludge, and little or no additional waste could be retrieved by continued deployment, resulting in little or no additional reduction of risk.

- Continued MS and high-pressure water retrieval of tank C-101 would not facilitate tank closure because little or no additional waste could be removed. The time and budget expended on continued retrieval operations could better be spent on activities that would achieve greater risk reduction, thereby doing more to facilitate tank closures.

Figure 4-6. Tank C-101 Waste Retrieval Progress.[38]



[38] Several of the retrieval performance graphs in this section show raw Operating Data versus "Adjusted" Data. The raw data was adjusted to account for factors such as evaporation and pore space, as explained in the applicable Retrieval Data Reports, e.g., RPP-RPT-58386.

Table 4-4. C-101 Tank Waste Retrieval Efficiency.

Operating Period	Bulk Volume Solids Retrieved (gal)*	Slurry Pumped (gal)	Solids in Slurry (vol %)
6/7/13	741	26,153	2.83
6/10/13	0	24,946	1.44
6/11/13 09:33 to 9/12/13 08:45	2,171	125,511	
6/12/13, 08:45 to 13:36	161	22,351	0.72
6/13/13	0	67,591	0.49
6/14/13	0	71,302	
6/17/13	0	43,369	
6/19/13	1,078	39,335	
7/9/13	651	65,956	0.99
7/10/13	322	49,388	0.65
7/11/13	0	65,205	0.08
7/22/13	80	41,886	
7/23/13	0	54,876	0.20
7/24/13	241	65,298	
7/25/13	201	37,991	0.53
7/26/13	0	0	0.04
8/8/13	0	14,458	
8/9/13	0	57,972	
8/12/13	46	57,236	
8/13/13	201	77,577	0.26
8/14/13	362	72,429	0.50
8/15/13	0	9,532	0.02
8/19/13, 10:25 to 23:00	0	69,024	
8/19/13, 23:00 to 8/20/13 17:09	0	33,608	
8/19/13, 17:09 to 8/21/13 21:18	0	132,171	
9/6/13	0	0	
9/9/13 16:58 to 22:50	0	30,224	
9/9/13 22:50 to 9/10/13 21:45	0	114,660	
9/10/13 21:45 to 9/11/13 11:36	76	70,504	

Source: RPP-RPT-55573, "Retrieval Completion Report for Modified Sluicing of Tank 241-C-101 Using Extended Reach Sluicing and High-Pressure Water."

* 0 gallons retrieved includes periods with net volume increase in tank C-101 due to the addition of liquid (water or supernate) and periods with net volume decrease in tank C-101 due only to the reduction of liquid volume in the tank.

Continued MS and high-pressure water tank C-101 retrieval would result in continued exposure to workers. Although retrieval operations are controlled from a control trailer, multiple field activities (e.g., valve line-ups, field measurements, monitoring) are required to support the retrieval operations, resulting in continued exposure.

- Continued MS and high-pressure water tank C-101 retrieval would increase schedule duration and, as a result, delay other retrieval activities, therefore adversely affecting the overall retrieval and treatment mission. The personnel involved in tank C-101 MS and high-pressure water retrieval could immediately be redeployed in other retrieval activities that would likely result in greater overall risk reduction.
- Continued MS and high-pressure water retrieval would incur costs without an associated reduction of risk.

Conclusion. Both the MS and high-pressure water retrieval technologies were performed in tank C-101 to the point where further operation of the combined technologies would not reduce risk significantly, while continuing to cause exposure to workers, increase costs, and delay the initiation or completion of other retrieval activities. Consequently, DOE-ORP has concluded that the MS and high-pressure water retrieval steps reached the limit of technology (RPP-RPT-58386).[39]

4.3.3.2 Tank C-102

4.3.3.2.1 Waste Retrieval Operations

An MS system comprised of two ERSSs with sluicer and high-pressure water nozzles was used to remove the waste from tank C-102. Supernate from DST AN-101 was used as the sluicing fluid to mobilize the tank C-102 waste. The resulting slurry was pumped from tank C-102 to DST AN-101, as described (and approved by Ecology) in RPP-22393, "241-C-102, 241-C-104, 241-C-107, 241-C-108 and 241-C-112 Tanks Waste Retrieval Work Plan." The solids settled in DST AN-101 and the supernate was recycled for sluicing. After the more readily-retrievable solids were removed from tank C-102, the high-pressure water nozzles were used to break up larger pieces of hard waste that could not be broken up by the ERSS high-pressure water nozzles alone. High-pressure water nozzles were identified as the second technology as described in RPP-22393. Once broken up, this waste was removed from the tank by sluicing with the ERSSs. Retrieval operations were performed during 85 operating days (155 shifts) starting on April 27, 2014 and ending on May 8, 2015. Both the MS and high-pressure water retrieval technologies were performed in tank C-102 to the point where further operation of the combined technologies would not reduce risk significantly while continuing to cause exposure to workers, increase costs, and delay the initiation or completion of other retrieval activities. Consequently, DOE-ORP concluded that the MS and high-pressure water waste retrievals had reached the limit of technology.

[39] DOE submitted RPP-55849, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-101" to Ecology via letter 14-TF-0012, dated 2/18/14. Ecology responded with letter 14-NWP-164 on 8/20/14. DOE submitted RPP-57570, "Retrieval Completion Certificate Report for 241-C-101" to Ecology via letter 14-TF-0113, dated 9/24/14. DOE submitted RPT-RPP-58386, "Retrieval Data Report for Single-Shell Tank 241-C-101" via letter 15-TF-0099, dated 9/24/15.

DOE-ORP prepared RPP-RPT-58676, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-102," documenting that retrieval operations undertaken on tank C-102 using MS with DST supernate and high-pressure water technologies deployed by two ERSS assemblies have been completed to the limit of technology, and that further retrieval is not practicable as that term is used in Appendix C, Part 1 of the Consent Decree.

4.3.3.2.2 Limit of Technology

Tank C-102 MS was performed starting on April 27, 2014 and ending on May 8, 2015. Figure 4-7 shows the sluicing retrieval system volume of waste retrieved as a function of the volume of slurry transferred from tank C-102 to DST AN-101.

Table 4-5 shows the retrieval efficiency for the last 16 days of tank C-102 retrieval sluicing operations, when the tank was pumped down to the extent possible to provide consistent estimates of retrieval efficiency. Table 4-5 shows that early on April 4, 2015, the requirements of the limit of technology definition were met following three consecutive operating periods. The concentration of solids in the slurry for the three operating periods was 0.29, 0.04, and 0.26 vol percent. As a result, the first criterion of RPP-50910 was met for MS (RPP-RPT-58676).

The second criterion associated with the limit of technology definition from RPP-50910 requires a demonstration that all reasonable attempts were made to enhance the effectiveness of MS in order to increase waste removal from all quadrants of the tank under consideration. By the end of MS in tank C-102, the only hard surface was the suspected concrete material under riser 2 and in a layer on the tank walls. After sluicing, a hard bathtub ring material on the lower part of the tank walls was exposed, broken into large chunks by sluicing. The hard waste higher up on the walls was very resistant to sluicing. To the extent practicable, waste had been sluiced out from under the hard waste. Hot water sluicing and high-pressure water washing of the tank walls and stiffener rings were performed to attempt to remove adhered waste. However, visual observations of this attempt showed no significant removal of the adhered waste.

Per the Consent Decree, the limits of technology "means that the recovery rate of that retrieval technology for that tank is, or has become, limited to such an extent that it extends the retrieval duration to the point at which continued operation of the retrieval technology is not practicable, with the consideration of practicability to include matters such as risk reduction, facilitating tank closures, costs, the potential for exacerbating leaks, worker safety, and the overall impact on the tank waste retrieval and treatment mission."

- The MS and high-pressure water retrieval operations had effectively removed the bulk of the tank C-102 sludge, and little or no additional waste could be retrieved by continued deployment, resulting in little or no additional reduction of risk.
- Continued MS and high-pressure water retrieval operations would result in continued exposure to workers. Although retrieval operations are controlled from a control trailer, multiple field activities (e.g., exhauster filter changes, valve line-ups, field measurements, monitoring) are required to support the retrieval operations, resulting in continued exposure.

- Continued MS and high-pressure water retrieval operations would increase schedule duration, with the potential to affect other retrieval activities and therefore the overall retrieval and treatment mission.
- Continued MS and high-pressure water retrieval operations would incur costs without an associated risk reduction.

Conclusion. Both the MS and high-pressure water retrieval technologies were performed in tank C-102 to the point where further operation of the combined technologies would not reduce risk significantly, while continuing to cause exposure to workers, increase costs, and delay the initiation or completion of other retrieval activities. Consequently, DOE-ORP has concluded that the MS and high-pressure water waste retrievals reached the limit of technology (RPP-RPT-58676).[40]

4.3.3.3 Tank C-103

4.3.3.3.1 Waste Retrieval Operations

The tank C-103 waste retrieval campaign began on November 6, 2005. The tank was retrieved using MS. Removed waste slurry was transferred to DST AN-106 (RPP-RPT-33060, "Retrieval Data Report for Single-Shell Tank 241-C-103").

4.3.3.3.2 Limit of Technology

Visual Observations. A video camera inside tank C-103 allowed operational monitoring of activities and results throughout the waste retrieval campaign. As retrieval progressed, it was observed that retrieval performance decreased as the readily mobilized sludge was depleted, leaving behind less mobile granular residues that did not readily pass through the pump inlet screen (Figure 4-8) (RPP-RPT-33060).

Trend in Retrieval Efficiency. The retrieval efficiency in gallons of waste retrieved per gallons of slurry transferred was used to determine the progress throughout the tank C-103 retrieval campaign. The volume of waste retrieved was determined by subtracting the slurry and water added to the tank from the volume transferred on a given day (RPP-RPT-33060).

[40] DOE submitted RPP-58676, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-102" to Ecology via letter 15-TF-0073, dated 8/10/15. Ecology responded with letter 15-NWP-177 on 10/2/15. DOE submitted RPP-RPT-58788, "Retrieval Completion Certificate Report for 241-C-102" to Ecology via letter 15-TF-0116, dated 11/30/15. DOE submitted RPT-RPP-59631, "Retrieval Data Report for Single-Shell Tank 241-C-102" via letter 16-TF-0115, dated 9/24/15.

Figure 4-7. Tank C-102 Sluicing Waste Retrieval Progress.

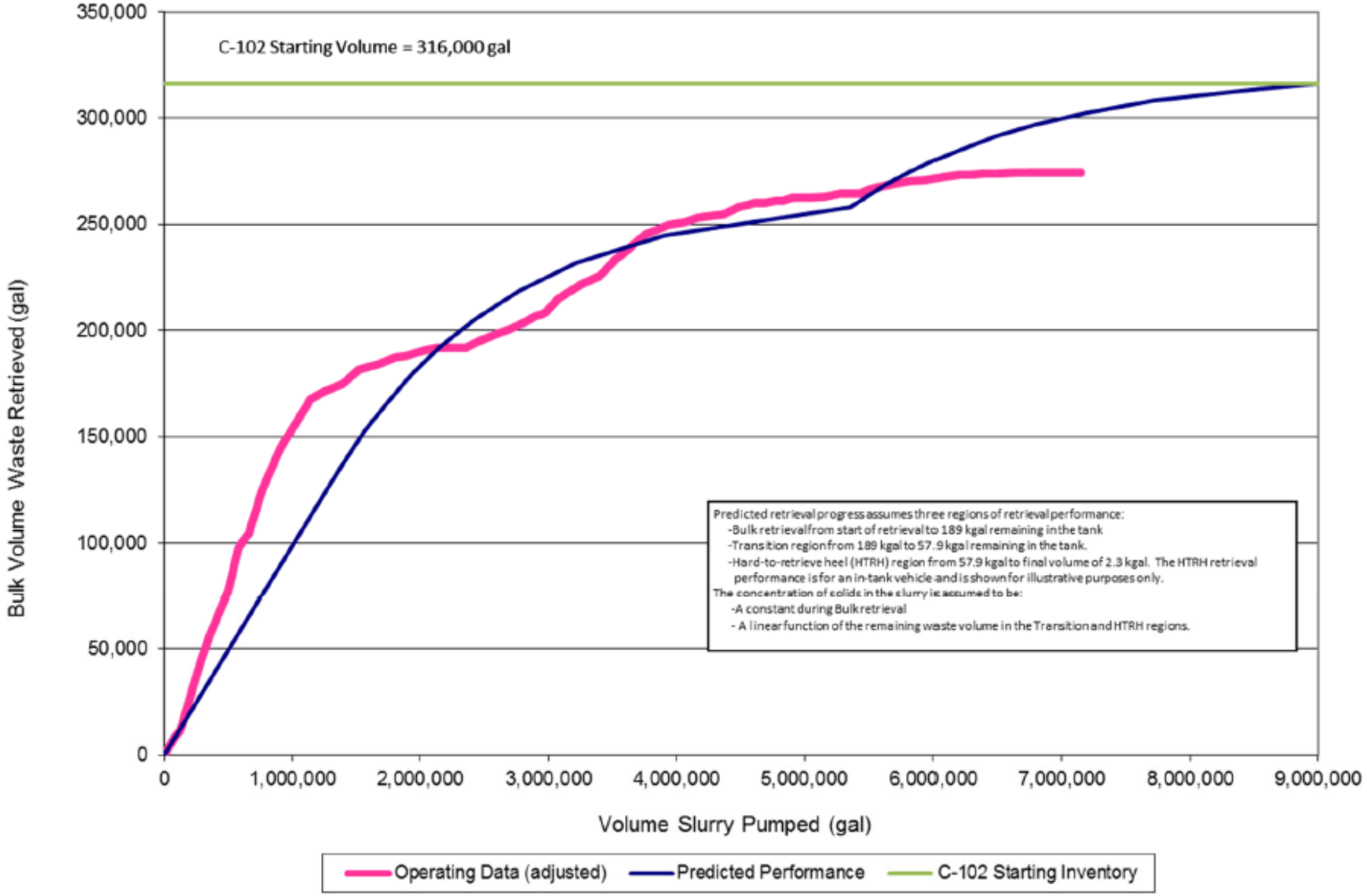


Table 4-5. Tank C-102 Waste Retrieval Efficiency for January 1 to May 8, 2015.

Operating Period Number	Operating Period	Bulk Volume Solids Retrieved (gal)*	Slurry Pumped (gal)	Slurry Operating Hours	High-Pressure Water Operating Hours	Solids in Slurry (vol %)
1	3/21/15	633	128,589	22.95	—	0.49
2	3/22/15	82	91,443	16.43	—	0.09
3	4/3/15	469	82,575	14.22	—	0.57
4	4/4/15	0	126,368	22.32	—	0.29
	4/5/15	715	121,729	22.47	—	
5	4/6/15	0	109,340	19.92	—	0.04
	4/8/15 to 4/10/15	0	156,598	27.97	5.92	
	4/11/15	0	128,318	22.77	—	
	4/12/15	0	129,752	23.27	—	
	4/13/15	0	13,529	2.70	—	
	4/15/15	230	46,660	8.48	—	
6	4/16/15	0	26,614	4.43	11.62	0.26
	4/17/15 04:50 to 10:45	0	17,067	2.78	2.07	
	4/17/15 10:45 to 4/18/15 04:15	166	19,254	3.40	9.23	
7	4/18/15 04:15 to 5/8/15 11:17	0	347,507	6.48	4.22	0.00

* 0 gallons retrieved includes periods with net volume increase in tank C-102 due to the addition of liquid (water or supernate) and periods with net volume decrease in tank C-102 due only to the reduction of liquid volume in the tank.

Figure 4-9 shows the retrieval efficiency for each day of tank C-103 retrieval operations. Retrieval efficiency values are lower than those observed in other tanks due to the use of recycled supernate. Large volumes of supernate were able to be used to sluice the material, so low efficiencies do not indicate overuse of water but rather utilization of recycled liquid from the DST. In the initial stages of retrieval, efficiencies between 5 percent and 15 percent were normal. However, efficiencies below 1 percent were typical after day 24. Retrieval performance decreased as the readily-mobilized sludge depleted, leaving behind less mobile granular residues that did not readily pass through the pump inlet screen. As the volume retrieved approached the starting waste volume, the efficiency declined and approached zero.

The spike in volumetric efficiency during the final rinse resulted from efforts to minimize the supernate pool volume during the rinse. Because the rinse water had to be intimately mixed with the solids heels, this opportunity was utilized to spread the solids into the depression surrounding the retrieval pump, thereby displacing the liquid that would have otherwise remained in the supernate pool.

Figure 4-8. Tank C-103 Video Still – Camera Elevation Approximately 5 feet from the Tank Bottom (August 25, 2006).

Waste Retrieval Progress. Progress of the tank C-103 waste retrieval campaign over operating days is shown in Figure 4-10. The volume of waste retrieved per day is estimated from a mass balance using the volume of the slurry transferred to DST AN-106 and the volume of supernate removed from DST AN-106 to perform sluicing. Waste retrieval progressed fairly steadily until day 23 when the volume of waste retrieved began to level off. No measurable progress was made from days 47 to 51. Some waste was retrieved during the last two days when flush water was used to rinse the solids and the supernate out of the tank (RPP-RPT-33060).

Conclusion. DOE concluded that waste retrieval operations were performed to the limits of technology for MS (RPP-RPT-33060).[41]

[41] DOE submitted RPP-RPT-33060, "Retrieval Data Report for Single-Shell Tank 241-C-103" via letter 07-TD-026, dated 4/19/07.

Figure 4-9. Tank C-103 Trend in Retrieval Efficiency.

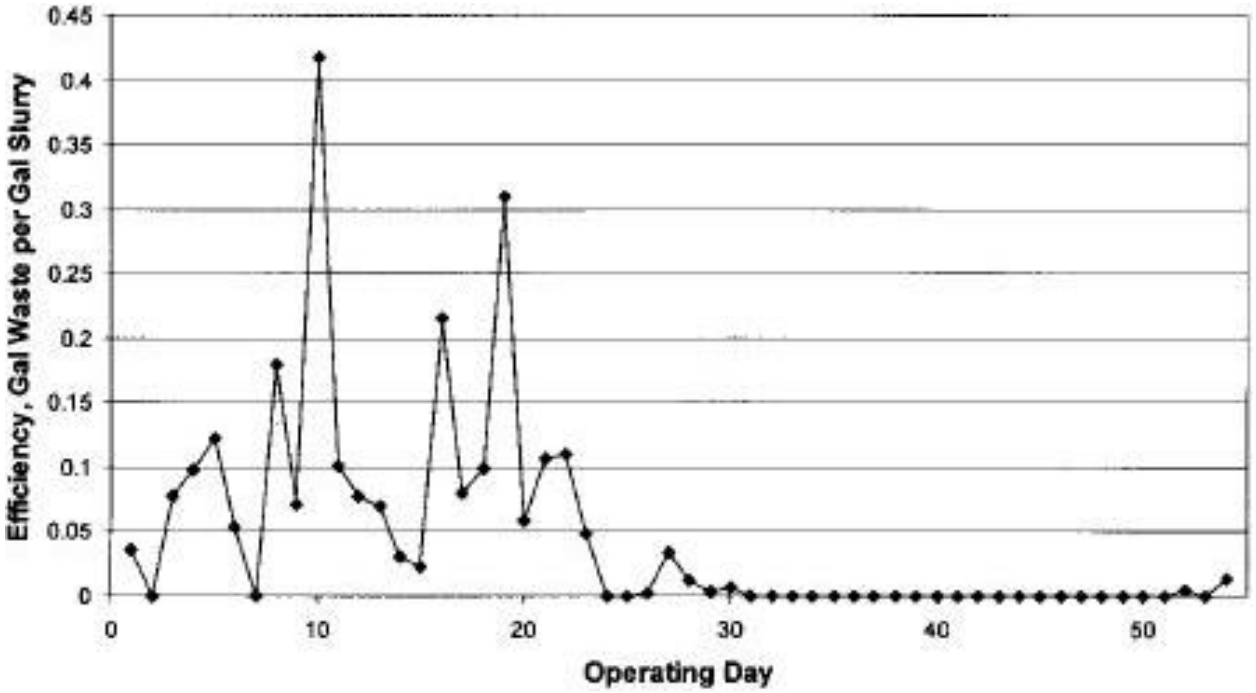
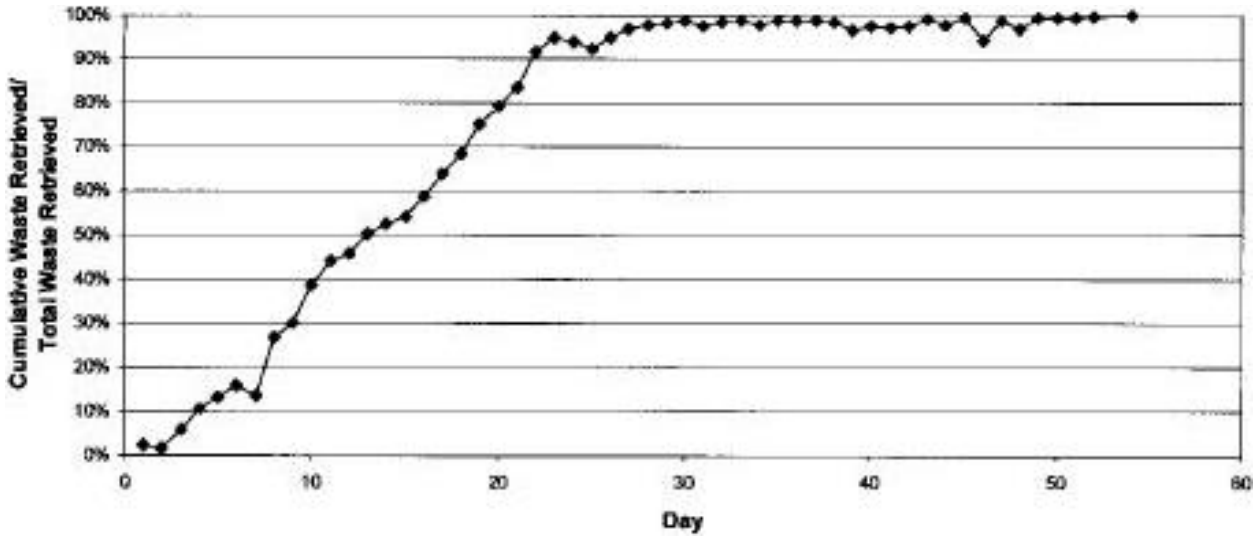


Figure 4-10. Tank C-103 Waste Retrieval Progress.



4.3.3.4 Tank C-104

4.3.3.4.1 Waste Retrieval Operations

Retrieval of tank C-104 waste occurred in two campaigns. The first campaign began January 8, 2009 using MS to remove the bulk of the waste. The second campaign began on June 14, 2012 using a caustic cleaning that was comprised of a chemical dissolution step followed by a water rinse. The caustic retrieval campaign reached the limit of technology on August 17, 2012 (RPP-RPT-54072, "Retrieval Data Report for Single-Shell Tank 241-C-104").

4.3.3.4.2 Limit of Technology.

Visual Observations. A video camera inside tank C-104 allowed operational monitoring of activities and results throughout the waste retrieval campaign. Video observation of physical characteristics of the tank and objects in the tank aided in measuring residual waste volume change at the end of retrieval. A reduction in waste volume in the tank was observed as retrieval progressed, as shown in Figure 4-11 (RPP-RPT-54072).

Waste Retrieval Progress. Figure 4-12 shows retrieval system performance as a function of the volume of slurry transferred from tank C-104 to DST AN-101. The occasional decreases in the volume retrieved in Figure 4-12 reflect fluctuations in the tank C-104 liquid pool volume near the end of the retrieval process. It was not always possible to pump the tank C-104 liquid pool to the same minimum heel at the end of each operating period. Figure 4-12 is annotated to highlight key events during the retrieval process. Retrieval system performance was tracked by trending the net waste volume increase in receiver DST AN-101 after accounting for water additions. This running volume balance did not distinguish between liquids and solids and did not account for solids dissolution or liquid evaporation. As the volume retrieved approached the starting waste volume, the estimate of the volume remaining in tank C-104 by difference became increasingly sensitive to uncertainties in the starting waste volume estimate because of pore space in the waste and cumulative measurement uncertainties. The operating data was adjusted near the end of retrieval to account for evaporation and pore space, as shown in the Adjusted Operating Data line in Figure 4-12 (RPP-RPT-54072).

Both the sluicing Operating Data and Adjusted Operating Data waste retrieval volumes in Figure 4-12 show the limit of technology being reached at ~4 million gal of slurry pumped.

Based on the performance metrics evaluated with the implementation of this technology, DOE concluded that MS was deployed to the limit of technology at tank C-104 (RPP-53823, "Retrieval Completion Certification Report for Tank 241-C-104").

The following is a discussion of the performance of the caustic cleaning process steps as specified in RPP-PLAN-51575, "Process Control Plan for Tank 241-C-104 Hard Heel Retrieval," which demonstrates that the limit of technology was met in tank C-104.

The caustic cleaning process was divided into two parts. Each part addressed a different chemical species: sodium fluoride phosphate and gibbsite. The first process was water dissolution of sodium fluoride phosphate.

Figure 4-11. Tank C-104 Video Still – Camera Elevation Approximately 18 feet from Tank Bottom (September 25, 2012).

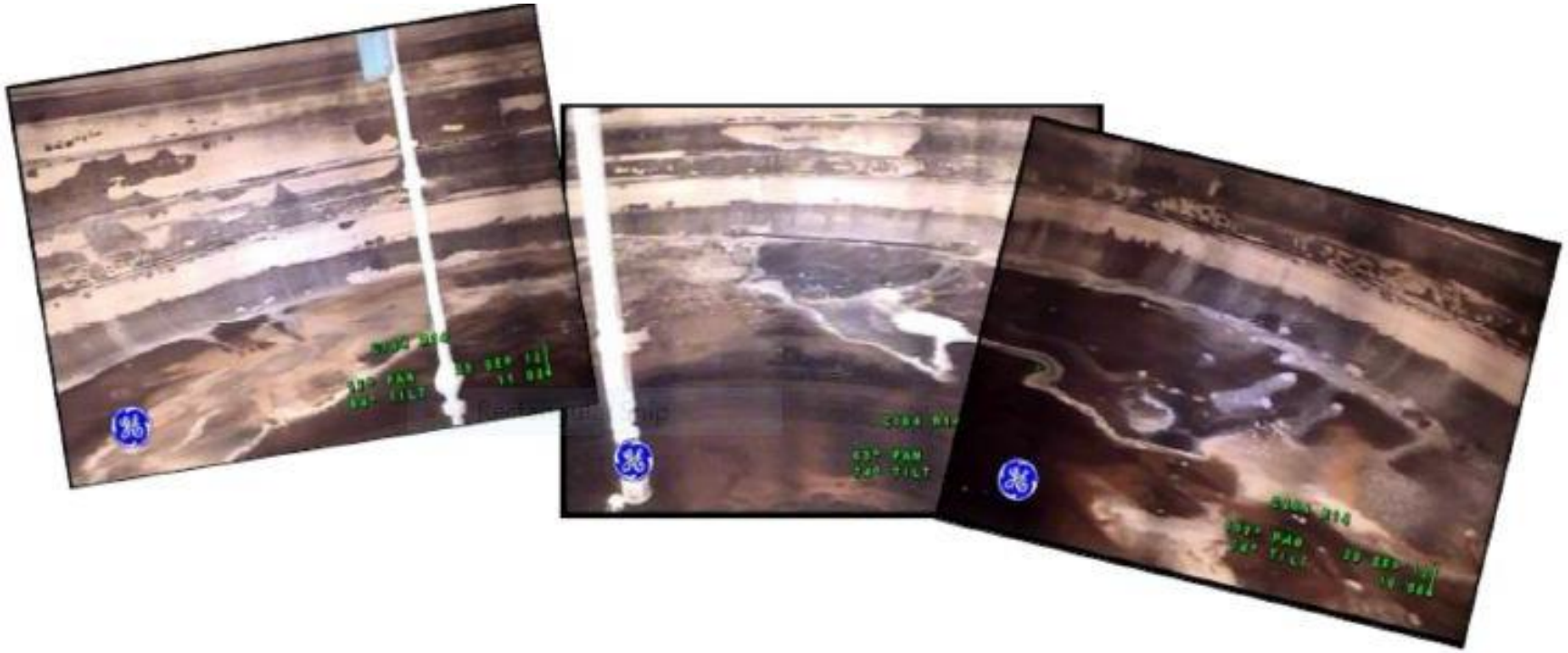
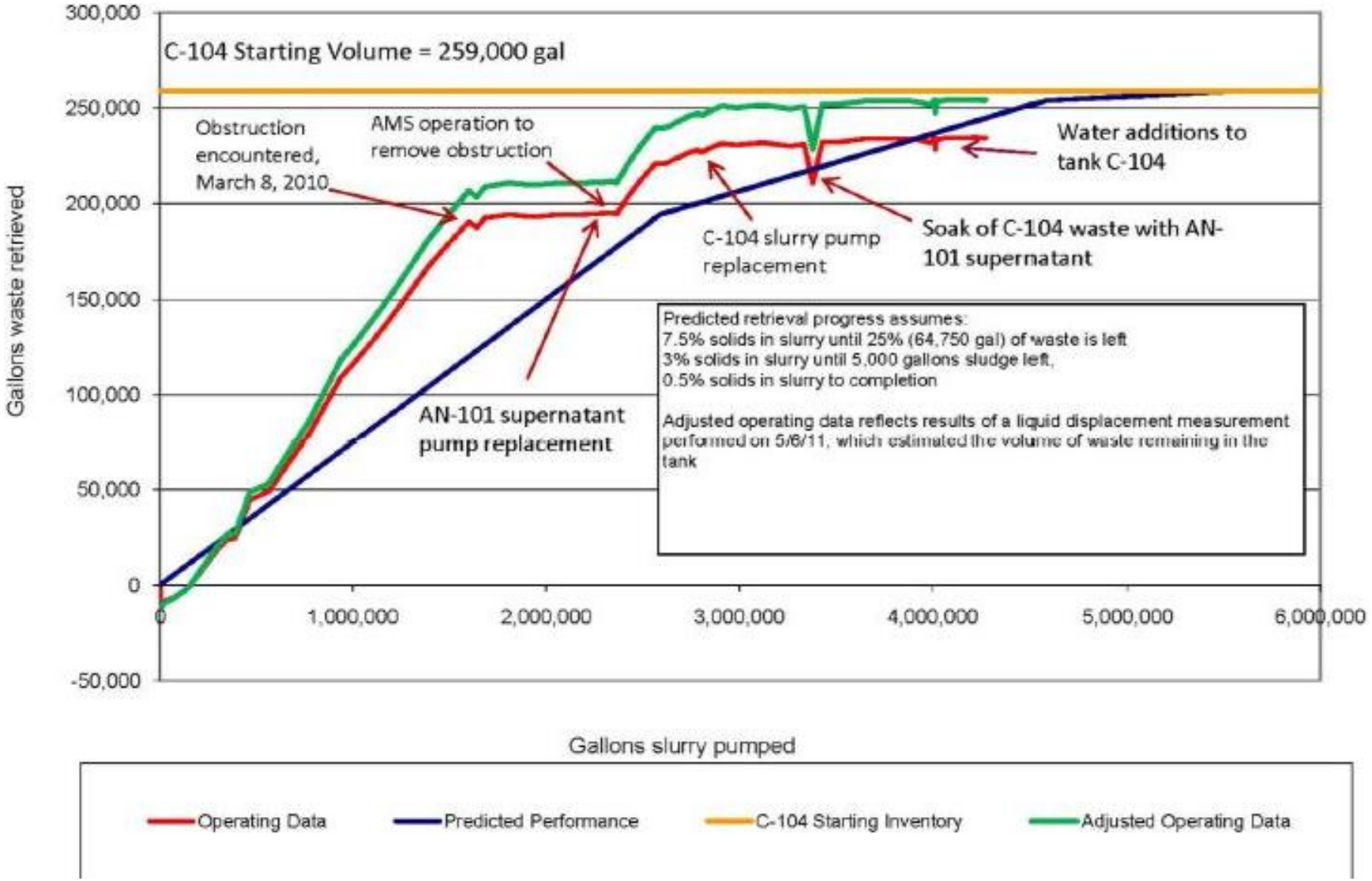


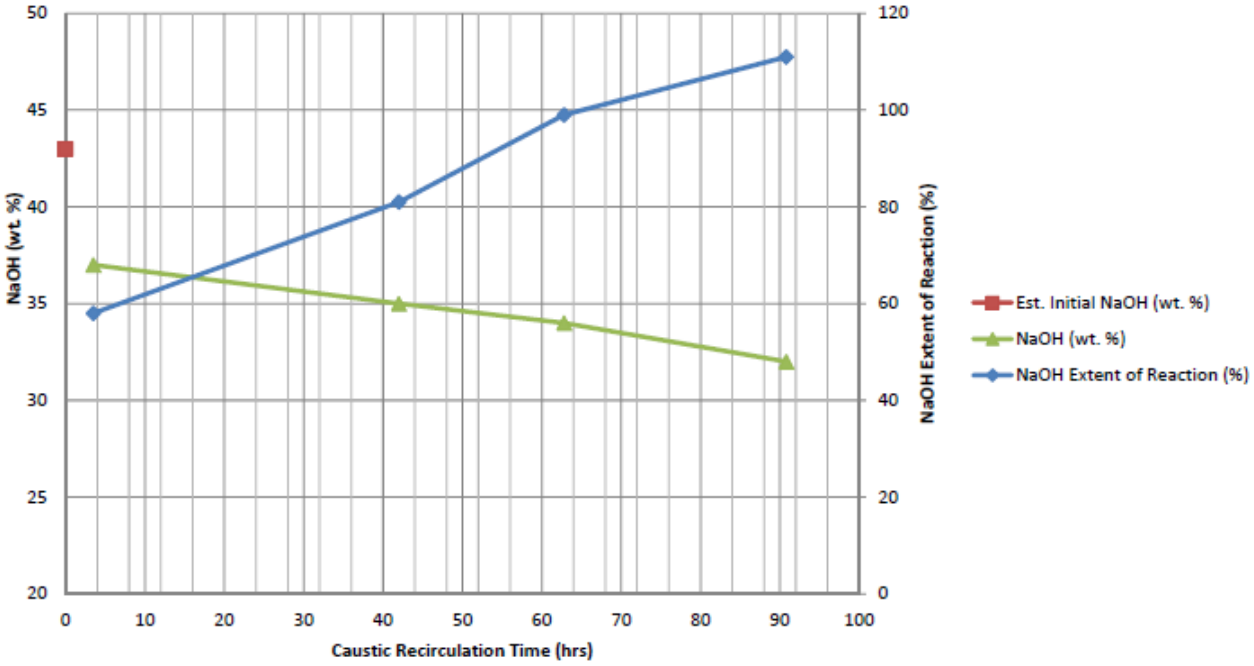
Figure 4-12. Tank C-104 Modified Sluicing Retrieval System Performance.



AMS = articulating mast system

The process was designed to retrieve aluminum compounds with specific emphasis on gibbsite. The process converted the aluminum compounds from a largely insoluble form to a much more soluble form by soaking in very high concentration caustic solution. This requires a long contact time to go to completion. Once the reaction went to completion, water was added to dilute the hydroxide and allow the soluble form (sodium aluminate) to dissolve; sodium aluminate dissolution is rapid. The contents were pumped from tank C-104 after the dissolution was complete. The process of converting gibbsite to the sodium aluminate form was tracked by sampling and analyzing the caustic concentration. Because much of the tank C-104 waste heel was above the liquid level, the liquid was circulated and the waste solids were sprayed with the caustic solution. Video shows that the large piles of waste were broken down and were washed below the liquid pool surface during the process. Figure 4-13 shows the results from sampling the caustic during the conversion reaction.

Figure 4-13. Tank C-104 Comparison of Caustic Concentration Levels and Sodium Hydroxide Extent of Reaction with Caustic Circulation Times.



Final water sluicing was an additional process step deemed necessary to remove solid materials that were deposited on the tank bottom during the volumetric displacement transfer following dissolution. Based on lessons learned from tank C-108, this sluicing step was defined as a part of the caustic cleaning process within the limits defined by the process control plan (RPP-PLAN-51575).

Following transfer of the dissolution liquors to receiver DST AN-101, 29,455 gal of water were used to sluice additional solids from tank C-104. At the completion of the water sluicing, the water and suspended waste slurry was transferred to DST AN-101.

Final sluicing and hard heel removal operations were shut down on tank C-104 on August 17, 2012. Water sluicing effectively removed additional solids and allowed for some additional

dissolution of remaining solids. Video evidence shows that sluicing operations continued to break up remaining waste solids, further diminished the size of waste piles, and moved fine waste materials toward the slurry pump. As noted above, chemical analysis of samples of the dissolution liquor also suggested that nearly half of the sodium aluminate generated during the metathesis was dissolved and removed during this sluicing operation.

Based on the performance metrics examined with the implementation of this technology and consideration of the factors specified in the Consent Decree, DOE concluded that the caustic cleaning retrieval technology has been deployed to the limit of technology at tank C-104.

Waste Retrieval Efficiency. The preliminary estimate for the MS campaign indicated that it would require 10.27 million gal of slurry to transfer the estimated 259,000 gal of tank C-104 waste to DST AN-101. In the first 1.6 million gal of the slurry pumped from tank C-104, over 200,000 gal of waste was transferred from tank C-104 to DST AN-101, at almost twice the expected rate. However, when the campaign had transferred ~82 percent of the forecasted waste volume (~210,000 gal) to DST AN-101 (operating day 22), the retrieval rate dropped off because an obstruction in the tank prevented the slurry pump from being lowered further. An articulating mast system was installed in tank C-104 to move the obstruction out from underneath the slurry pump. Retrieval activities restarted and 252,000 gal of waste was transferred by operating day 50 (Figure 4-13 for retrieval efficiency rates) (RPP-RPT-54072). As can be seen from Figure 4-13, the rate of waste retrieval by caustic cleaning progressed linearly as anticipated.

Conclusion. DOE concluded that waste retrieval operations were performed to the limits of technology for MS caustic cleaning (RPP-53823).[42]

4.3.3.5 Tank C-105

Physical waste retrieval has recently been completed for tank C-105. Retrieval operations began in June 2014. The first two technologies deployed were venturi vacuum with water and supernate, followed by high-pressure water spray, both implemented via the MARS-V system. Approximately 91,000 gal of the tank waste volume was retrieved. A third technology was deployed in August 2017, using chemical dissolution (caustic), with an ERSS. This campaign removed approximately 28,000 gal of additional waste before the apparent limit of the technology was reached. Waste was transferred to DST AN-106. The final engineering report on retrieval efficiency, limits of technology, and final residual volume is anticipated in the near future.

4.3.3.6 Tank C-106

4.3.3.6.1 Waste Retrieval Operations

Two retrieval technologies were deployed to retrieve waste from tank C-106. The first technology was sluicing (also known as “past practice” sluicing), which began in November 1998 and reached the limit of technology in October 1999. The second technology

[42] DOE submitted RPP-53823, “Retrieval Completion Certification Report for Tank 241-C-104” to Ecology via letter 15-TF-0018, dated 3/21/13. DOE submitted RPT-RPP-54072, “Retrieval Data Report for Single-Shell Tank 241-C-104” via letter 14-TF-0013, dated 02/18/14.

was MS with acid dissolution, which was deployed in April 2003 and completed in December 2003. Based on the declining performance data of these two technologies, it was determined that these methods would not retrieve the additional waste required to meet the HFFACO criteria of less than 360 ft^3 (RPP-20658, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106").

4.3.3.6.2 Limit of Technology

Sluicing System Retrieval Campaign, 1998 to 1999. To address a high-heat safety issue, a tank C-106 waste retrieval effort using a sluicing system was initiated in November 1998 and completed in October 1999 (HNF-5267, "Waste Retrieval Sluicing System Campaign Number 3 Solids Volume Transferred Calculation"). Sluicing operations were conducted using DST AY-102 supernate as a sluicing medium.

The initial waste volume in September 1998 was ~230,000 gal, of which ~197,000 gal was sludge (HNF-EP-0182-126, "Waste Tank Summary Report for Month Ending September 30, 1998").

The sluicing effort successfully resolved the tank C-106 high-heat safety issue. The campaign also met the following waste retrieval requirements: (RPP-20577)

1. Retrieve at least 95 percent (~187,000 gal) of the estimated 6 ft of total sludge;
2. Retrieve waste until the rate of sludge removal is less than 7,500 gal [~7.6 cm (3 in.)] per 12-hour sluice batch and evidence of diminishing retrieval effectiveness is documented for three consecutive batches.

These requirements defined the limit of sluicing retrieval capability for tank C-106. In December 1999, Ecology provided DOE written notification that the waste retrieval criteria requirements had been met for this retrieval campaign (Fitzsimmons 1999, "Completion of Hanford Federal Facility Agreement and Consent Order Interim Milestone M-045-03B").

Approximately 44,892 gal (6,001 ft^3) of solid and liquid waste remained in July 2000 (RPP-12547, "Tank 241-C-106 Residual Liquids and Solids Volume Calculation"). The volume of waste in tank C-106 was measured in July 2000. The estimate of solids remaining in the tank was 9,056 gal (1,211 ft^3), the same as was previously calculated; however, the volume of liquid decreased by ~10,000 gal. The August 2002 estimate of waste volume in tank C-106 was 35,986 gal (4,811 ft^3) (RPP-12547). The liquid reduction was attributed to evaporation (RPP-20658).

The tank C-106 evaporation rate was evaluated based on measured moisture content in the air being exhausted from the tank following conclusion of the 1998 to 1999 waste retrieval campaign. The total difference between the 2000 and 2002 measurements is consistent with past calculations and operational experience with evaporation rates in SSTs. Evaporation rates are based on material balances and visual inspections. Inaccuracies are noted but do not affect the overall retrieval efficiency.

The 1998 to 1999 sluicing campaign was completed in October 1999. The ventilation system (which also served tank C-105) operated until June 2001. Prior to 1998, tank C-106 was a high-heat tank and the evaporation rate was ~189 gal/day (in 1994). Following the 1998 to 1999

retrieval, the average evaporation rate was between 10 and 24 gal/day (RPP-20658). Monthly psychrometric readings were taken for tank C-106 until 2001 (RPP-20658).

Modified Sluicing and Acid Dissolution Retrieval Campaign – 2003. To remove the remaining waste in tank C-106, acid dissolution was used to dissolve solids. Oxalic acid, which had been used at the Hanford Site and other DOE sites to decontaminate tanks and equipment, was used to dissolve solids and reduce waste particle size to enable waste transfer. MS incorporated various performance enhancements over the "past practice" sluicing techniques that were used to remove the bulk of tank C-106 waste. These enhancements included combinations of pump and nozzle designs to break up the solids and move them to the pump intake. The combination of the acid dissolution and the mechanical breakup of waste by a nozzle stream was designed to maximize removal of waste (RPP-20658).

The effectiveness of oxalic acid to remove contamination on waste processing equipment at the DOE Savannah River Site facilities is documented in WSRC-TR-2003-00401, "Waste Tank Heel Chemical Cleaning Summary." Laboratory-scale testing of acid dissolution of tank C-106 waste demonstrated that nearly 70 percent of the waste solids dissolved in oxalic acid (RPP-17158, "Laboratory Testing of Oxalic Acid Dissolution of Tank 241-C-106 Sludge").

Several methods of operation were used for the tank C-106 waste retrieval operation:

- Oxalic acid was added in discrete and accurately measured batches through the mixer eductor or the pump drop-leg (RPP-20658).
- Acid was recirculated with the mixer-eductor (for the first four batches of oxalic acid); the acid was removed using the retrieval pump. Water was continuously added (between 85 and 350 gpm) through one of the two sluicers to mobilize and redistribute, as well as to remove solids, with subsequent or concurrent removal by the retrieval pump (RPP-20658).
- A flow totalizer was used to measure the water added to tank C-106. A flow totalizer reading is expected to be within 0.5 percent accuracy based on the manufacturer's information. The accuracy can be affected by temperature, percent solids in a slurry, flow rate, and pressure. For water additions, these conditions were fairly constant and with no solids present. For the material balance, additions to the system (water or oxalic acid) are subtracted from the amount of change in the DST AN-106 level. The result (difference) is the estimate of waste removed from tank C-106.

The oxalic acid dissolution process leached additional waste constituents directly from the sludge and reacted with carbonates in the waste to increase solid waste porosity. The loss of carbonates and the agitation of the waste using the mixer-eductor increased the surface area of solids and therefore the amount of surface sites available for leaching waste constituents during subsequent sluicing and acid dissolution events. The acid dissolution reaction for each acid batch reached steady state after an average of 7 days based on in-tank monitoring, indicating that all the available acid reacted completely with the waste. At the completion of the acid reaction, the dissolved wastes were transferred via a pump to DST AN-106 (RPP-20658).

The MS used a hydraulic process that deployed an articulated high-pressure water head that moved the slurry to the retrieval pump intake. In this campaign, MS was initiated after the third

acid batch and used after each subsequent oxalic acid batch to remove additional waste. The equipment configuration of the single sluicing nozzle reached the limit of operational effectiveness to retrieve solid waste after the fourth acid dissolution cycle and second sluicing retrieval. The single sluicer nozzle, which was located in riser 3, was no longer effective in moving solids from the far side of the tank to the pump in the middle of the tank. Additionally, MS created piles of solids against the tank walls in the location of the tank circumference farthest from the sluicer toward the opposite wall. The motive force of the sluicer nozzle at this configuration was not able to move the remaining waste to the pump intake (RPP-20658).

In response to the diminished performance of the single sluicer head, the mixer-eductor was removed and replaced with a second sluicer nozzle. The second nozzle was installed in riser 7 and was used to break up the remaining waste piles and move the waste to the pump intake. Following this, oxalic acid was added for a sixth time to dissolve the remaining waste. The residual waste volume represents the quantity remaining after MS following the sixth oxalic acid addition and fourth MS operation (RPP-20658).

Recirculation of the oxalic acid batches to enhance the acid and waste reaction was no longer possible after removing the mixer eductor following the fifth acid batch. However, good contact between the waste and acid was realized without recirculation because most of the waste had been leveled into a thin layer, allowing the majority of the waste to be submerged in acid (RPP-20658).

Table 4-6 contains the material balance of the MS operations and indicates the approximate volume of waste that was transferred with each batch. Waste retrieval technology efficiency, based on percent solids in the slurry, was calculated to document the performance of the technology. An observed declining trend of waste removed for each subsequent MS operation ranged from 8 percent for the first operation to 0.3 percent for the final operation (RPP-20658).

Table 4-6. Material Balance Estimates for Sluice Water Additions to Tank C-106[a].

Modified Sluicing Operation	Volume of Water Added (gal)	Volume Transferred to tank AN-106 (gal)	Waste Volume Retrieved[b] (gal)	Retrieval Efficiency (estimated vol%)
1	56,160	61,033	4,873	8
2	46,472	48,079	1,607	3.3
3	59,228	60,085	857	1.4
4	83,501	83,718	217	0.3

[a] From RPP-20658, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106."

[b] Estimate of volume of waste removed for each sluicing campaign.

Three performance measures were used to determine that MS and acid dissolution had reached the limit of technology (RPP-19919, "Campaign Report for the Retrieval of Waste Heel from Tank 241-C-106"). The performance measures were as follows.

- **Acid Dissolution** – The acid dissolution process was used to dissolve and break down the sludge and the solid waste prior to MS. The result included increased solution density and a smaller waste particle size that allowed increased waste removal once MS commenced. The smaller particle size enabled more waste to be entrained during MS and subsequently pumped out of the tank. The estimated 18,000 gal of waste left in the tank prior to retrieval was equivalent to a layer that averaged about 6.5 in. across the bottom of the 75-ft-diameter tank. After oxalic acid was added, the waste was soaked to allow the waste digestion process to complete (acid reaction stabilized) and the acid pool was agitated by the mixer-eductor to facilitate the acid-waste reaction. At the completion of the soak period, the retrieval pump was used to remove the solution including entrained waste from the tank.

  The acid dissolution reacted as predicted in the Process Control Plan and the data was recorded for each batch until steady-state pH readings were attained. Oxalic acid was added in six separate batches and the dissolution performance ended in diminished returns for the last two batches. In the final batch, the pH of the solution showed a gradual increase during the first 6 days, indicating that the acid had reacted with the waste and no increase occurred (steady state) during the rest of the contact period. The average pH over the last 4 days was ~0.79, but never reached the expected acid depletion endpoint (a pH of about 1.5), indicating that the exposed waste was fully reacted. This was an indication that all the waste available to dissolve had reacted, that waste remained unreacted, and that the limit of technology to further dissolve and entrain waste had been reached. The result of waste forms not dissolving in the acid are consistent with the laboratory testing, which documented that up to 30 percent of the solids would not dissolve in oxalic acid (RPP-17158).

- **Waste Entrainment** – The waste solids remaining were resistant to further breakdown by acid dissolution or by mechanical breakup by the MS stream. This was documented by the diminished mass transfer of solids in the waste slurry pumped from the tank. Therefore, the remaining solids would not likely be entrained in the waste slurry at a rate equal to or higher than the efficiencies documented in the last MS batches.

- **Sluicing Nozzle Efficiency** – The waste that could be mobilized to the pump intake had been moved to within the influence of the pump and retrieved as shown in the post-retrieval video. The performance criteria of the sluicing nozzle included breaking up the solid waste and moving the waste to the pump intake. In this retrieval, when the acid dissolution performance began to diminish, the single sluicing nozzle became ineffective in moving the remaining solid waste to the pump inlet. The mixer eductor was removed and replaced by a second nozzle, which allowed the remaining piles of waste to be moved toward the pump inlet or spread out to facilitate additional exposure of waste surfaces to acid. The two nozzles were not able to appreciably move additional waste to the pump inlet during the last MS, as indicated by the diminishing amount of entrained waste recorded.

The continued viability of MS with acid dissolution technologies to remove waste from tank C-106 was assessed by extrapolation of the performance data provided in RPP-20110, "Stage I Retrieval Data Report for Single-Shell Tank 241-C-106." The historical data were used with an assumed 60,000-gal sluicing batch and two extrapolation methods to estimate waste removal efficiencies to provide a range on the number of MS operations needed to remove at least 99 percent of the waste from the tank. The actual waste volume reduction and efficiency per MS operation realized by continued sluicing likely is expected to be bounded by these extrapolation methods.

The first extrapolation method used a constant waste removal efficiency for each MS operation. This constant removal efficiency method provides a reasonably optimistic estimate for continued tank waste removal because waste removal efficiencies remain constant even though there is less and less waste remaining in the tank. Using the waste removal efficiency value of 0.3 percent from results shown for MS operation four in RPP-20110, it is estimated that six to seven more MS campaigns will be required to meet the waste retrieval target. These additional MS campaigns will require approximately 360,000 to 420,000 gal of additional sluicing water.

The second extrapolation method used the method described in Appendix B of RPP-20577 to calculate a declining waste removal efficiency function based on the historical waste removal efficiency results from RPP-20110. Using this declining removal efficiency method reflects the diminishing return concept and will result in longer retrieval operations and increased liquid volume estimates for continued tank waste removal. The estimate for Alternative A shown in Appendix C of RPP-20577, uses a waste removal efficiency that declines from 1.0 to 0.07 percent and indicates that more than 1.8 million gal of sluicing water will be needed to meet the waste retrieval goal. In this scenario, the initial retrieval efficiency is assumed to be greater than the efficiency observed at the conclusion of the 2003 retrieval campaign (0.3 percent) due to improvements realized by operational experience, and then declining to 0.07 percent.

This analysis shows that under optimistic (constant) retrieval efficiencies, significant quantities of additional sluicing water will be required to remove residual tank waste, and retrieval liquids would constrain the available DST storage capacity. If the declining retrieval efficiency approach is experienced, the waste retrieval goal may never be reached and/or the volume of retrieval liquids would rapidly exceed the available DST storage capacity, limiting capacity required to support additional tank waste retrievals.

Conclusion. The limit of technology for retrieving waste from tank C-106 has been reached for deployment of the following:

1. Sluicing (1998 to 1999) as concurred with by Ecology in Fitzsimmons 1999;
2. MS with acid dissolution (2003) based on the technology performance data summarized above and documented in RPP-19919.

The nominal residual waste volume in tank C-106 at the limit of technology was calculated to be ~370 ft^3. When uncertainties associated with the volume calculation methods were evaluated, the residual waste volume was calculated to be between 275 ft^3 (2,060 gal) and 467 ft^3 (3,497 gal) at a 95 percent UCL (RPP-20658).

Therefore, key radionuclides have been removed from tank C-106 to the maximum extent that is technically and economically practical. [43]

4.3.3.7 Tank C-107

4.3.3.7.1 Waste Retrieval Operations

Retrieval of tank C-107 waste occurred in three campaigns (RPP-RPT-58150, "Retrieval Completion Certification Report for Tank 241-C-107"). Retrieval of tank C-107 stored waste was conducted between September 26, 2011 and August 7, 2014. The two main waste retrieval technologies used in tank C-107 for bulk retrieval were MS and the use of high-pressure water and pump backstop as delivered with the MARS arm. The third retrieval technology was conducted using water-based chemical dissolution and MS using the MARS arm. DOE-ORP concluded that waste retrieval operations were performed to the limits of the MARS sluicing technology, the high-pressure water retrieval technology, and the water-based chemical dissolution and MS (RPP-RPT-58295, "Retrieval Data Report for Single-Shell Tank 241-C-107").

4.3.3.7.2 Limit of Technology

Retrieval System Performance. The sluicing retrieval system effectively removed most of the sludge from tank C-107, including the small-particle-size waste that could be removed and transferred. The waste composition was unlike other WMA C tanks, in that the waste was not dominated by gibbsite and thus unlikely to require caustic cleaning for the majority of the waste. For this reason, the MARS-S was selected to conduct the waste retrieval primarily through mechanical impact of liquid upon the waste solids resulting in the fluidization and pumped retrieval of the size-reduced material. Supernatant liquid from DST AN-106 and high-pressure water were provided for a hydraulic mining operation (RPP-RPT-58295).

The MARS-S provided multiple technologies to be deployed for waste retrieval within one tool set. The MARS-S end-effector had two types of supernate sluicing nozzles as well as

[43] DOE submitted RPP-20110, "Stage I Retrieval Data Report for Single-Shell Tank 241-C-106" via letter 04-TPD-025, dated 2/27/04. DOE submitted RPP-20577, "Stage II Retrieval Data Report for Single-Shell Tank 241-C-106" and RPP-20658, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106" via letter 04-TPD-059, dated 6/3/04.
In response to NRC Requests for Additional Information (RAIs), ORP prepared RPP-RPT-26695, "NRC Staff Comments and DOE-ORP Responses Associated with DOE-ORP Documents Establishing the Extent of Retrieval for Tank 241-C-106," submitted via letter 05-YPD-080, dated 8/18/2005.
On May 18, 2006, ORP submitted the Hanford Initial SST PA, DOE/ORP-2006-01, rev 0 via letter 06-TPD-028.
On April 18, 2008, ORP submitted RPP-20658 rev 3 which was an update to the basis for exception to the HFFACO retrieval criteria for C-106, requesting NRC review, via letter 08-TPD-017; on the same date, ORP also submitted RPP-20658 rev 3 to Ecology and EPA, via letter 08-TPD-018.
On January 30, 2009, NRC (Patrice M. Bubar) submitted a request for additional information (28 comments) in response to 08-TPD-017, sent to ORP (SJ Olinger).
On March 16, 2009, ORP sent letter 09-TPD-015 stating that ORP understands the nature of the RAIs from January 30, 2009 but believes that the WMA C PA being prepared for the TPA Action Plan, Appendix I, Section 2.5 will provide a suitable basis for addressing the RAIs. DOE plans no further action related to the prior correspondence, as these activities are overcome by the WMA C PA and the planned consultation with NRC concerning this Draft WIR Evaluation.

high-pressure water nozzles. The slurry pump mast had a re-deployable backstop designed to provide a waste solids collection, suspension, and breakup with high-pressure water nozzles and supernate nozzles within the backstop.

Trends and specific operations during the retrieval are depicted in Figure 4-14. The retrieval trend displayed in Figure 4-14 indicates a good retrieval rate to ~450 hours of operations, using a combination of MARS-S sluicing and high-pressure water retrieval technologies.

Based on the performance metrics examined with the implementation of MARS-S, high-pressure water, and chemical retrieval technologies and consideration of the factors specified in the Consent Decree, DOE-ORP concluded that these retrieval technologies had been deployed to the limit of technology (RPP-RPT-58150).

Waste Retrieval Efficiency. The preliminary estimate for the tank C-107 MS rate campaign indicated that it would require over 9 million gal of slurry to transfer the estimated 247,000 gal of waste to DST AN-106 (RPP-PLAN-40145). In the first 425 hours of the slurry being pumped from tank C-107, over 220,000 gal of waste was transferred to DST AN-106. However, when the campaign had transferred ~85 percent (~350 hours of operation) the waste retrieval rate slowed appreciably.

Conclusion. DOE-ORP has concluded that waste retrieval operations were performed to the limits of the MARS-S technology, the high-pressure water retrieval technology, and the water-based chemical dissolution and MS (RPP-RPT-58295).[44]

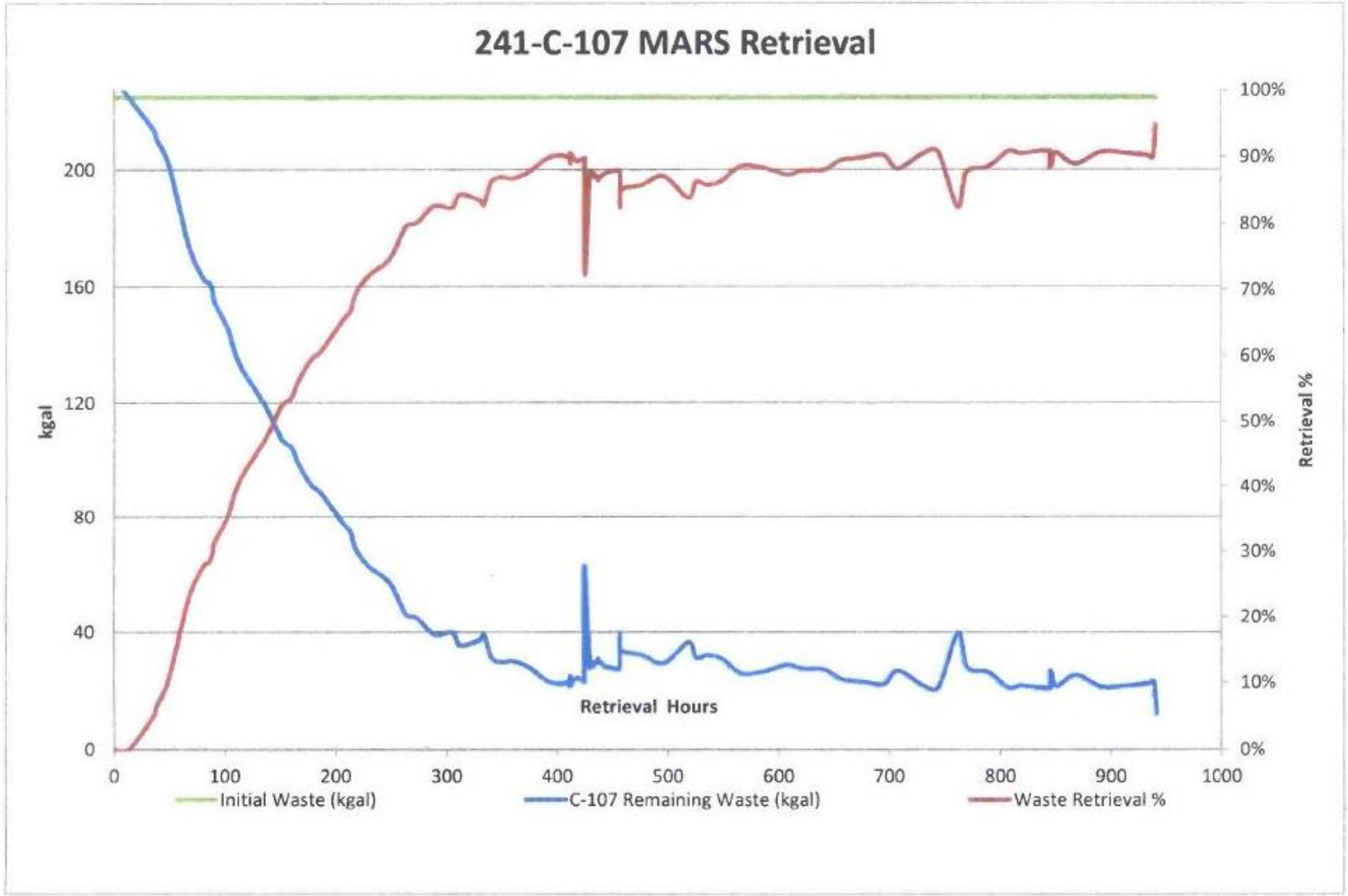
4.3.3.8 Tank C-108

4.3.3.8.1 Waste Retrieval Operations

The tank C-108 MS campaign began on December 20, 2006 and was suspended on April 27, 2007 after reaching the limit of technology. The caustic cleaning campaign began on October 13, 2011 and concluded on March 22, 2012 after reaching the limit of technology. The tank C-108 waste that was removed was transferred to DST AN-106 (RPP-RPT-55896, "Retrieval Data Report for Single-Shell Tank 241-C-108").

[44] DOE submitted RPP-58150, "Retrieval Completion Certificate Report for 241-C-107" to Ecology via letter 14-TF-0114, dated 9/30/15. DOE submitted RPT-RPP-58295, "Retrieval Data Report for Single-Shell Tank 241-C-107" via letter 15-TF-0086, dated 9/14/15.

Figure 4-14. Tank C-107 Retrieval Performance Trends.



MARS = mobile arm retrieval system

4.3.3.8.2 Limit of Technology

DOE-ORP relied on the following three types of data to determine when the limit of technology to retrieve waste from tank C-108 was reached:

1. Examination of in-tank photos/videos to record the waste surface contours, form, and characteristics;
2. Use of retrieval performance efficiency based on daily material mass balance calculations;
3. Use of retrieval performance data trends estimated from material balances to demonstrate that a consistent pattern is present indicating that as much waste has been removed as possible.

Visual Observations. A video camera inside tank C-108 allowed operational monitoring of activities and results throughout the waste retrieval campaign. Video observation of physical characteristics of the tanks and objects in the tanks aided in measuring residual waste volume change at the end of retrieval. Reduction in waste volume in the tank was observed as retrieval progressed, as shown in Figure 4-15 (RPP-RPT-55896).

Waste Retrieval Progress. Before MS began, most of the waste in tank C-108 consisted of a soft brown sludge. The MS progressed quickly over the first 11 days of operation as the soft sludge was readily mobilized by the sluicers and pumped from the tank. Most of the soft sludge had been removed by January 11, 2007, leaving behind larger-sized, lighter-colored solids that required more effort to break up and mobilize. Most of the area under and between the two sluicers had been cleared of solids; the tank bottom was either exposed or covered by a relatively thin layer of solids. The sluicers were able to move these solids about the tank, but the solids tended to settle too quickly to be entrained in the slurry and pumped. The bulk of the remaining solids were near the tank knuckle (the section connecting the tank dish and the tank walls) on the east and west sides of the tank furthest from the sluicers (RPP-RPT-55896).

Figure 4-16 shows MS performance as a function of the volume of slurry transferred from tank C-108 to DST AN-106. The occasional decreases in the volume retrieved shown in Figure 4-16 reflect fluctuations in the ending tank C-108 liquid pool volume. It was not always possible to pump the tank C-108 liquid pool to the same minimum heel at the end of each operating period.

MS performance was tracked by trending the net waste volume increase in receiver DST AN-106 after accounting for water additions; this is shown as the Operating Data line in Figure 4-16. This running volume balance did not distinguish between liquids and solids and did not account for solids dissolution or liquid evaporation. As the volume retrieved approached the starting waste volume, the estimate of the volume remaining in tank C-108 by difference became increasingly sensitive to uncertainties in the starting waste volume estimate and cumulative measurement uncertainties.

The Adjusted line in Figure 4-16 is an estimate of the actual volume of tank C-108 waste retrieved. Subtracting the results of the volume displacement measurements (RPP-CALC-33487, "Estimate of Waste Volume and Percent Retrieved for Tank 241-C-108") from the starting

volume of 66,000 gal gives an estimate of 58,800 gal retrieved as of April 12, 2007, ~17,800 gal more than the volume estimated from the running volume balance (Operating Data).

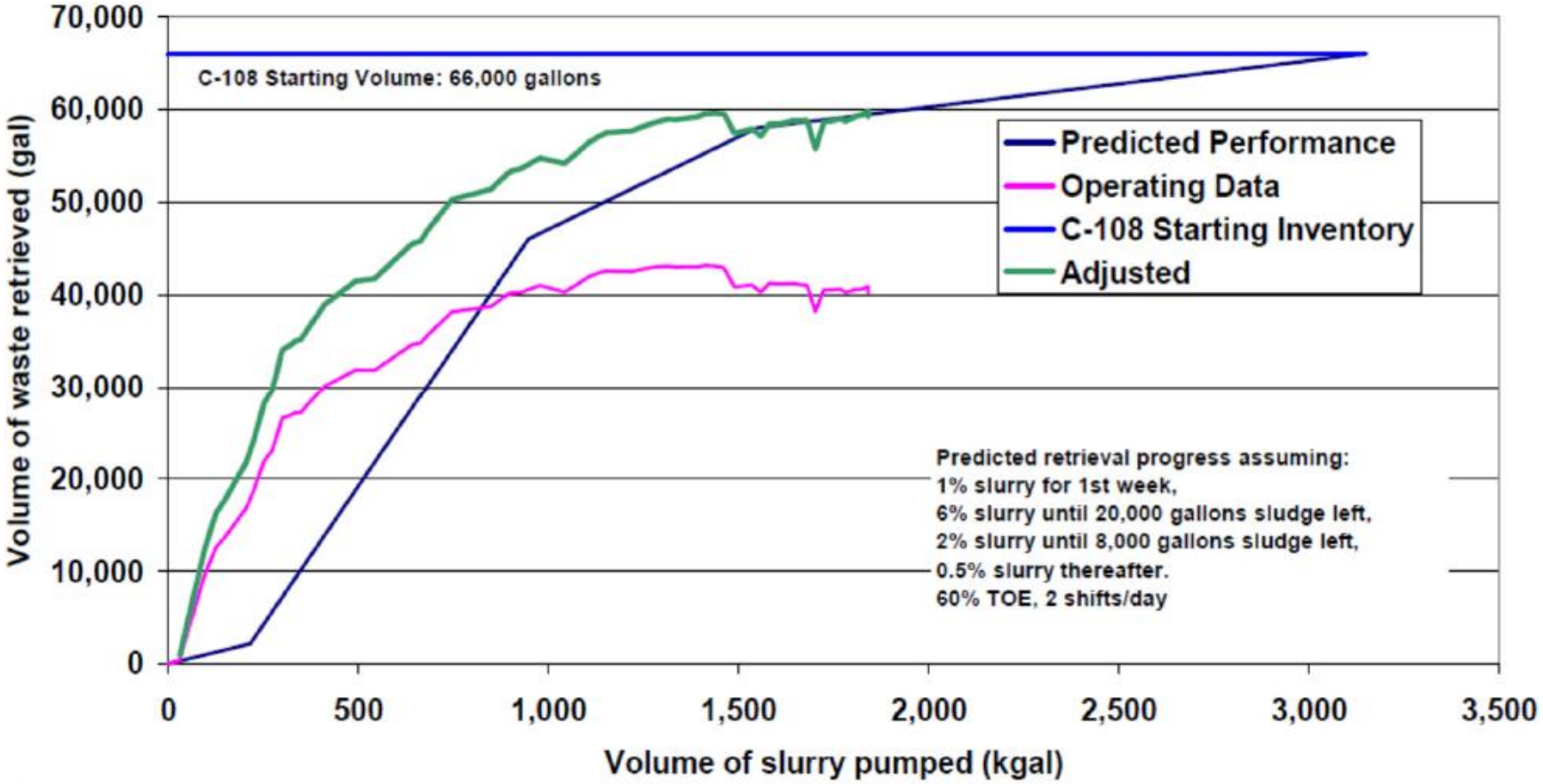
Figure 4-15. Tank C-108 Video Still Recorded September 16, 2012, Camera Elevation Approximately 8 feet from Tank Bottom.

The O.R.S.S. next to SP-2 to illustrate the height of the pile.

Both the sluicing Operating Data and Adjusted waste retrieval volumes show the limit of technology being reached following the transfer of ~1.5 million gal of slurry. The retrieval campaign and limit of technology are discussed in detail in RPP-52290, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108."

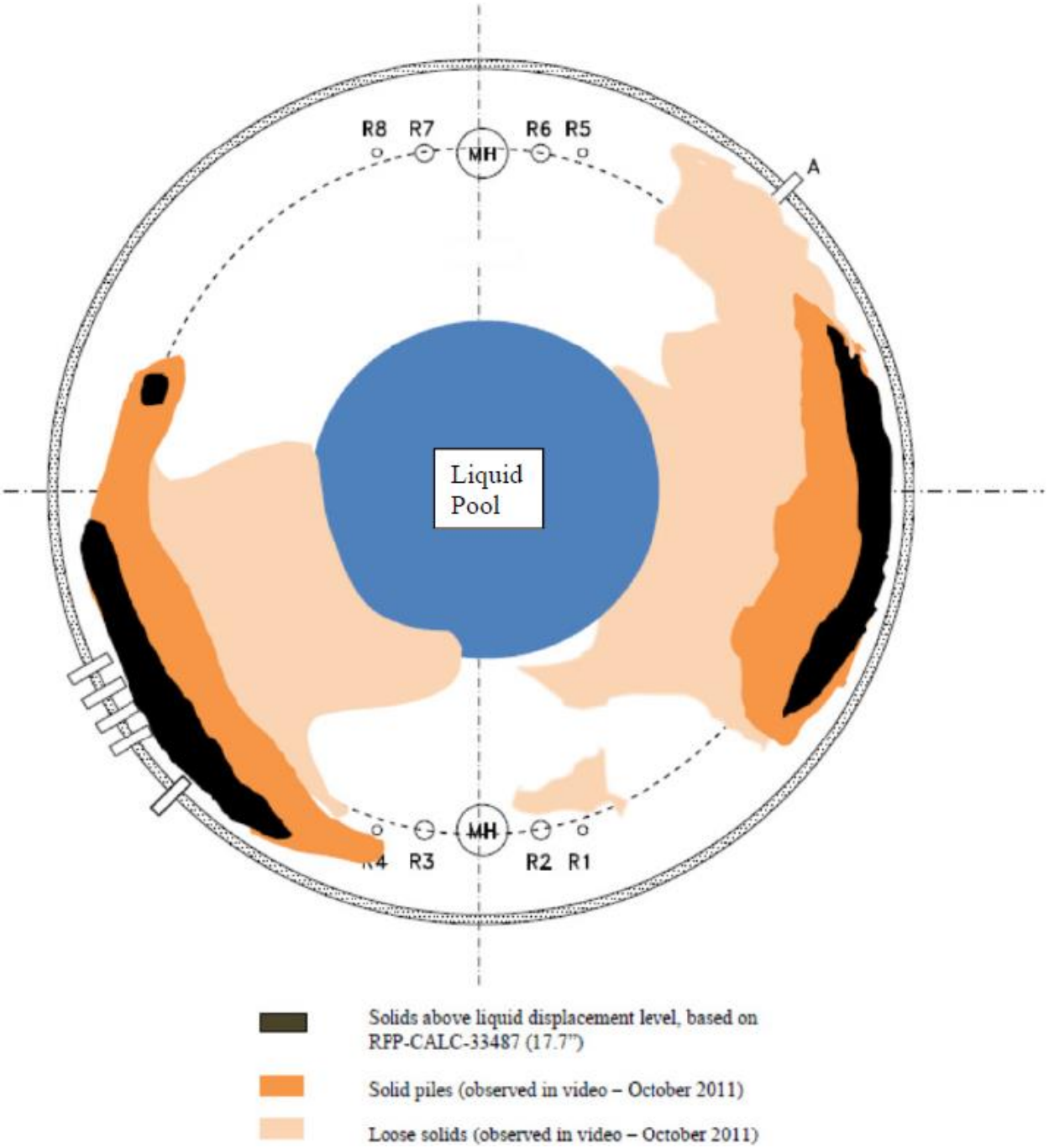
Figure 4-17 shows a diagram of the approximate distribution of solid material following MS. The bulk of the remaining waste was mostly solids (hard heel) not movable by sluicing action and insoluble in DST AN-106 supernate. Samples of the residual waste were obtained and analyzed. Solid phase characterization results show the presence of two primary constituents: gibbsite and natrophosphate in an approximate 1:1 ratio (40 wt percent gibbsite and 60 wt percent natrophosphate) (LAB-RPT-10-00001, "Results of Physicochemical Characterization and Caustic Dissolution Tests on Tank 241-C-108 Heel Solids").

Figure 4-16. Tank C-108 Modified Sluicing Waste Retrieval System Performance.



TOE = Total Operating Efficiency

Figure 4-17. Approximate Distribution of Material after Modified Sluicing in Tank C-108.

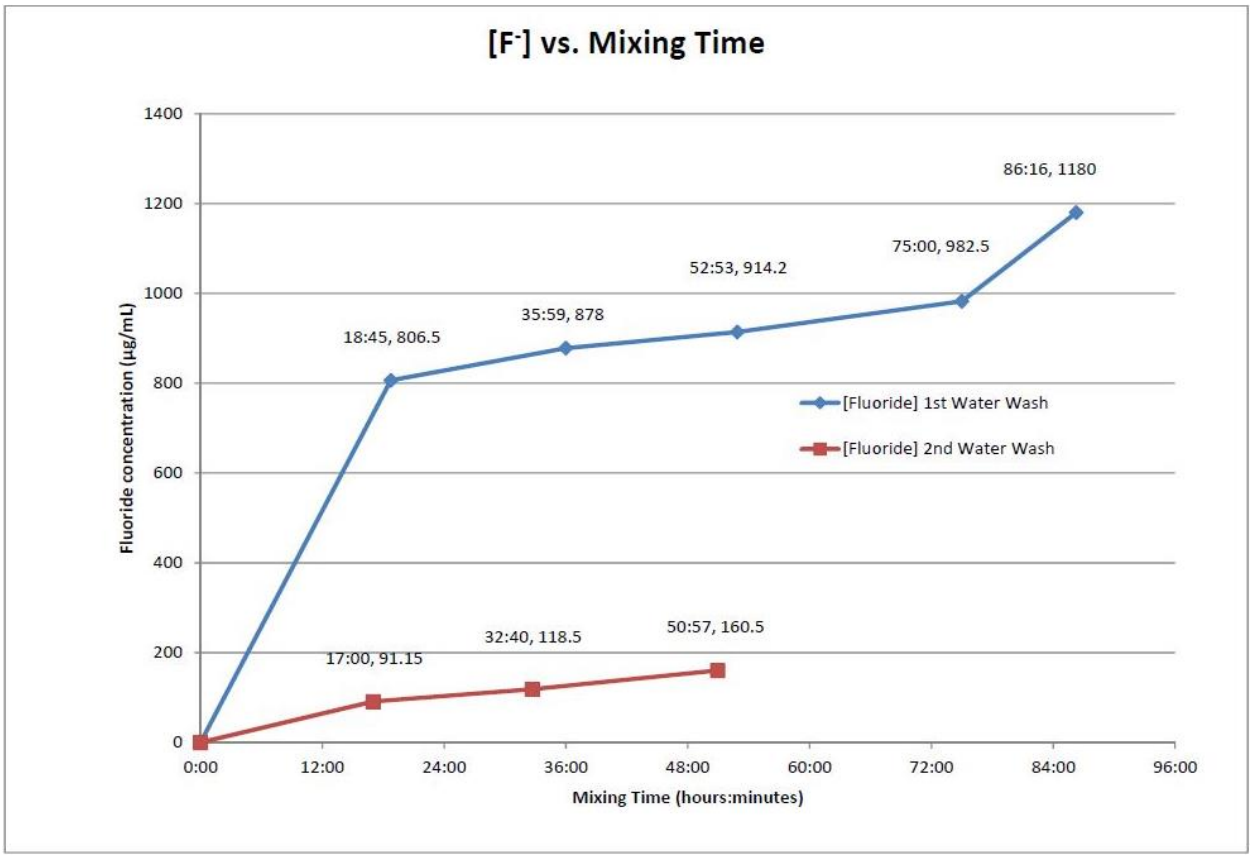


Reference: RPP-CALC-33487, "Estimate of Waste Volume and Percent Retrieved for Tank 241-C-108."

The caustic cleaning process was divided into two parts. Each part addressed a different chemical species: sodium fluoride phosphate and gibbsite. The progress of sodium fluoride phosphate water dissolution was tracked by periodic sampling of the liquid and analyzing for fluoride concentration in the liquid. It was anticipated that the fluoride concentration would rise

rapidly and then slow as the solids were depleted or the liquid became saturated. Figure 4-18 shows the sampling results as a function of the circulation/mixing time.

Figure 4-18. Fluoride Concentration Chart for Tank C-108.



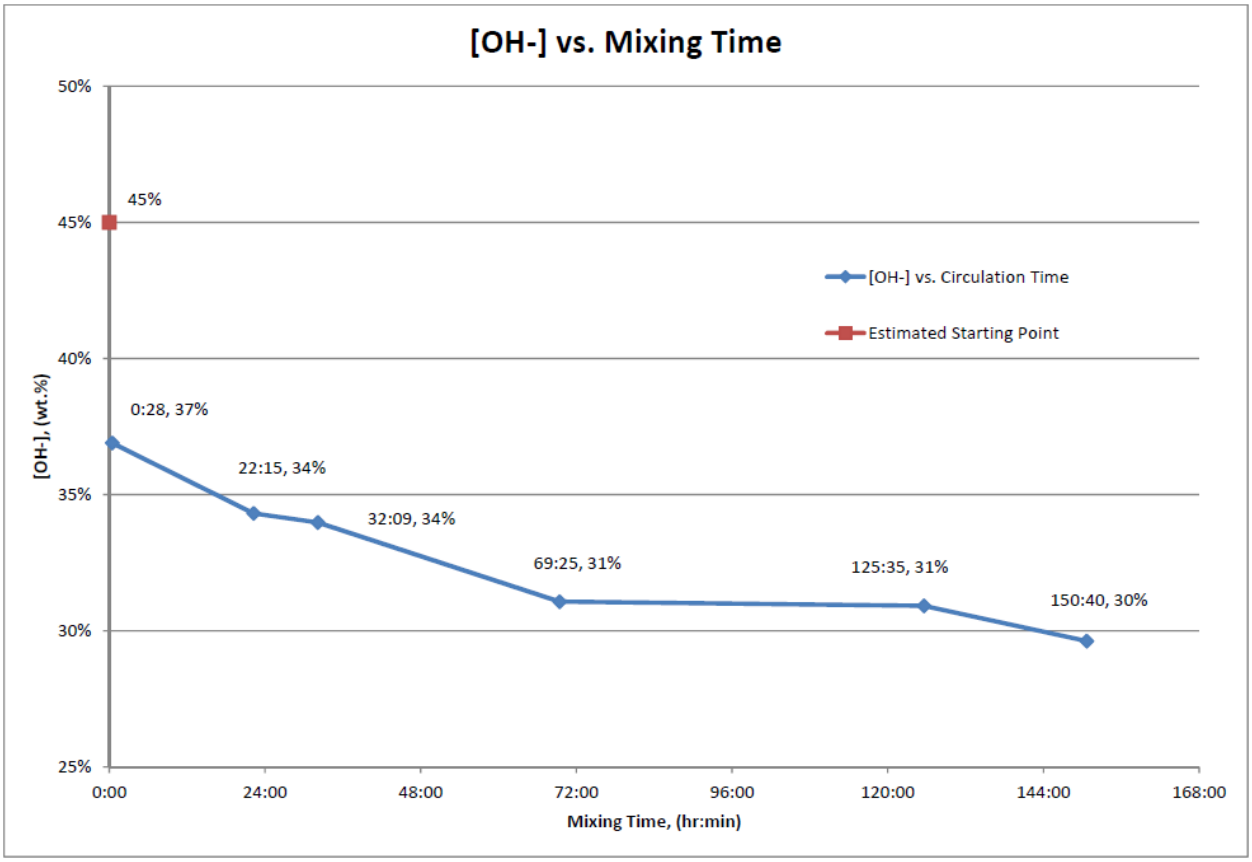
Reference: RPP-RPT-55896, "Retrieval Data Report for Single-Shell Tank 241-C-108,"

The upper line in Figure 4-18 (diamonds) represents the first water wash and the lower line (squares) represents the second water wash. During the first water wash it was anticipated that the initial dissolution process would be completed between October 23 and November 1, 2011. The tank remained quiescent with no mixing from November 2, through December 29, 2011, due to concerns over the possibility of equipment being damaged by freezing; the liquid was sampled on December 30, 2011. After initial dissolution, the dissolution rate slowed but was fairly constant. Solubility of sodium fluoride phosphate is temperature sensitive. Under the conditions of the first wash, it was projected that the solution reached about 60 percent of saturation. However, it was estimated that not more than 40 percent of the available sodium fluoride phosphate had dissolved (RPP-RPT-55896). Therefore, it was decided to perform a second water wash. The second wash proved to be fairly ineffective in achieving additional dissolution as can be seen by the low total concentration achieved and the lower rate of increase graphed in Figure 4-18.

The second part of the caustic dissolution process was designed to retrieve aluminum compounds with specific emphasis on gibbsite, the second most common compound found in the tank C-108 post-sluicing sample. The process converted the aluminum compounds from a largely insoluble

form to a much more soluble form by soaking in very high concentration caustic solution. This is a slow reaction and requires a long contact time to go to completion. Once the reaction went to completion, water was added to dilute the hydroxide and allow the soluble form (sodium aluminate) to dissolve. Sodium aluminate dissolution is rapid. After the dissolution was complete, the contents were pumped from tank C-108. The process of converting gibbsite to the sodium aluminate form was tracked by sampling and analyzing the caustic concentration. Because much of the waste heel was above the liquid level in tank C-108, the liquid was circulated and the waste solids were sprayed with the caustic solution. Video shows that the large piles of waste broke down and were washed below the liquid pool surface during the process. Figure 4-19 shows the results from sampling the caustic during the conversion reaction (RPP-RPT-55896).

Figure 4-19. Hydroxide Concentration Chart for Tank C-108.



Reference: RPP-RPT-55896, "Retrieval Data Report for Single-Shell Tank 241-C-108,"

The diamonds along the curve in Figure 4-19 represent sampling events. Each sampling event is labeled with the total circulation time and measured hydroxide concentration. The reaction appears to have progressed fairly well during the first four samples. The results from the last three samples were within the sampling analytical error. From a practical standpoint those samples were the same value, indicating the reaction had stopped.

There are two reasons that reaction would stop: (1) the caustic concentration drops too low to sustain the reaction or (2) the available gibbsite has already reacted. Laboratory results indicate

that reaction should continue until the caustic concentration is ~25 wt percent if there is gibbsite present. Because the caustic concentration was ~30 wt percent, it was concluded that the available gibbsite was reacted.

DOE-ORP concluded that the process went to completion and reached its practical limits. (RPP-RPT-55896) Tank C-108 caustic solution was circulated for ~3 hours on March 19, 2012 and little to no visual change was observed. The decision was made to add water on March 20, 2012 for sodium aluminate dissolution based on sample results and visual observations.

Waste Retrieval Efficiency. The preliminary estimate for the tank C-108 MS campaign indicated that the rate of waste retrieval would require 3.2 million gal of slurry to transfer the estimated 66,000 gal of waste to DST AN-106. In the first 300,000 gal of the slurry pumped from tank C-108, over half of the waste was transferred to DST AN-106 at almost twice the expected rate. However, when about a third of the forecasted slurry volume had been transferred (1 million gal) to DST AN-106, the tank C-108 waste retrieval rate become insignificant (RPP-RPT-55896).

Laboratory analysis report LAB-RPT-10-00001 shows that a significant portion of the tank C-108 post-sluicing residual waste would dissolve in a combination of water and caustic cleaning steps. The result of these actions removed only ~28 percent of the estimated post-sluicing residual waste volume.

Conclusion. DOE-ORP concluded that MS waste retrieval operations were performed to the limit of technology. RPP-52290 was developed to assess whether a third tank C-108 waste retrieval campaign should be undertaken. RPP-52290 was issued in May 2012 and updated as Revision 1 in August 2012 to incorporate new information. The report concludes that the two waste retrieval technologies deployed at tank C-108 had each been deployed to their respective limit of technology, and that a further waste removal campaign is not practicable as that term is used in Appendix C, Part 1, of the Consent Decree. Ecology agreed with the RPP-52290 premise in letter response 12-NWP-178, "Re: Department of Ecology Response to the United States Department of Energy's Letter 12-TF-0037, dated September 4, 2012, and Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108, RPP-52290, Rev. 1".[45]

4.3.3.9 Tank C-109

4.3.3.9.1 Waste Retrieval Operations.

The first waste retrieval campaign for tank C-109 was approved by Ecology on June 15, 2005 and included MS with assistance from the FoldTrack® MRT. The tank C-109 MS waste retrieval campaign began June 19, 2007 and reached the limit of technology on August 23, 2007. Sluicing operations with the FoldTrack MRT began on June 2, 2008. At the end of MS with the

[45] DOE submitted RPP-52290, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108" to Ecology via letter 12-TF-0037, dated 9/4/12. Ecology responded with letter 12-NWP-178 on 11/16/12. DOE submitted RPP-53869, "Retrieval Completion Certificate Report for 241-C-108" to Ecology via letter 13-TF-0025, dated 5/1/13. DOE submitted RPT-RPP-55896, "Retrieval Data Report for Single-Shell Tank 241-C-108" via letter 13-TF-0120, dated 11/27/13.

FoldTrack MRT operations, the remaining waste was comprised mostly of solids (hard heel) that were not mobilized by sluicing and were insoluble in the DST AN-106 supernate. The second waste removal technology approved by Ecology on February 16, 2012 was chemical dissolution (caustic cleaning). The caustic cleaning retrieval operations began on March 8, 2012 and reached the limit of technology on September 12, 2012 (RPP-RPT-55284, "Retrieval Data Report for Single-Shell Tank 241-C-109").

4.3.3.9.2 Limit of Technology.

Visual Observations. A video camera inside tank C-109 allowed operational monitoring of activities and results throughout the waste retrieval campaign. Video observation of physical characteristics of the tanks and objects in the tanks aided in measuring residual waste volume change at the end of retrieval. Figure 4-20 (RPP-RPT-55284) shows photographs of several areas in tank C-109 after completion of all caustic cleaning steps.

Figure 4-20. Photographs of Tank C-109 at Completion of Caustic Cleaning.

Waste Retrieval Progress. Before MS began, most of the waste in tank C-109 consisted of a soft brown sludge that was readily mobilized by the sluicers and pumped from the tank. The retrieval progressed quickly over the first few days of operation. By June 22, 2007, some of the tank bottom was visible and lighter-colored, harder solids under the soft sludge were starting to

be uncovered. Most of the soft sludge had been removed by July 23, 2007. Most of the area under and between the two sluicers had been cleared of solids; the tank bottom was either exposed or covered by a relatively thin layer of solids. The sluicers were able to move the solids about the tank, but the solids tended to settle too quickly to be readily entrained and removed by the slurry pump. The bulk of the remaining solids were located near the tank knuckle (the section connecting the tank dish and the tank walls) on the east and west sides of the tank furthest from the sluicer installations (RPP-RPT-55284).

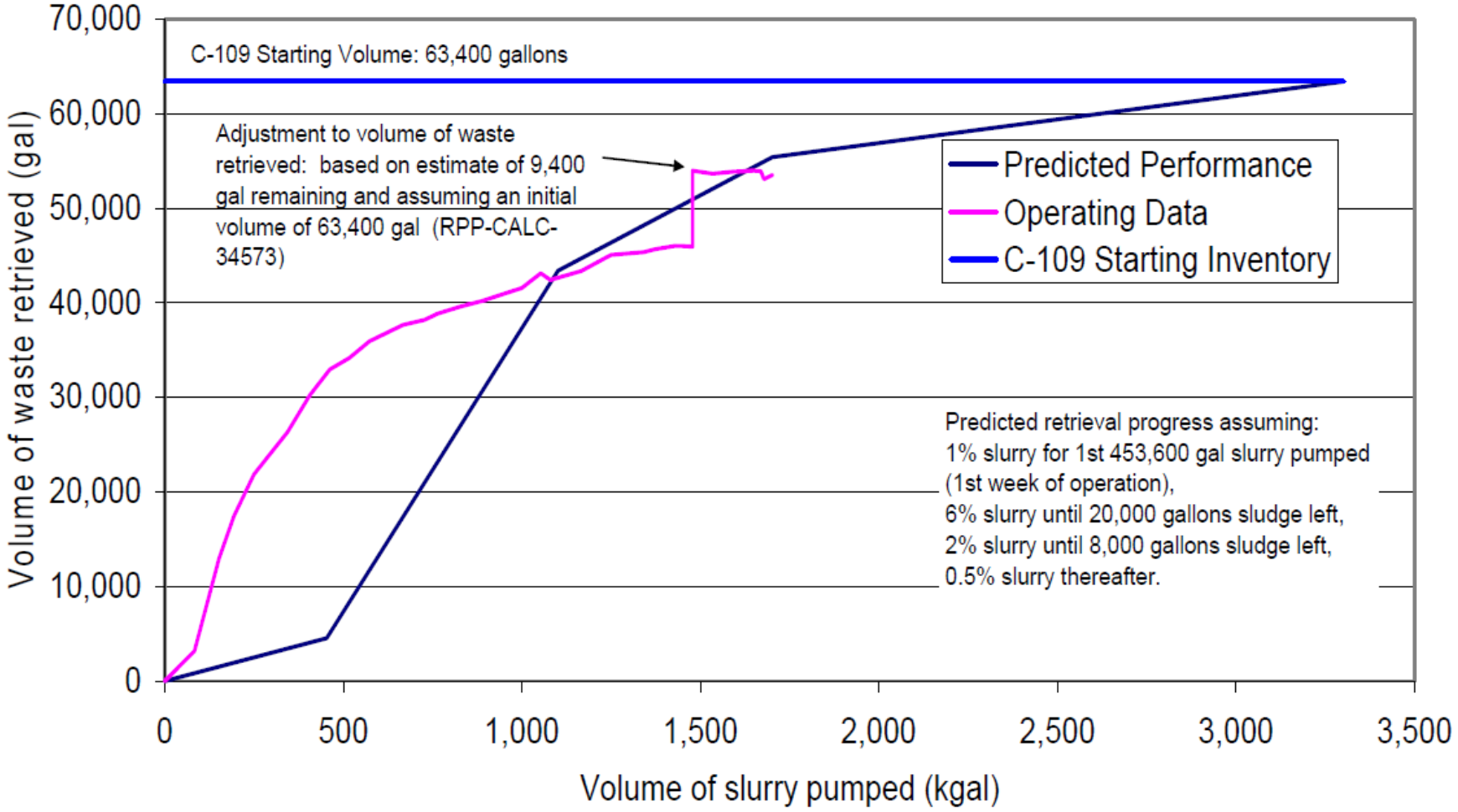
Figure 4-21 shows retrieval system performance as a function of the volume of slurry transferred from tank C-109 to DST AN-106. The occasional decreases in the volume retrieved in Figure 4-21 reflect fluctuations in the ending tank C-109 liquid pool volume. It was not always possible to pump the tank C-109 liquid pool to the same level at the end of each operating period.

Retrieval system performance was tracked by trending the net waste volume increase in receiver DST AN-106 after accounting for water additions; this is shown as the Operating Data line in Figure 4-21. This running volume balance does not distinguish between liquids and solids and does not account for solids dissolution or liquid evaporation. As the volume of waste material received by DST AN-106 approaches the starting waste volume of tank C-109, the estimate of the volume remaining in tank C-109 using the difference between these two numbers becomes increasingly sensitive to uncertainties in the starting waste volume estimate and cumulative measurement uncertainties. The running volume balance has been subsequently adjusted as described below to generate an estimate of the actual volume of waste retrieved during MS.

On July 26, 2007, ~25,000 gal of supernatant liquid from DST AN-106 were added to tank C-109 to soak the solids. The liquid was added in 5,000-gal increments, and a level measurement was taken following the addition of each increment. The level measurement was obtained using the Enraf instrument located in riser R-1. Level measurements in DST AN-106 were also taken before and after each supernate transfer. As the liquid was added to tank C-109, the difference was calculated between the expected rise in the surface level (based on the tank dimensions) and the actual rise in surface level. The actual rise in surface level is affected by the volume of solids remaining in the bottom of the tank. This method is referred to as the “volume displacement method” and allows the volume of the solids that become covered by liquid to be calculated. Details of the calculations are documented in RPP-CALC-34573, “Estimate of Waste Volume and Percent Retrieved for Single-Shell Tank C-109.” The calculation estimates that 9,400 gal of waste remained in tank C-109 on July 26, 2007. Subsequent material balances adjust that volume to ~9,880 gal. The bulk of the remaining waste is estimated to be comprised mostly of solids that are not mobilized by sluicing and insoluble in DST AN-106 supernate. The sluicing Operating Data waste retrieval volumes in Figure 4-21 show the limit of technology being reached at ~1.75 million gal of slurry pumped.

The following is a discussion of the performance of the caustic cleaning process steps as specified in RPP-PLAN-51371, “Process Control Plan for Tank C-109 Waste Heel Retrieval,” which demonstrates that the limit of technology was met in tank C-109. The caustic cleaning process was divided into two parts. Each part addressed a different chemical species: sodium fluoride phosphate and gibbsite. The first process was water dissolution of sodium fluoride phosphate.

Figure 4-21. Tank C-109 Modified Sluicing Waste Retrieval System Performance.



Reference: RPP-RPT-55284, "Retrieval Data Report for Single-Shell Tank 241-C-109."

Dissolution of the natrophosphate (also known as sodium fluoride phosphate) during the heel wash step was tracked by periodic sampling of the liquid and analyzing for the fluoride concentration in the liquid. Laboratory test results indicate that the concentration of fluoride should rapidly increase initially, and then gradually reach equilibrium as the natrophosphate is dissolved. Figure 4-22 shows the sampling results as a function of the circulation/mixing time. Figure 4-23 shows the remaining solids before and after the water wash step.

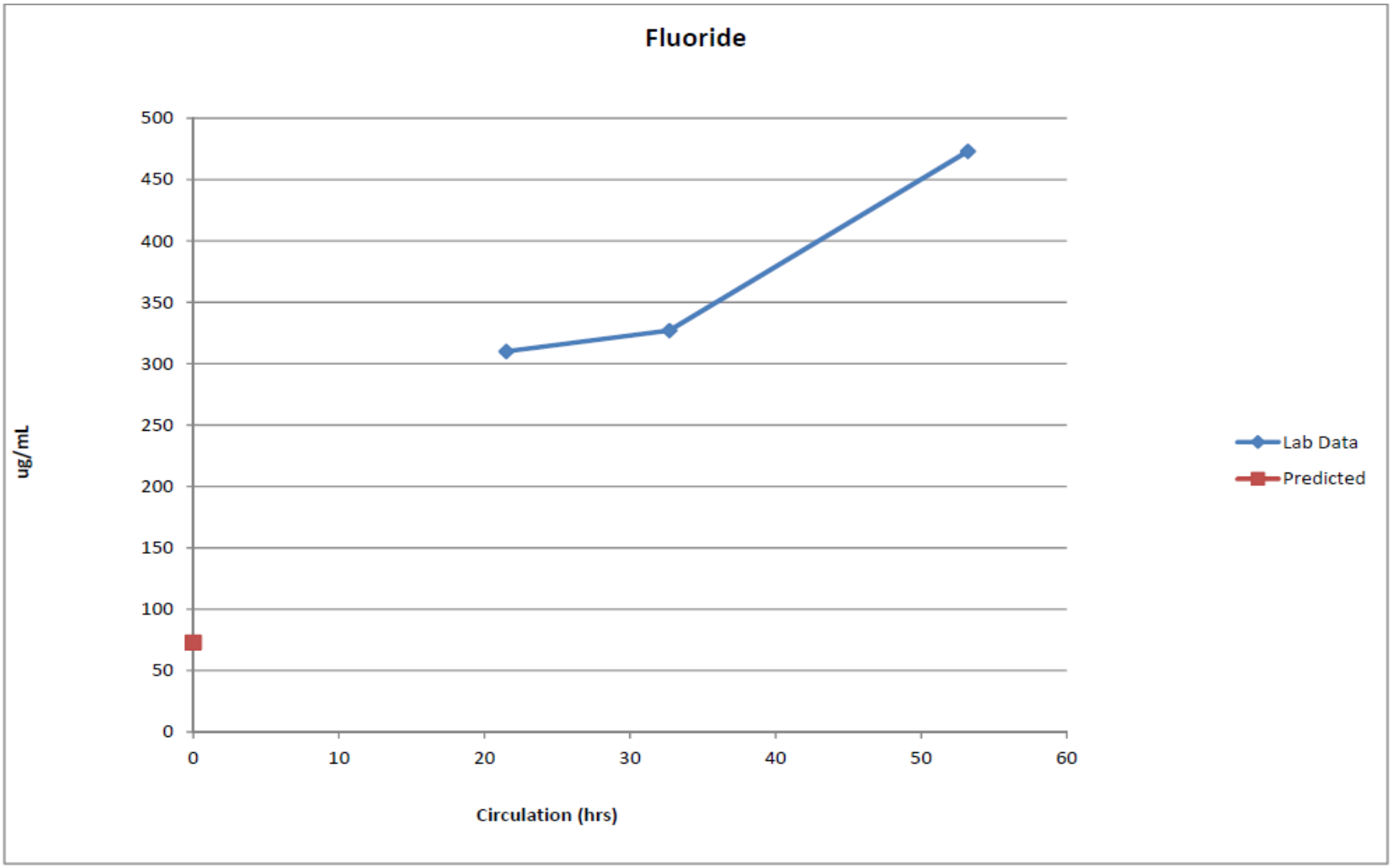
Based on RPP-RPT-51386, "Tank 241-C-109 Hard Heel Retrieval Flowsheet," estimates for the amount of fluoride in solution after dissolution is completed, it is estimated that ~30 percent of the natrophosphate may have dissolved into solution (RPP-RPT-53486, "Single-Shell Tank 241-C-109 Hard Heel Retrieval Completion Report"). Based on the predicted starting concentration, it appears that there was little change in the fluoride concentration between the first and second sample. There was also a prolonged period before the third sample could be taken because of a pump failure.

Because additional circulation time for the first water wash and a second water wash appeared to be largely ineffective during earlier retrieval of tank C-108 (RPP-RPT-52449, "Single-Shell Tank 241-C-108 Hard Heel Retrieval Completion Report"), it was determined that the wash water for tank C-109 would be transferred immediately after the third sample was taken. The potential for a second water wash following the metathesis reaction was included in the planning, in case additional natrophosphate dissolution was required. Photographs taken of the same in-tank locations before and after the water wash step (Figure 4-23) indicate that the water wash reduced the overall quantity of solids, and broke up many of the larger solid chunks in the tank. These observations supported the decision to initiate the metathesis reaction.

The second part of the caustic dissolution process was designed to retrieve aluminum compounds with specific emphasis on gibbsite. The process converted the aluminum compounds from a largely insoluble form to a much more soluble form by soaking in very high concentration caustic solution (50 wt percent NaOH). This is a slow reaction and requires a long contact time (approximately one month) to go to completion. Once the reaction went to completion, as indicated by OH and Al sample results (Figure 4-24), water was added to dilute the hydroxide and allow the soluble form (sodium aluminate) to dissolve. The sodium aluminate dissolution is rapid. After the dissolution was complete, a sample was taken and the contents were pumped from tank C-109. The process of converting gibbsite to the sodium aluminate form was tracked by sampling and analyzing the caustic concentration. Because much of the waste heel was above the liquid level, the liquid was circulated and the waste solids were sprayed with the caustic solution. Video shows that the large piles of waste broke down and were washed below the liquid pool surface during the process.

On September 12, 2012, ~15,000 gal of water were added to tank C-109 and transferred to DST AN-106 to sluice remaining solids and rinse the tank. Sluicing was performed first with sluicer number 1 (in riser R-7), then with sluicer number 2 (in riser R-2). The fines were readily mobilized during the water sluicing step. The sluicers were intentionally directed toward the larger chunks and piles of waste remaining near the sides of the tank farthest from the sluicers. The pressurized water was observed to break up the chunks and continue to reduce the size of remaining waste piles.

Figure 4-22. Fluoride Concentration as a Function of Circulation Time.



Reference: RPP-RPT-55284, "Retrieval Data Report for Single-Shell Tank 241-C-109."

Figure 4-23. Tank C-109 Remaining Solids before and after Water Wash Step.

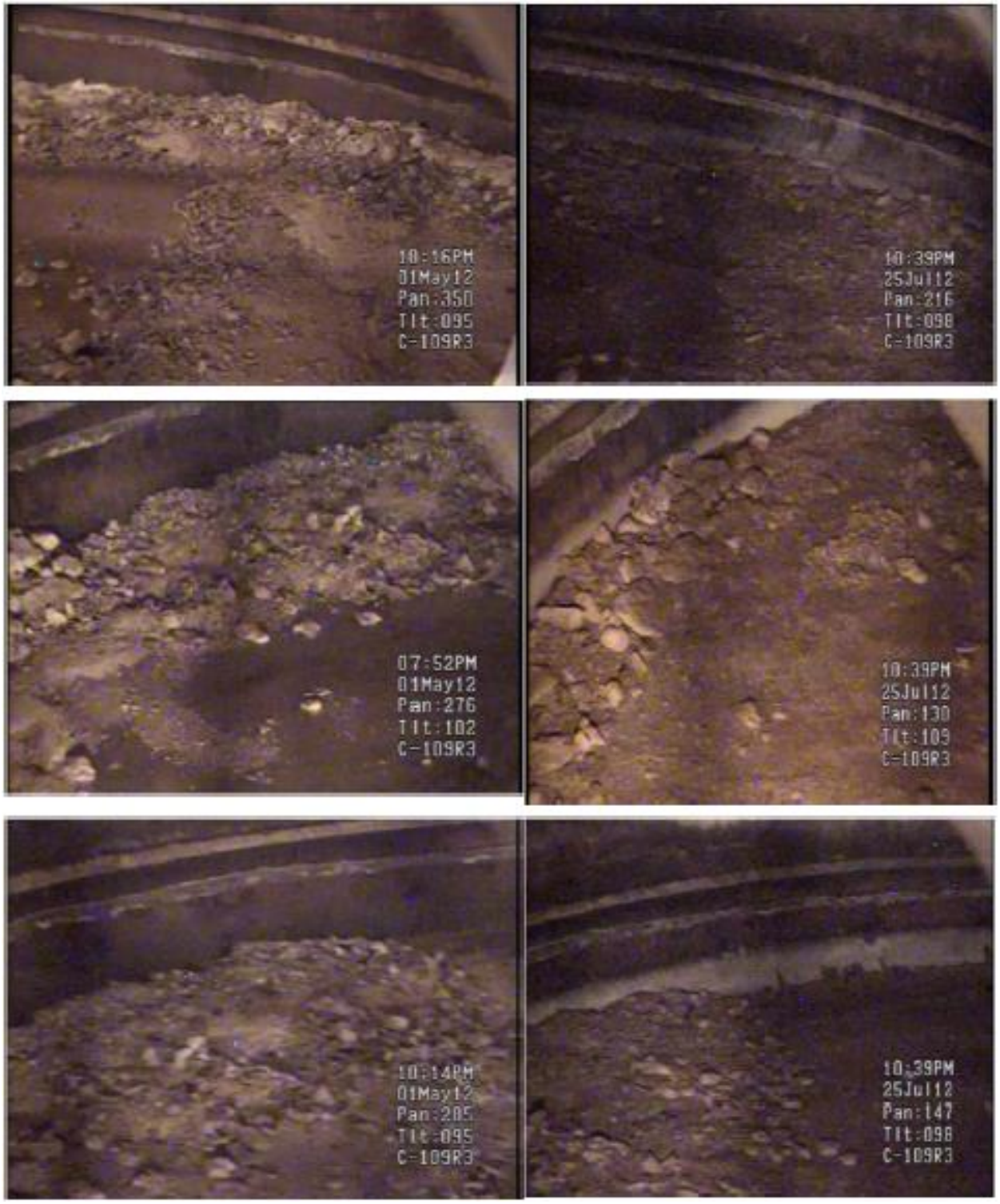
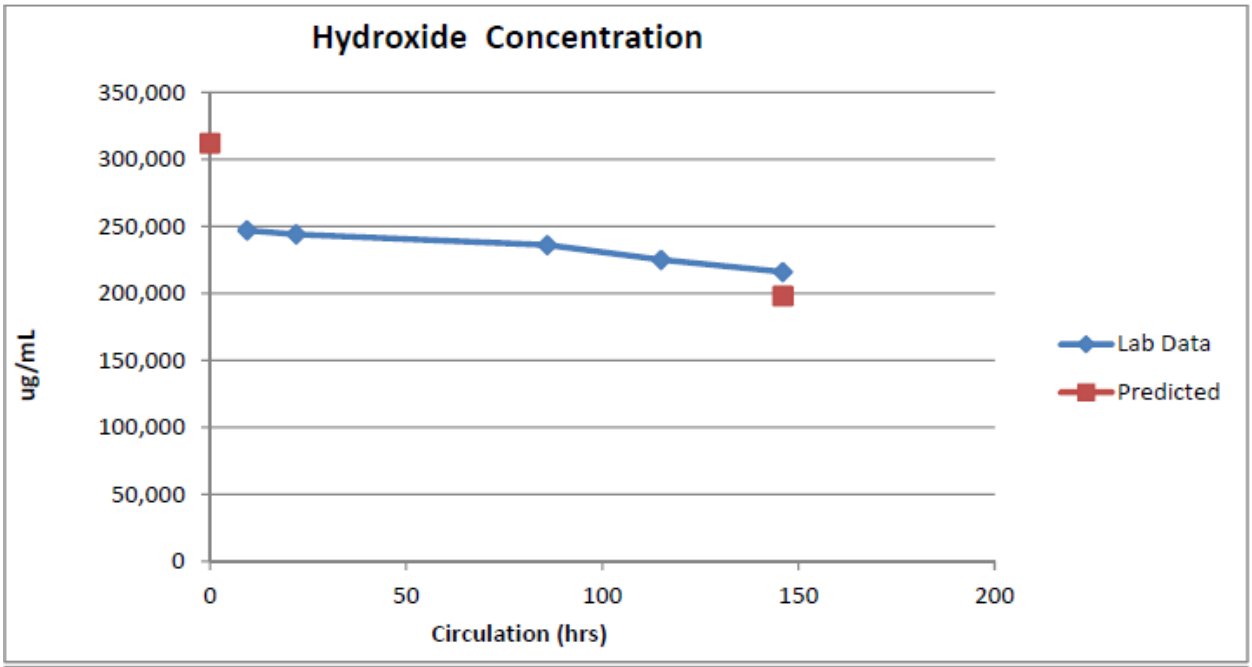
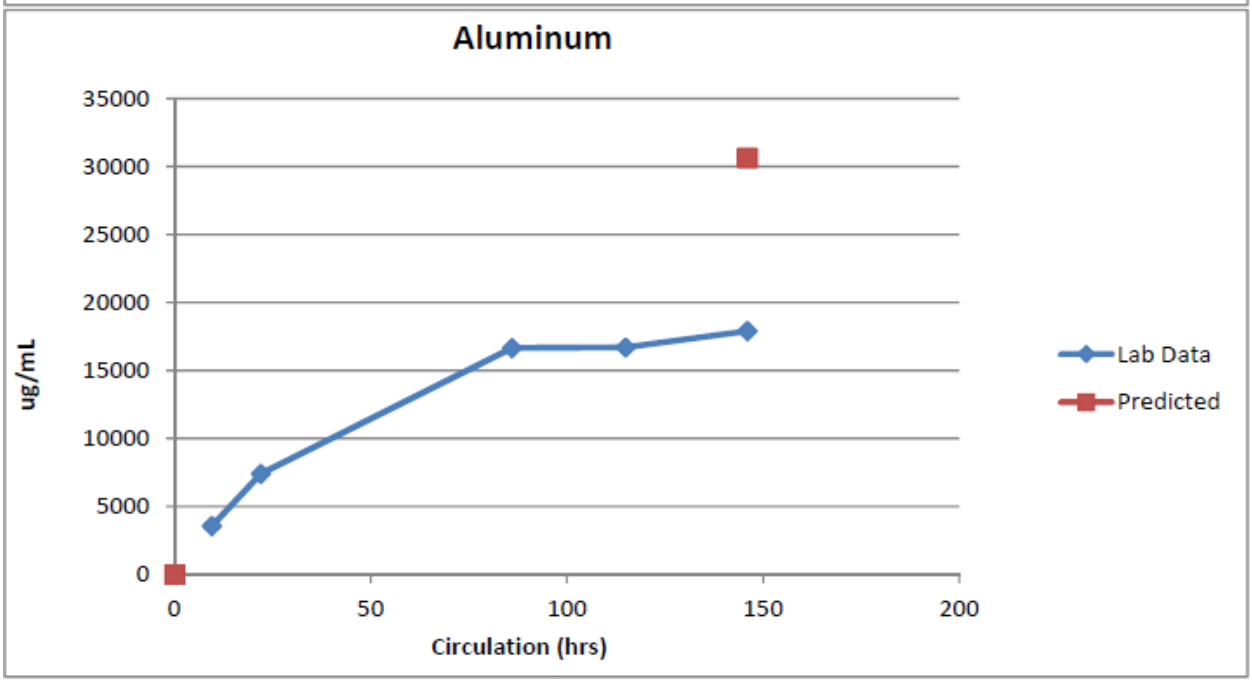


Figure 4-24. Tank C-109 Sample Analysis Results during Circulation of Caustic.





A decision was made to deploy a second water sluicing step, with an additional ~15,000 gal (as allowed in process control plan RPP-PLAN-51371). Visual observation at the end of the first water sluicing step showed that the majority of the remaining solids were closer to sluicer number 1 than to sluicer number 2, so the second water sluicing began with the use of sluicer number 1.

At the beginning of the second step, the slurry pump in the center of the tank was raised ~1 in. to allow sluicing under the pump intake to remove any solids that may interfere with effective

retrieval. The pump was then immediately lowered to ~1 in. lower than its previous position for the remainder of this water sluicing step. Sluicing operations continued to focus on breaking up remaining waste solids and moving the resulting fine material to the slurry pump.

Reduction of the solid material remaining in tank C-109 was observed during both of the first two water sluicing steps. A decision was made to perform a third water sluicing step, using an additional ~15,000 gal of water. Sluicing operations continued to focus on breaking up remaining waste solids and moving the resulting fine material to the slurry pump. Less material break-up of the remaining consolidated solids was observed in this sluicing step than in the previous steps.

At the conclusion of the third water sluicing step, the results were evaluated to determine if a fourth water sluicing step would be effective. The recovery of waste solids had declined significantly with each of the first three water sluicing steps. Observations during the sluicing indicated that sluicing was becoming less and less effective in breaking up the remaining solids. It was concluded that an additional water sluicing step would not be effective. The caustic cleaning retrieval process was completed on September 13, 2012.

Waste Retrieval Efficiency. The preliminary estimate for the tank C-109 MS campaign indicated that it would require 2.8 million gal of slurry to transfer the estimated 63,400 gal of waste to DST AN-106. In the first 600,000 gal of the slurry pumped from tank C-109, over 38,000 gal of waste was transferred from to DST AN-106. Between 600,000 and 1.75 million gal of slurry transferred, the retrieval rate leveled off, and it was determined that the bulk of the remaining waste was comprised mostly of solids that were not mobilized by sluicing and were insoluble in DST AN-106 supernate (RPP-RPT-55284).

As can be seen from Figure 4-22 and Figure 4-24, the rate of waste retrieval by caustic cleaning progressed linearly as anticipated.

Conclusion. Tank C-109 was retrieved using the MS and caustic cleaning technologies as described in RPP-21895, "241-C-103 and 241-C-109 Tanks Waste Retrieval Work Plan." MS was performed starting on June 19, 2007 and reached its limit of technology on August 23, 2007. Caustic cleaning was performed starting on May 1, 2012 and reached its limit of technology on September 12, 2012. Documentation concerning the effectiveness of the tank C-109 retrieval technologies may be found in RPP-53824, "Retrieval Completion Certification Report for Tank 241-C-109." [46]

4.3.3.10 Tank C-110

4.3.3.10.1 Waste Retrieval Operations

Tank C-110 waste retrieval has used three technologies, each to its limit of technology. MS was the first technology used, which removed ~90 percent of the initial waste inventory. The other two technologies used were the FoldTrack® MRT combined with high-pressure water. The tank C-110 MS waste retrieval campaign began September 22, 2008 and was completed on

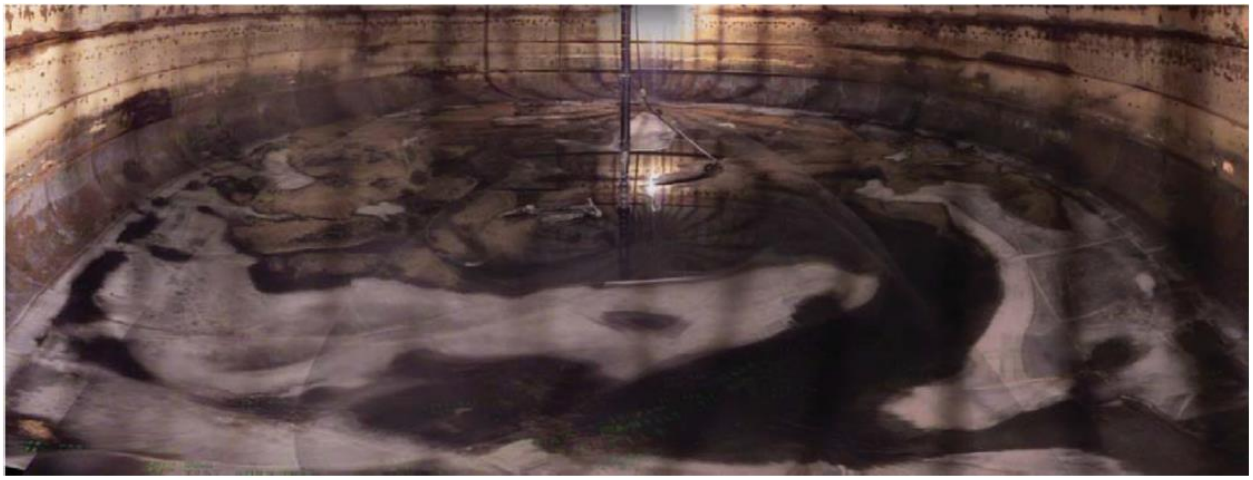
[46] DOE submitted RPP-53824, "Retrieval Completion Certificate Report for 241-C-109" to Ecology via letter 13-TF-0037, dated 6/4/13. DOE submitted RPT-RPP-55284, "Retrieval Data Report for Single-Shell Tank 241-C-109" via letter 14-TF-0020, dated 3/13/14.

April 27, 2009. The FoldTrack MRT mechanical and high-pressure water retrieval began on August 14, 2013 and reached the limit of technology on October 16, 2013 (RPP-RPT-56796, "Retrieval Data Report for Single-Shell Tank 241-C-110").

4.3.3.10.2 Limit of Technology

Visual Observations. A video camera inside tank C-110 allowed operational monitoring of activities and results throughout the waste retrieval campaign. Video observation of physical characteristics of the tanks and objects in the tanks aided in measuring residual waste volume change at the end of retrieval. Reduction in waste volume in the tank was observed as retrieval progressed, as shown in Figure 4-25 (RPP-RPT-56796).

Figure 4-25. Tank C-110 Photo Mosaic Looking to the North from Riser 3.



Waste Retrieval Progress. The MS process effectively removed most of the sludge from tank C-110. Most of the waste in tank C-110 consisted of a soft brown sludge that was readily mobilized by the sluicers and pumped from the tank. The retrieval progressed quickly over the first few days of operation. Grainier, light-colored solids became more prevalent as the softer, dark-colored sludge was washed out of the tank. A few larger chunks of material and some hard material on the tank bottom were observed, but the bulk of the light-colored waste appeared sandy and mobile. Although mobilized by the sluicers, this waste settled rapidly and was not easily retrieved with the existing installed equipment (RPP-RPT-56796).

Figure 4-26 shows retrieval system performance as a function of the volume of slurry transferred from tank C-110 to DST AN-106. The occasional decreases in the volume retrieved in Figure 4-26 reflect fluctuations in the ending tank C-110 liquid pool volume. It was not always possible to pump the tank C-110 liquid pool to the same minimum heel at the end of each operating period.

Retrieval system performance was tracked by trending the net waste volume increase in receiver DST AN-106 after accounting for water additions. This running volume balance did not distinguish between liquids and solids and did not account for solids dissolution or liquid evaporation. As the volume of waste retrieved approached the starting waste volume, the estimate of the volume remaining in tank C-110 by difference became increasingly sensitive to

uncertainties in the starting waste volume estimate because of pore space in the waste and of cumulative measurement uncertainties. The operating data was adjusted near the end of retrieval to account for evaporation and pore space, as shown in the Adjusted Operating Data line in Figure 4-26.

Based on the volume displacement and video evaluation established in previous waste volume determinations and by using subsequent material balances, the total volume of waste left in tank C-110 was ~17,200 gal (2,300 ft^3) (RPP-CALC-55938, "Estimated Waste Volume Remaining in Single-Shell Tank 241-C-110 after Hard Heel Retrieval"). An estimated 160,900 gal (21,500 ft^3) or ~90 percent of the waste had been retrieved at the end of sluicing operations. Based on the performance metrics evaluated with the implementation of MS and consideration of these other factors, DOE-ORP concluded that the MS retrieval technology was deployed to the limit of technology at tank C-110 (RPP-56214, "Retrieval Completion Certification Report for Tank 241-C-110").

The following is a discussion of the performance of the enhanced MS using the in-tank FoldTrack® MRT system as specified in RPP-PLAN-53943, "Process Control Plan for Tank 241-C-110 Waste Heel Retrieval" that demonstrates that the limit of technology was met in tank C-110.

The solids in tank C-110 consisted primarily of natrophosphate. A combination of mechanical waste conditioning, high-pressure water, and sluicing was selected to retrieve the remaining solids (RPP-PLAN-48868, "Single-Shell Tank 241-C-110 Hard Heel Retrieval Method Selection"). Mechanical waste conditioning and sluicing was performed to remove the waste.

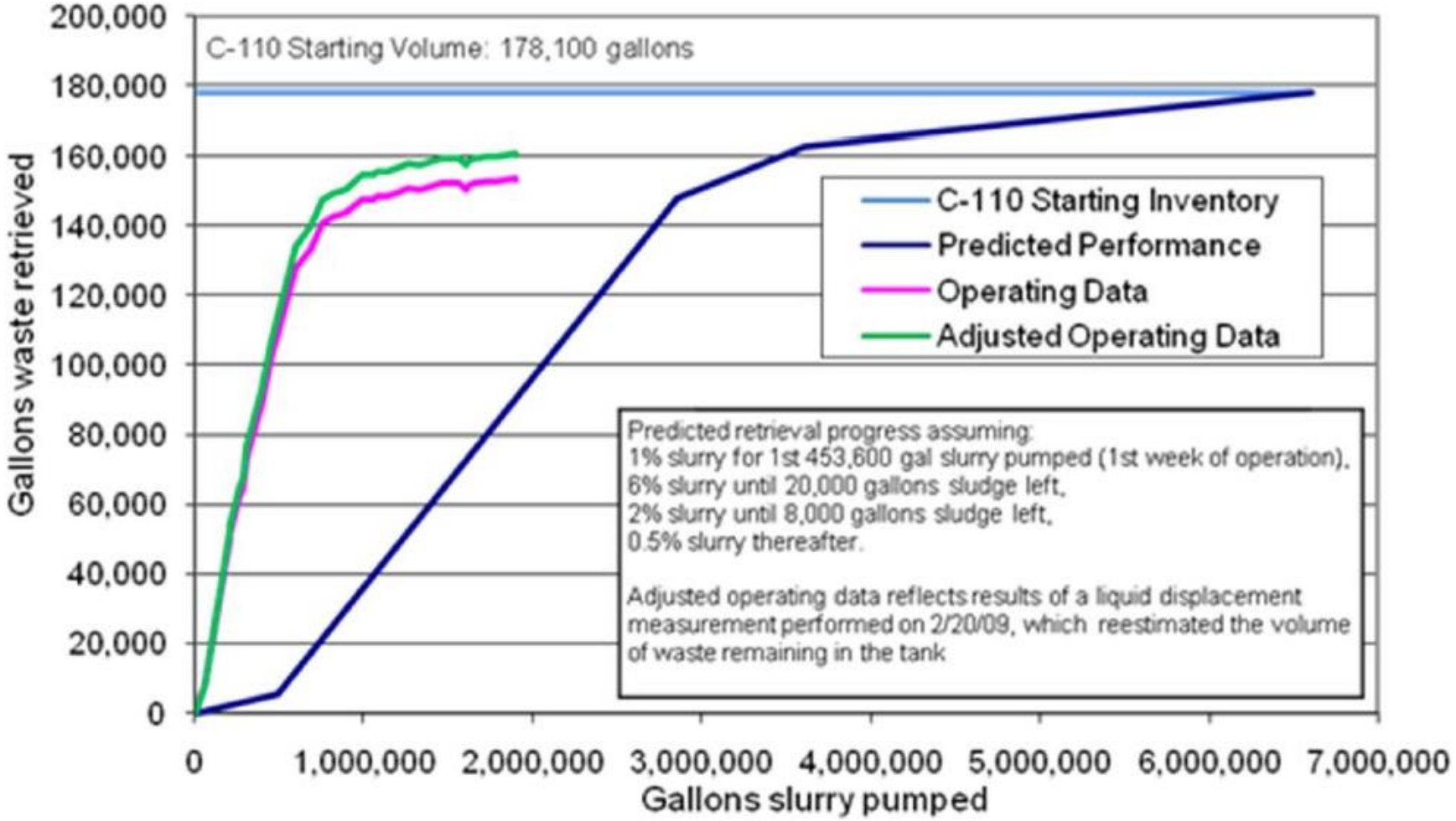
The FoldTrack MRT provided mechanical waste conditioning to enable removal of the waste. High-pressure water and sluicing were then applied as needed. In the final days of operation, hydraulic fluid leaks were observed and the MRT was used only as a backstop during sluicing.

Hot water was then sluiced into the tank to size-reduce solids and to move solids toward the pump. High-pressure hot water was also applied through the FoldTrack MRT nozzles to wash sluiced solids into the pump and to suspend the solids. The slurry was then pumped from the tank. Plow-blade and high-pressure water operations were conducted as specified in the process control plan (RPP-PLAN-53943) and the tank waste retrieval work plan (RPP-33116, "241-C-110 Tank Waste Retrieval Work Plan").

Following transfer of the dissolution liquors to DST AN-106, ~15,000 gal of hot water were used to knock down piles as much as possible in preparation for final liquid displacement and flush. It was then determined that solids were almost completely covered by the water addition. The waste was pumped down while adding high-pressure water through the FoldTrack MRT nozzles in an attempt to enhance solids removal. There was a noticeable reduction in the solids volume after the final liquid displacement.

Final tank C-110 sluicing and hard heel removal operations were shut down on October 16, 2013. Based on the performance metrics examined with the implementation of these technologies and consideration of the factors specified in the Consent Decree, DOE-ORP concluded that the FoldTrack MRT mechanical and high-pressure water retrieval technologies had been deployed to the limit of technology.

Figure 4-26. Tank C-110 Modified Sluicing System Performance.



Reference: RPP-RPT-56796, "Retrieval Data Report for Single-Shell Tank 241-C-110."

Waste Retrieval Efficiency. The preliminary estimate for the tank C-110 MS campaign indicated that it would require ~6.7 million gal of slurry to transfer the estimated 178,000 gal of tank C-110 waste to DST AN-106. In the first 700,000 gal of slurry pumped from tank C-110, over 140,000 gal of waste was transferred to DST AN-106, over three times the expected rate. However, when the campaign had transferred ~87 percent of the forecasted waste volume (~154,000 gal) to DST AN-106 (operating day 17), the retrieval rate dropped off (RPP-RPT-56796).

Conclusion. As can be seen from Figure 4-27, the rate of waste retrieval by the FoldTrack MRT and high-pressure water progressed nearly linearly. DOE-ORP concluded that waste retrieval operations were performed to the limits of MS, FoldTrack MRT, and high-pressure water retrieval technology at tank C-110 (RPP-56214).[47]

4.3.3.11 Tank C-111

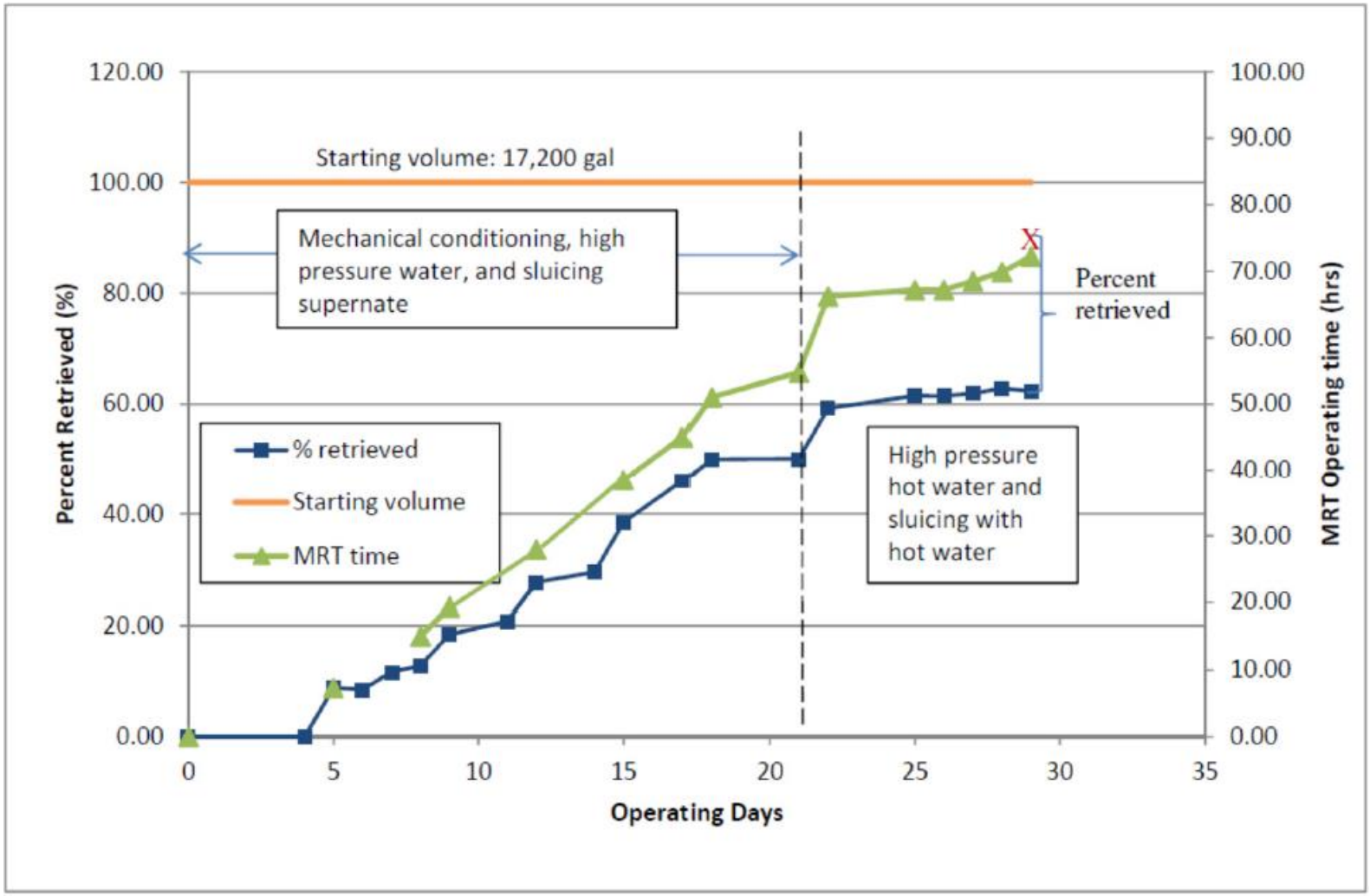
4.3.3.11.1 Waste Retrieval Operations

Tank C-111 waste retrieval was performed using MS, high power wash (HPW) and ERSS with caustic preconditioning and caustic dissolution. MS was selected because it requires less DST supernate storage and management along with an anticipated shorter retrieval duration over Mobile Retrieval System (MRS). MS was used for bulk retrieval of waste from September 14, 2010 to November 4, 2010. The sluicing system in tank C-111 consisted of two sluicers located at the north and south ends of the tank and a variable-depth slurry pump located in the middle of the tank. Two closed-circuit video cameras were installed to support sluicing. The hydraulic sluicers, slurry pump, and a motor-operated valve to control the supernatant flow rate were controlled from a control trailer near the tank. The MS system reduced the volume of waste by only one percent.

Hard heel retrieval began in October 2015 and included the second and third technologies deployed, which included HPW using an ERSS and chemical dissolution using caustic. The hard heel retrieval process selected included the following methods: (1) sluicing using the ERSS and HPW, (2) caustic pre-conditioning, (3) sluicing with supernate and HPW, (4) caustic dissolution, and (5) final supernate sluicing and water rinses. The order was determined to be optimal because it allows for more efficient use of the caustic; splitting the total allotted volume of caustic across two strikes that are separated by sluicing operations allows for new surface area to be exposed and potentially react with the caustic solution. These methods were determined to be the best methods for retrieving tank C-111 based on the experiences from the bulk retrieval operations performed in tanks C-101, C-102, and C-112 and heel retrieval operations performed in tanks C-108, C-109, and C-104.

[47] DOE submitted RPP-56214, "Retrieval Completion Certificate Report for 241-C-110" to Ecology via letter 14-TF-0007, dated 1/29/14. DOE submitted RPT-RPP-56796, "Retrieval Data Report for Single-Shell Tank 241-C-110" via letter 14-TF-0086, dated 8/6/14.

Figure 4-27. Volume Balance Results for Tank C-110 Retrieval.



X = 87.8%, 15,100 gal retrieved based on liquid displacement measurement and video

MRT = mobile retrieval tool

4.3.3.11.2 Limit of Technology

Retrieval System Performance. Bulk retrieval operations were performed during 26 operating days (53 shifts) starting on September 14, 2010 and ending on November 4, 2010. Bulk retrieval consisted of modified sluicing of tank C-111. Contrary to expectations from pre-retrieval sampling, the waste surface was hard and resistant to sluicing. By September 27, the tank C-111 waste had been sluiced with over 800,000 gal (106,944 ft^3) of supernate with no significant waste retrieval. From October 1 to October 22, 2010, about 8,000 gal (1,069 ft^3) of hot water (110 to 126 °F) was added to tank C-111 in an attempt to dissolve sodium phosphate and soften or break up the waste. The water was recirculated in the tank from October 25 to 27, 2010. However, no significant increase in waste retrieval efficiency was observed.

Hard heel retrieval operations were performed during approximately 83 operating days (131 shifts) starting on October 4, 2015 and ending on March 30, 2016. Care was taken when using HPW to position the ERS nozzles close to the waste surface, so each ERS could be more effectively used to break up the waste surface and mobilize solids towards the slurry pump.

Caustic preconditioning, while not a retrieval technology, was used to convert insoluble aluminum compounds into sodium aluminate, a significantly more soluble form, through reaction with a caustic solution. This step was intended to dissolve aluminum compounds and soften the waste crust to make the waste more susceptible to sluicing and HPW activities. A volume of 14,930 gal of 50 wt percent caustic (approximately 19.4 M) with a temperature range of 80 to 100 °F was added to tank C-111 from trucks through a drop leg (RPP-RPT-59292, "Single-Shell Tank 241-C-111 Hard Heel Retrieval Completion Report"). The caustic solution was recirculated using the slurry pump and each ERS. During recirculation, the caustic stream was focused on wetting the solids that were not submerged and agitating the caustic pool to promote mixing. After the reaction had gone to its practical end, the solution was diluted using tank AN-101 supernate in an attempt to maximize the solubility of sodium aluminate.

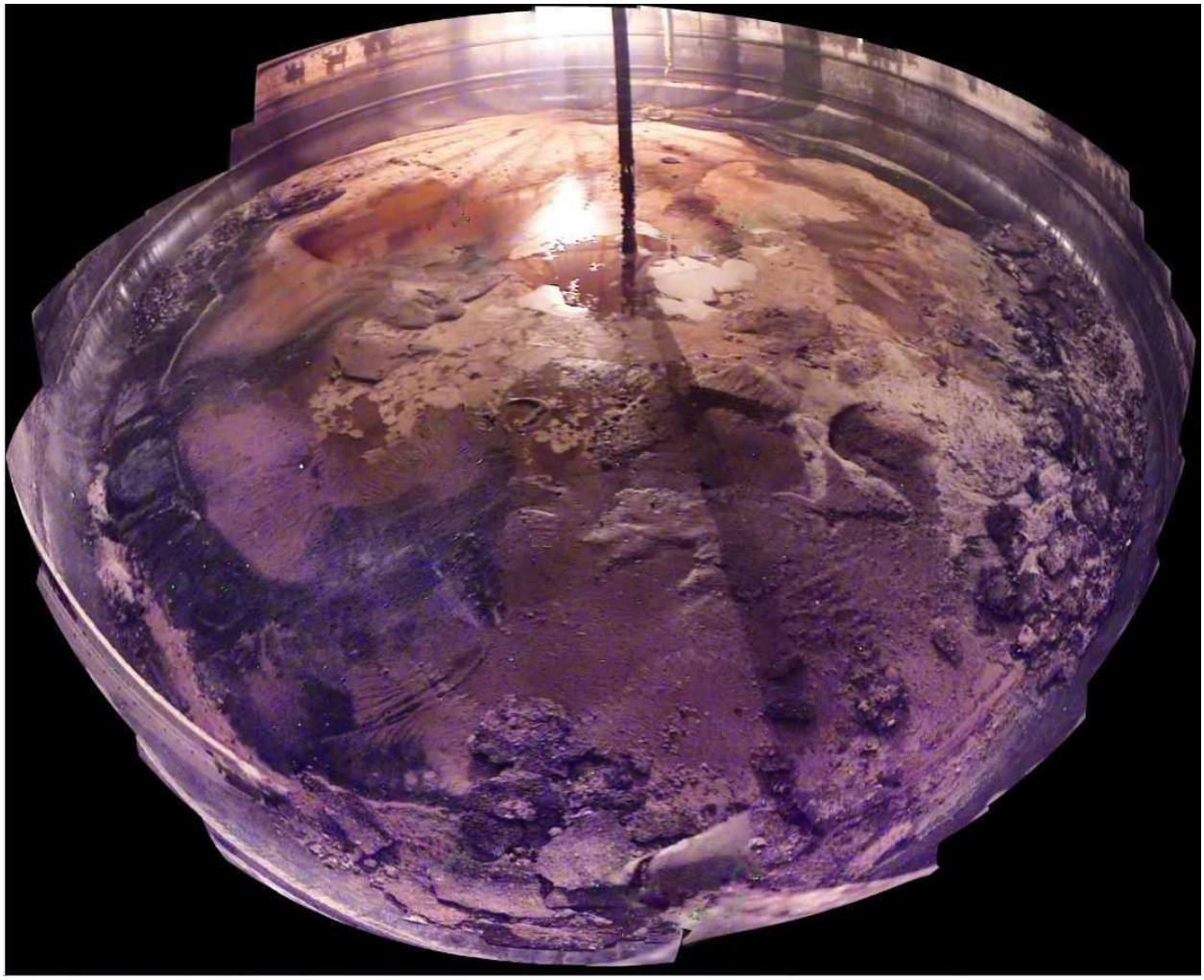
The second round of modified sluicing and HPW were intended to remove the bulk of the remaining solids in tank C-111. It was predicted in RPP-37739 that after caustic preconditioning the solids would be sufficiently softened and/or size reduced to allow for improved recovery rates. Sluicing was carried out in the same fashion described above. HPW was used in an effort to further size reduce the residual solids.

When sluicing efficiency decreased, a second round of caustic dissolution was performed using 16,930 gal of 50 wt percent sodium hydroxide to dissolve aluminum compounds and soften the remaining waste to make it more susceptible to sluicing. Then the solution was diluted to approximately 8.0 M using tank AN-101 supernate in an attempt to maximize the solubility of sodium aluminate.

Waste Retrieval Efficiency. The final sluicing was performed following caustic dissolution to mobilize solids that had been size-reduced or broken up by the caustic dissolution step. A water rinse of residual waste must be performed after the final use of supernate in tank C-111 as required by RPP-37739. The preliminary residual volume was estimated in RPP-CALC-60840 to be approximately 7,700 gal (approximately 1,030 ft^3). Figure 4-28 shows a panoramic photo taken prior to the final water additions. A significant amount of tank liner can be seen and the

waste is well below the approximate starting level near the first stiffener ring. There were two apparent primary solid types remaining in tank C-111 at the end of retrieval. A lighter colored sandy material can be seen on the top of Figure 4-28. A darker colored material can be seen along the perimeter of the tank and tended to be in plates or other large agglomerations. The sandy waste was easily mobilized with the sluicers; however, the particles could not be suspended in supernate or flush water and removed by the slurry pump. The dark agglomerates were largely impervious to both sluicing and HPW. Following caustic, the plate-like agglomerations were more susceptible to sluicing and HPW; however, the waste chunks that were broken off remained too large to mobilize with the slurry pump.

Figure 4-28. Panoramic Image of Residual Tank C-111 Waste.



Tank C-111 reached the limits of technology following the two criteria in RPP-50910, "Single-Shell Tank Waste Retrieval Limit of Technology Definition for Modified Sluicing," for waste retrieval of SST using modified sluicing (these criteria were established after bulk retrieval of tank C-111 had been completed).

The first criterion under RPP-50910 has been met for bulk retrieval modified sluicing, ERSS sluicing and high-pressure water operations, and chemical dissolution using caustic. The limit of technology for the bulk retrieval phase using the sluicing retrieval system is defined in RPP-50910 in terms of performance, specifically the volume of waste retrieved as a function of the volume of slurry (i.e., solids plus recycled tank AN-101 supernate) transferred from tank C-111 to tank AN-101). Although there is no defined limit of technology for HPW or caustic dissolution technologies, the final four operating periods (consistent with the definition for modified sluicing in RPP-50910) were unable to retrieve any tank C-111 solids. Accordingly, DOE determined on March 14, 2016 that the limits of technology for ERSS sluicing, HPW operations, and chemical dissolution using caustic, were also reached in tank C-111 (RPP-RPT-59292).

The second criterion under RPP-50910 was also met. All reasonable efforts to enhance the effectiveness of the waste retrieval system were attempted. For bulk retrieval using modified sluicing, hot water was added to the tank in an attempt to dissolve and break up the waste, but this had little effect. As noted, 1.4 million gal of supernate and water were used and well over three operating periods of negligible retrieval before bulk retrieval operations were halted. Sluicing using the ERSS and HPW in tank C-111 was intended to break up waste to create additional surface area and to size-reduce solids so that they could be pumped.

As the retrieval progressed, there appeared to be two primary types of solids in tank C-111 based on visual inspection of the waste. There was a light colored sandy material and a darker colored solid that tended to be in large chunks. The light colored material was readily mobilized by the supernate stream and did not appear to be size-reduced by the HPW. Some of the darker colored solids could be broken up by HPW, but the process was slow and the resulting agglomerates remained too large to be removed from the tank by the slurry pump. However, the bulk of the darker solids appeared to be impervious to the HPW. Additionally, the use of HPW caused the headspace of the tank to fog up which required frequent shut downs and the added moisture loading strained the ventilation system. TOC determined that additional HPW use was unlikely to retrieve a significantly greater volume of waste.

The final hydroxide concentration prior to dilution was 11.9 M. The reaction reached an ending hydroxide concentration that was comparable to those achieved in other WMA C tanks with a relatively small reduction in concentration being due to added water. Based on these results and the additional recirculation that occurred after the final grab sample was taken, it was determined that the reaction had reached its practical end. (RPP-RPT-59363, “Retrieval Completion Certificate Report for 241-C-111,” Rev 0).

According to the Consent Decree, the limits of technology should consider risk reduction, facilitating tank closures, costs, the potential for exacerbating leaks, worker safety, and the overall impact on the tank waste retrieval and treatment mission. Modified sluicing, HPW using an ERSS, and chemical dissolution using caustic retrieval operations were evaluated considering these criteria:

- The modified sluicing from Bulk Retrieval, variable depth sluicers, had very little impact on the removal of tank waste. At the end of modified sluicing operations, very little of the tank C-111 waste had been retrieved and the waste surface was still hard.

- The caustic dissolution had some effect on the waste. During caustic recirculation it was observed that there was some slumping of waste adhering walls into the caustic pool. This allowed for some additional waste retrieval.
- Continued caustic dissolution would increase the amount of caustic added to tank C-111 and transferred into the DST system. This increase would lead to more waste transfer operations in the DST system, more evaporator operations, and limitations on DST space that would further limit future retrieval activities.
- Continued HPW sluicing and/or chemical dissolution of tank C-111 would result in additional exposure to workers. Although retrieval operations are controlled from a control trailer, multiple field activities (exhauster filter changes, valve line-ups, field measurements and monitoring, camera/light changes, etc.) are required to support the retrieval operations, resulting in additional exposure.
- Continued use of the HPW sluicing and/or chemical dissolution on tank C-111 reached a point where their effectiveness was limited. Further use of either technology would have limited benefits while incurring significant costs and posing additional risk.
- Continued deployment of HPW sluicing and/or chemical dissolution would delay the completion of retrieval activities at other tanks with limited benefits. At this point in time, any delay in completion would have the potential to adversely affect schedules of other retrieval activities.

Conclusion. As a result, DOE-ORP has concluded that three technologies-- modified sluicing, HPW using an ERSS, and chemical dissolution using caustic/water -- have been deployed to the limits of technology.

The three approved retrieval technologies have been deployed to the "limits of technology" as described in Part 1 of Appendix C of the Consent Decree, and therefore no further action is necessary, although the final waste volume will not meet the Consent Decree waste residual goal of 360 ft^3 or less.

The Retrieval Completion Certification Report for Tank 241-C-111 (RPP-RPT-59363, Rev. 0) documents the completion of retrieval operations on the single-shell tank C-111 on March 30, 2016, using three technologies. The report provides a summary of information upon which the decisions to cease tank retrieval operations in tank C-111 were based. This report is the mechanism by which DOE asserts that the selected retrieval technologies have reached their respective limits of technology.[48]

4.3.3.12 Tank C-112

4.3.3.12.1 Waste Retrieval Operations

Tank C-112 waste retrieval was done using two retrieval technologies, each to the limit of technology, using a sluicing system comprised of an ERSS and a fixed-height sluicing assembly

[48] DOE submitted RPP-RPT-59363, "Retrieval Completion Certificate Report for 241-C-111" to Ecology via letter 16-TF-0090, dated 8/25/16. DOE submitted RPP-RPT-60173, "Retrieval Data Report for Single-Shell Tank 241-C-111" to Ecology via letter 17-TPD-0018, dated August 11, 2017.

located near the top of the tank, similar to those used in previous tank waste retrieval operations. The tank C-112 MS campaign began on December 28, 2011, and was suspended on April 18, 2012 after reaching the limit of technology. The caustic dissolution campaign began on November 18, 2013 and concluded on January 31, 2014 after reaching the limit of technology. The tank C-112 waste that was removed was transferred to tank AN-101. RPP-RPT-58140, "Retrieval Completion Certification Report for Tank 241-C-112," documents that the two retrieval technologies deployed in tank C-112 retrieved the waste to the limit of technology as required by the Consent Decree.

RPP-56935, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-112," was developed to assess whether a third waste retrieval technology should be implemented at tank C-112. That report was issued in July 2014 and updated as Revision 1 in December 2014 to incorporate comments from Ecology. It concludes that the two waste retrieval technologies deployed at tank C-112 had each been deployed to its respective limit of technology, and that implementation of a third technology is not practicable as that term is used in Appendix C, Part 1, of the Consent Decree.

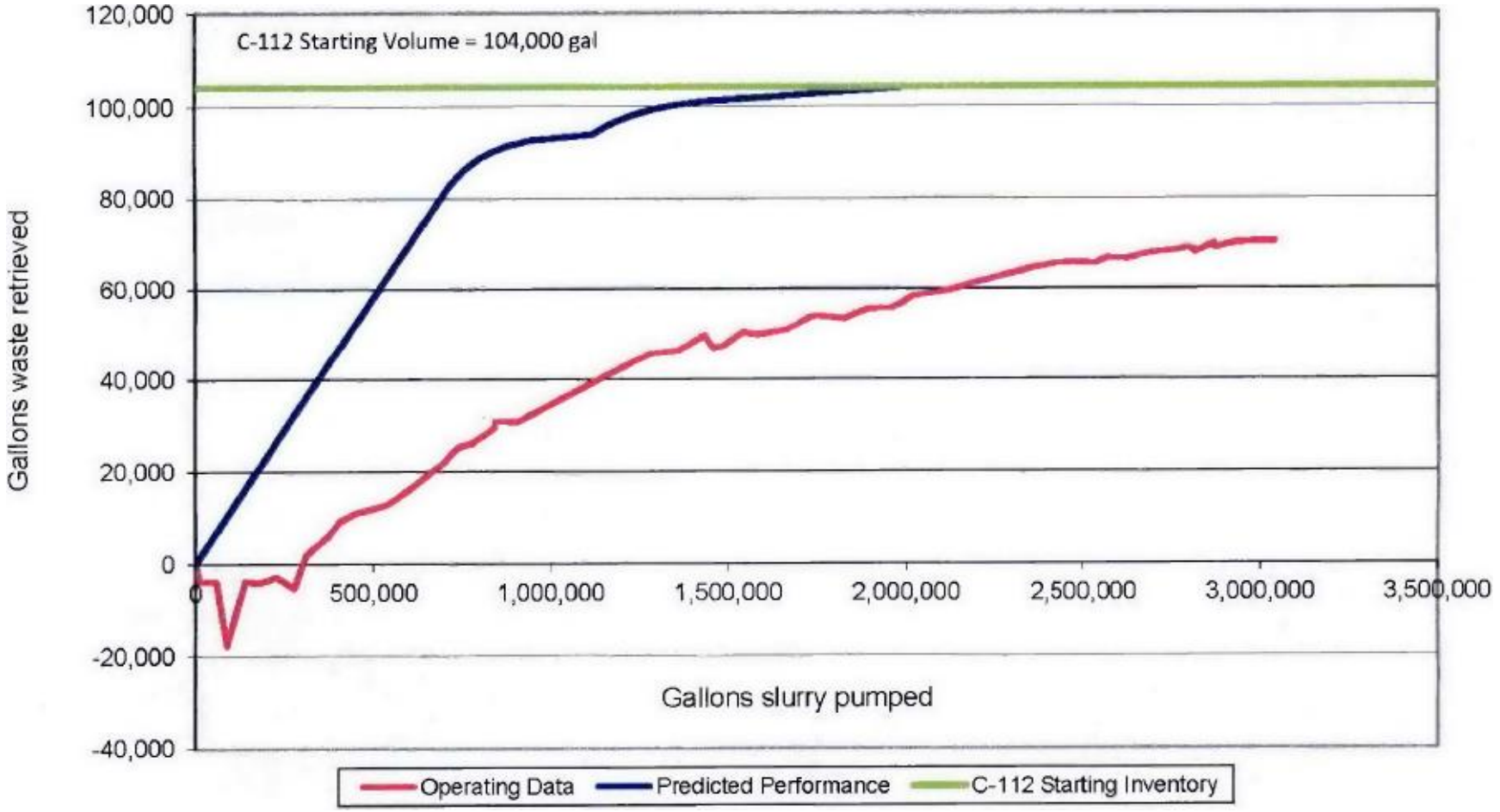
4.3.3.12.2 Limit of Technology

Retrieval System Performance. On December 28, 2011, an MS campaign began to remove the 104,000 gal of tank C-112 waste that remained after interim stabilization. The waste in the tank consisted of soft brown sludge overlaid with a hard waste surface. Sluicing operations had to penetrate the hard surface to access the sludge. The ERSS and a standard sluicer were successful in creating cracks and openings in the hard surface, allowing most of the underlying sludge to be mobilized and retrieved using the slurry pump (RPP-RPT-58490, "Retrieval Data Report for Single-Shell Tank 241-C-112").

The sluicing retrieval system removed slightly over two-thirds of the sludge from tank C-112; essentially the small particle size waste that could be removed and transferred. In most tanks that have had waste retrieved by MS, the rate of waste retrieval is initially high and then falls off as the easily-retrieved waste is removed and the heavier and larger particles in the waste remain. Figure 4-29 shows the initial sluicing campaign retrieval system performance. As shown by the slope of the line in Figure 4-29, the waste retrieval rate for tank C-112 remained relatively constant throughout the waste retrieval operation, being slightly higher in the first ~1.5 million gal of slurry pumped than the second. At the end of sluicing operations, an estimated 33,600 gal (4,490 ft^3) remained in tank C-112.

Solids still covered the tank bottom at the end of the MS operations. The concentration of solids in the transferred slurry for three operating periods (ending on April 18, 2012) were 0.2, 0.5, and 0.3 vol percent (RPP-RPT-52480, "Retrieval Completion Report for Modified Sluicing of Tank 241-C-112"). Cracks in the hard waste surface were present in all areas of the tank bottom. To the extent practicable, waste had been sluiced out from under the hard waste. In an attempt to soften the hard waste surface, ~13,800 gal of supernate from tank AN-101 was pumped into tank C-112 during sluicing operations and allowed to stand for four days, but no change in the hard waste was observed.

Figure 4-29. Tank C-112 Waste Retrieval Progress.



Reference: RPP-RPT-58490, "Retrieval Data Report for Single-Shell Tank 241-C-112."

The hard heel retrieval operation (chemical retrieval) started with caustic pre-conditioning followed by sluicing with supernate. This approach was determined to be the best method for retrieving the remaining heel solids in tank C-112 (RPP-PLAN-55462, "Single-Shell Tanks 241-C-111 and 241-C-112 Hard Heel Retrieval Technology Selection"). The first step was to add 12,000 gal of caustic (19.4 M NaOH). The caustic was introduced to the tank through a drop leg. Mixing was achieved using the slurry pump to circulate the caustic while alternating flow through the ERSS and standard sluicer. The liquid was pumped out to DST AN-101 at the end of the first processing step. Solutions samples were taken to monitor caustic concentrations during this operational step.

The second step involved MS of the solids remaining in tank C-112 following the caustic pre-conditioning. Sluicing was performed with either the ERSS or the standard sluicer, depending on the location of the visible solids, using supernate from DST AN-101. When sluicing no longer appeared effective in removing more solids, the liquid level in the tank was reduced as much as possible. Hot water was added to dissolve the sodium fluoride phosphate, sodium aluminate, and sodium phosphate compounds that were present in significant quantities; and to remove other compounds as well (e.g., insoluble oxides of uranium, iron, and bismuth; fluorapatite; sodium aluminosilicate). The hot water was recirculated and pumped out to DST AN-101. Hot water was also used in the final three rinses of the residual waste.

A second caustic dissolution cycle began with the addition of another ~12,000 gal of 19.4 M NaOH through a drop leg. The caustic was recirculated using the ERSS and standard sluicer as before. Following recirculation, the liquid was pumped from tank C-112 to DST AN-101. Sluicing with supernate was repeated to remove any additional waste particles that were small enough to be suspended. The tank C-112 residual liquid level was then reduced to the minimum achievable by the slurry pump (RPP-RPT-56900, "Single-Shell Tank 241-C-112 Hard Heel Retrieval Completion Report").

The use of caustic and the ERSS/standard sluicing operations resulted in the breakup of only some of the large pieces of solids in the tank. The ERSS was only effective at breaking up the large waste pieces at close range and required that the solids be sluiced to be close to the ERSS nozzle. Because large pieces of solids were not easily moved with the sluicers, a relatively small volume of solid waste was removed during sluicing. Waste particles the size of sand and larger could not be suspended and pumped out of the tank.

The sample taken on January 20, 2014, after an additional six days of caustic recirculation, showed that the reaction had dropped off dramatically. During that time the hydroxide concentration only dropped from 10.6 to 9.62 M. The amount of caustic added had been more than enough to continue reacting, if there had been any waste material that would react with caustic. Thus, it was concluded that the caustic dissolution step had reached its limit of technology. Volume displacement calculations and video evaluation were performed during the January 28, 2014 pump-out of liquid from tank C-112 (RPP-CALC-56856, "Estimated Waste Volume Remaining in Single Shell Tank 241-C-112 after Hard Heel Retrieval"). A liquid surface remains on much of the waste in the tank. The liquid is mostly water from drain back after flushing the transfer lines and is only ~1 in. deep over the solids.

It was concluded that all reasonable efforts to enhance the effectiveness of the caustic/water dissolution process were made. Toward the end of retrieval operations, ERSS nozzles were positioned to move waste solids from the north side of the tank toward the opposite sluicer. Additional sluicing and washing of the tank walls and stiffener rings following caustic recirculation was attempted to remove adhered waste. Visual observations of this attempt showed no significant retrieval of the adhered waste. (RPP-RPT-58490)

Because the estimate of waste residual remaining in tank C-112 following the deployment of MS and chemical retrieval technologies exceeded the Consent Decree volume requirement, DOE submitted to Ecology a request to forego implementation of a third technology that would otherwise be required by the terms of the Consent Decree (RPP-56935). In RPP-56935, DOE evaluates a set of candidate technologies for hard heel waste retrieval that are reviewed and documented in RPP-RPT-44139. That evaluation concludes none of the existing retrieval technologies have a reasonable expectation of successful retrieval of much additional tank C-112 waste. That evaluation also notes that the use of a new chemical retrieval using another chemical agent is the most viable choice for a third retrieval technology; however, the time frame of such a development and the actual effectiveness of such a chemical process are uncertain.

Waste Retrieval Efficiency. The preliminary estimate for the tank C-112 MS campaign indicated that it would require 2 million gal of slurry to transfer the estimated 104,000 gal of waste to DST AN-101. The rate at which the waste slurry pumped from tank C-112 to DST AN-101 was lower. However, when the campaign had transferred ~90 percent of the waste, ~3,000,000 gal of slurry had been used and the technology was concluded (RPP-RPT-58490).

Conclusion. DOE-ORP has concluded that waste retrieval operations were performed to the limit of technology for MS and high-pressure water retrieval (RPP-RPT-58140). The RPP-56935 Practicability Evaluation Request concludes that the two waste retrieval technologies deployed at tank C-112 had each been deployed to their limit of technology, and that implementation of a third technology was not practicable as that term is used in Appendix C, Part 1, of the Consent Decree. Ecology has concurred to forego implementing a third chemical cleaning for tank C-112 (Letter 1227037, "Re: Response to United States Department of Energy Letter 14-TF-0087, dated August 4, 2014, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-112"").[49]

4.3.3.13 Residual Waste Volumes

The post-retrieval measurements of tank residual waste volumes were performed for each tank using the CCMS. Post-retrieval residual waste volume estimates were made using the CCMS method per TFC-ENG-FACSUP-CD-22, "Post-Retrieval Tank Waste Volume Determination." The total measured volume of residual waste in a tank consists of the sum of volumes remaining

[49] DOE submitted RPP-56935, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-112" to Ecology via letter 14-TF-0087, dated 8/4/14. Ecology responded with letter 14-NWP-210 on 9/29/14. DOE submitted RPP-58140, "Retrieval Completion Certificate Report for 241-C-112" to Ecology via letter 14-TF-0115, dated 9/30/14. DOE submitted RPT-RPP-58490, "Retrieval Data Report for Single-Shell Tank 241-C-112" via letter 15-TF-0098, dated 9/30/15.

in the tank dish, on the tank walls, on the stiffener rings, and in the void spaces in equipment left in the tank.

The residual waste volumes remaining in the 100 Series tanks after retrieval campaigns are shown in Table 4-7, along with the pre-retrieval volumes and waste volume retrieved from each tank. The tank retrieval operations have removed approximately 96 percent of the waste volume from the 100-series tanks at WMA C.[50]

Table 4-7. Waste Tank Retrieval History for the 100 Series Tanks.

Tank	Waste Volume Pre-Retrieval gal (ft^3)	Waste Volume Retrieved gal (ft^3)	Residual Waste Remaining gal (ft^3)
C-101[a]	77,500 (10,360)	72,505 (9,693)	4,995 (667)
C-102[b]	316,000 (42,200)	295,500 (39,500)	20,500 (2,700)
C-103[c]	77,800 (10,400)	75,269 (10,062)	2,531 (338)
C-104[d]	259,000 (34,600)	257,400 (34,380)	1,600 (220)
C-105[e]	122,175 (16,332)	~117,000 (15,640)	~4,800 (650)
C-106[f]	230,000 (30,746)	227,230 (30,376)	2,770 (370)
C-107[g]	247,000 (33,000)	236,600(31,610)	10,400 (1,390)
C-108[h]	66,000 (8,823)	63,030 (8,426)	2,970 (397)
C-109[i]	63,400 (8,480)	61,680 (8,250)	1,720 (230)
C-110[j]	178,000 (23,800)	176,227 (23,563)	1,773 (237)
C-111[k]	34,900 (4,670)	30,010 (4,016)	4,890 (654)
C-112[l]	104,000 (13,900)	93,900 (12,552)	10,100 (1,348)

[a] RPP-55849, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-101".
[b] RPP-RPT-58676, "Tank 241-C-102 Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-102."
[c] RPP-RPT-33060, "Retrieval Data Report for Single-Shell Tank 241-C-103."
[d] RPP-RPT-54072, "Retrieval Data Report for Single-Shell Tank 241-C-104."
[e] RPP-RPT-59015, "Single-Shell Tank 241-C-105 First Technology Retrieval Completion Report."
[f] RPP-20577, "Stage II Retrieval Data Report for Single-Shell Tank 241-C-106."
[g] RPP-RPT-58295, "Retrieval Data Report for Single-Shell Tank 241-C-107."
[h] RPP-52290, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108."
[i] RPP-RPT-55284, "Retrieval Data Report for Single-Shell Tank 241-C-109."
[j] RPP-RPT-56796, "Retrieval Data Report for Single-Shell Tank 241-C-110."
[k] RPP-RPT-59714, "Tank 241-C-111 Residual Waste Inventory Estimates for Component Closure Risk Assessment"
[l] RPP-RPT-58490, "Retrieval Data Report for Single-Shell Tank 241-C-112."

[50] The total pre-retrieval radionuclide inventory for the WMA-C tanks was 1.59×10^7 Ci (RPP-RPT-42323, Rev. 3). The total post-retrieval radionuclide inventory for the WMA-C tanks is currently estimated at 5.9×10^5 (BBI database as of 10/1/17). Therefore, the retrieval of 96 percent of the waste volume has also removed approximately 96% of the radionuclide activity from the WMA-C tanks.

4.3.4 Waste Retrieval from 200-Series Tanks

The four 200-series tanks in WMA C are tanks C-201, C-202, C-203, and C-204.

HFFACO Milestone M-045-00 requires that the 200-series tanks be retrieved to less than 30 ft^3 or the limit of technology, whichever is lower.

The following sections summarize waste retrieval operations for the WMA C 200-series tanks.

4.3.4.1 Waste Retrieval Operations for the 200-Series Tanks

The WMA C 200-series tanks were retrieved using a vacuum retrieval system (VRS) that consisted of an articulating mast system with a vacuum head, a vacuum pump, a slurry vessel, and a number of slurry transfer pumps. Use of this system minimized both the need to add water to the tank and the in-tank pooling of liquids. Removed waste was diluted with raw water and transferred to DST AN-106.

The tank C-203 retrieval campaign began June 30, 2004 and was completed on March 24, 2005. The tank C-202 retrieval campaign began June 30, 2005 and was completed on August 11, 2005. The tank C-201 retrieval campaign began October 25, 2005 and was completed on March 23, 2006. The tank C-204 retrieval campaign began on July 23, 2006 and was completed on December 11, 2006.

4.3.4.2 Limit of Technology for the 200-Series Tanks

HFFACO Milestone M-045-00 states in part the following:

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

In addition, HFFACO Milestone M-045-00B, which identifies requirements for demonstration retrievals, provides in part:

> "Waste shall be retrieved to the double-shell tank (DST) system to the limits of the technology (or technologies) selected."

This section presents information to demonstrate completion of Milestone M-045-00 retrieval goals, and removal of waste and key radionuclides from the 200-series tanks to the maximum extent technically practical. This section presents information on the VRS as it was initially configured and subsequently modified to continue the retrieval operation throughout the 200-series waste retrieval campaign in compliance with RPP-16525, "C-200-Series Tanks Retrieval Functions and Requirements," and RPP-16945, "Process Control Plan for the 241-C-200 series Waste Retrieval System." Unless otherwise noted, data presented in this section were developed in accordance with procedure TFC-ENG-CHEM-P-47, "Single-Shell Tank Retrieval Completion Evaluation."

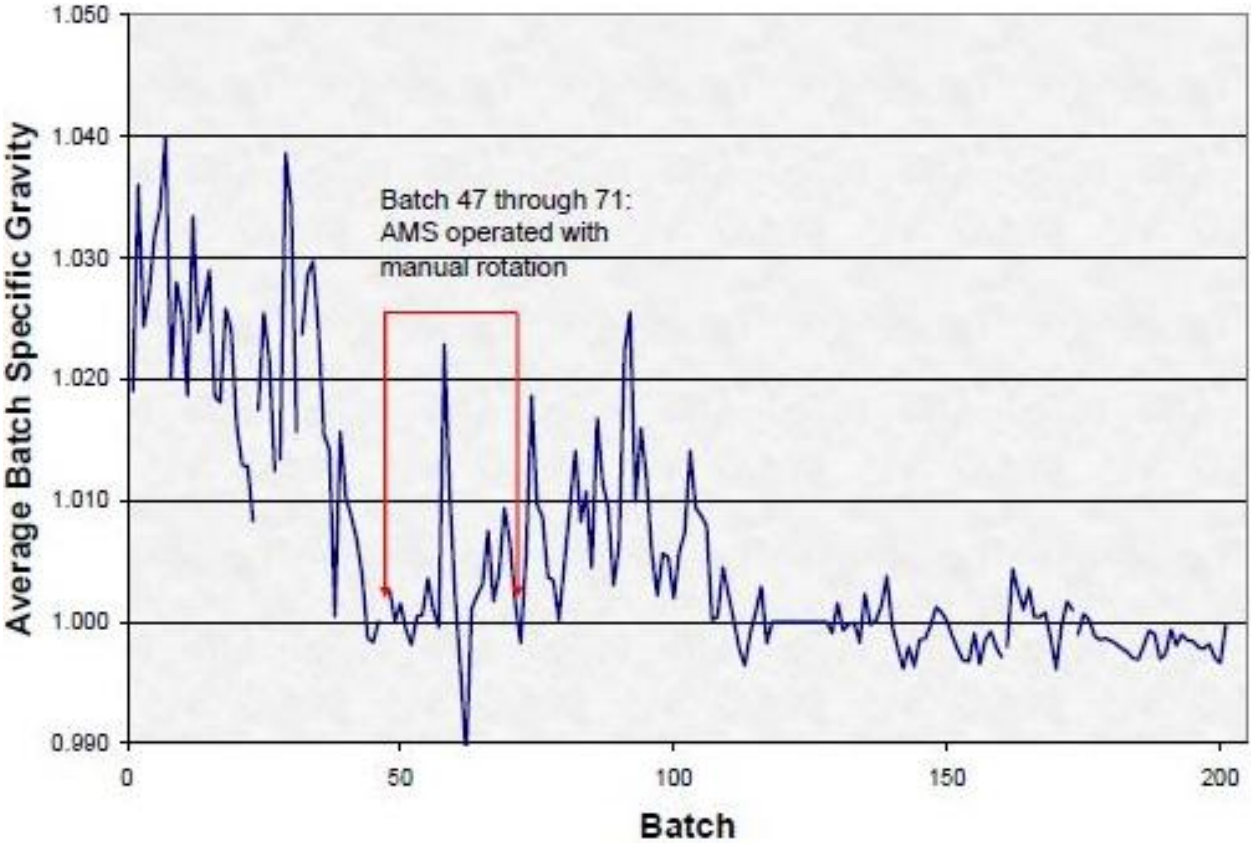
Neither Milestone M-045-00 nor Milestone M-045-00B prescribes a basis for determining when a technology has reached the limit of its capability to retrieve waste. Figure 4-5 illustrates the general concept of diminishing returns over time as a waste retrieval activity progresses towards its limit.

DOE relied on the following types of data to establish progress towards meeting the limit of the VRS capacity to retrieve waste from the 200-series tanks and determine when the end of retrieval was reached for each 200-series tank:

1. Examination of in-tank photos/videos to observe and record the waste surface contours, form, and characteristics;
2. Estimation of retrieval performance efficiency based on comparison of batch specific gravity (SpG) measurements;
3. Use of retrieval performance data trends estimated from mass balances to demonstrate that a consistent pattern is present indicating that as much waste has been removed as practical;
4. Ratio of water used to waste recovered.

Visual Observations. A video camera inside the 200-series tanks allowed operational monitoring of activities and results throughout the waste retrieval campaign. Video observation of physical characteristics of the tanks and objects in the tanks aided in measuring residual waste volume change at the end of retrieval. A reduction in waste volume in the 200-series tanks was observed as retrieval progressed, as shown in Figure 4-30.

Figure 4-30. Example Slurry Specific Gravity Evaluation for Tank C-204.



AMS = articulating mast system

Reference: RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204."

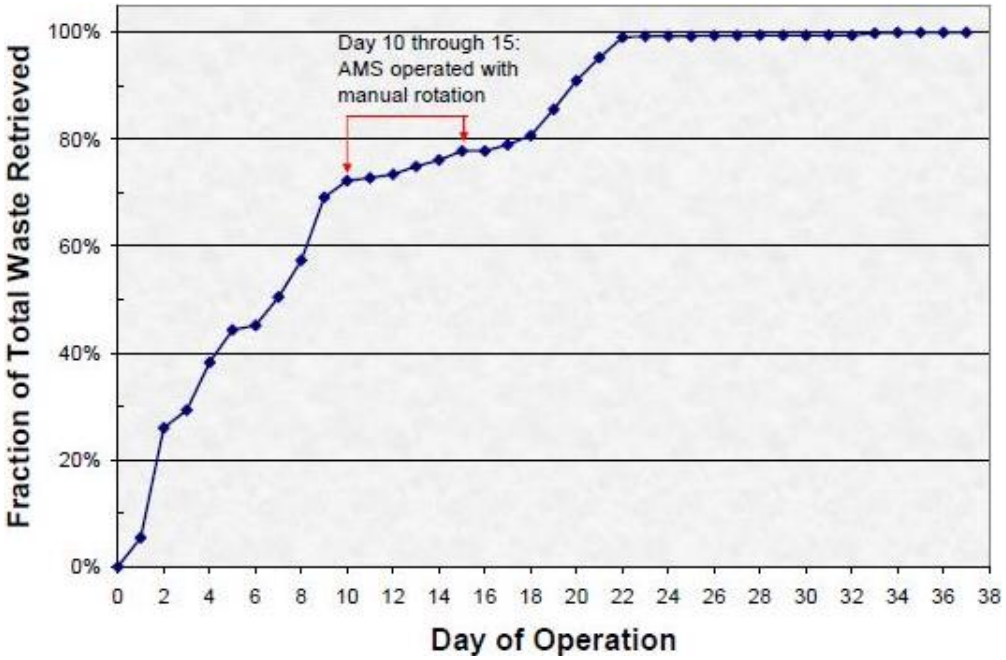
Trend in Specific Gravity of Waste Slurry. The SpG of undiluted waste from the 200-series tanks was substantially higher than the SpG of water used to transport the waste. Water, however, composed most of the waste slurry volume. Initially, the composite SpG of the slurry was higher than the SpG of water but lower than the SpG of undiluted waste. As the volume of retrieved waste diminished over time, the SpG of the slurry declined until it approximated the SpG of water.

A Coriolis meter was used to measure the relative density (because water with a SpG of 1.0 was used as reference material, the relative density is equal to the SpG) of the slurry from each of the 200-series tanks as it is being pumped to DST AN-106.

On most retrieval operating days for a particular 200-series tank, several slurry batches were transferred to DST AN-106. While the SpG of individual batches varied from one batch to another, a clear trend of declining SpG (the SpG of the slurry declined toward 1.0) was indicated over the course of the retrieval campaigns for the 200-series tanks. In the later stages of the retrieval campaigns for a particular 200-series tank, the SpG of the slurry did not vary greatly from 1.0, indicating that the content of the slurry was approximating water, and that the VRS limit of technology to retrieve waste in a specific 200-series tank had been reached, as shown in Figure 4-30.

Trends in Volume of Residual Waste. Waste retrieval progress for each of the 200-series tanks was tracked during the retrieval campaigns. The volume of waste retrieved per day or shift and the volume of waste remaining after each operational day were tracked and trended to determine when the limits of the VRS had been reached during each retrieval campaign for the 200-series tanks, as shown in Figure 4-31.

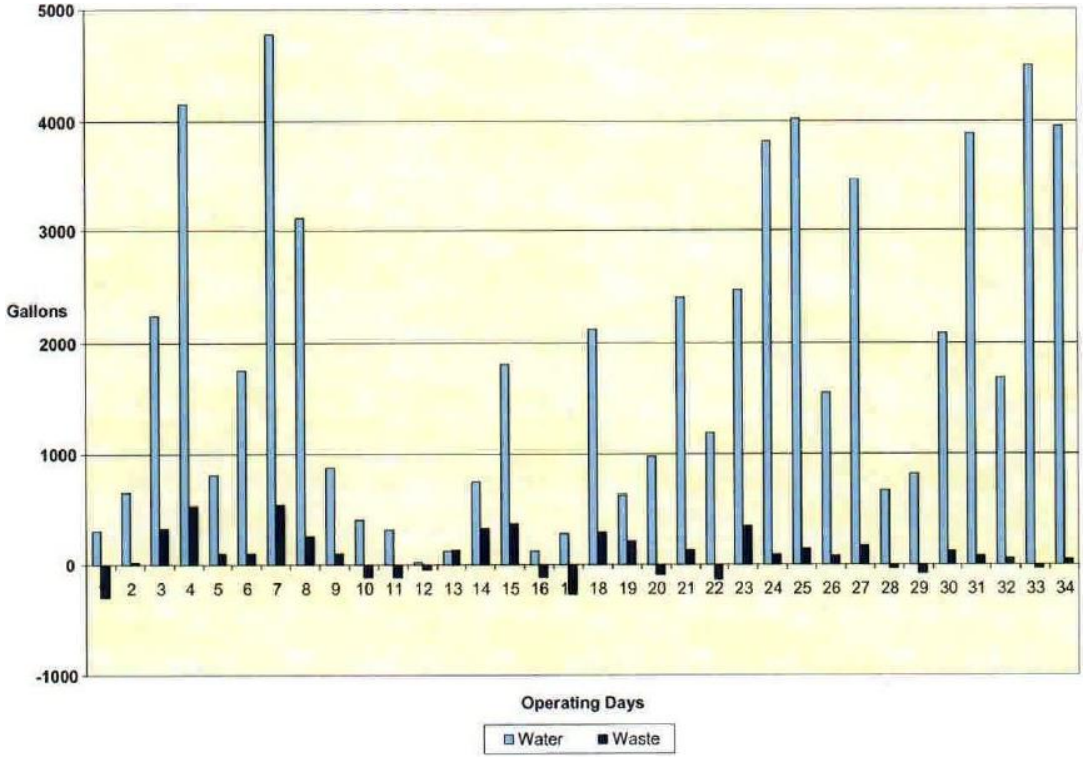
Figure 4-31. Example Waste Retrieval Progress Evaluation for Tank C-204.



AMS = articulating mast system
Reference: RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204."

Trends in Ratio of Water Used to Waste Recovered. Water was used to scarify (break up) waste forms in tanks C-202 and C-203, and to transport waste in slurry to receiving DST AN-106. Volumes of water used for some or all of these purposes were measured on each operating day. The ratio of waste retrieved to water used was an indicator of waste retrieval efficiency. Approaching the limit of technology was indicated by diminishing waste recovery on a constant or increasing water use. The trends are shown in Figure 4-32.

Figure 4-32. Example Trend in Waste Used to Waste Recovered for Tank C-203.



Conclusion. Based on the above criteria, DOE concluded that waste retrieval operations were performed to the limits of the VRS technology. Retrieval of the 200-series tank waste is documented in RPP-RPT-30181, "Retrieval Data Report for Single-Shell Tank 241-C-201"; RPP-RPT-29095, "Retrieval Data Report for Single-Shell Tank 241-C-202"; RPP-RPT-26475, "Retrieval Data Report for Single-Shell Tank 241-C-203"; and RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204."

4.3.4.3 Residual Waste Volumes for the 200-Series Tanks

The post-retrieval measurements of tank residual waste volumes were performed for each tank using the CCMS. Post-retrieval residual waste volume estimates were made using the CCMS method per TFC-ENG-FACSUP-CD-22, "Post-Retrieval Tank Waste Volume Determination." The total measured volume of residual waste in a tank consists of the sum of volumes remaining

in the tank dish, on the tank walls, on the stiffener rings, and in the void spaces in equipment left in the tank.

The residual waste volumes remaining in the 200 Series tanks after retrieval campaigns are shown in Table 4-8, along with the pre-retrieval volumes and waste volume retrieved from each tank.

Table 4-8. Retrieval History for the WMA C 200 Series Tanks.

Tank	Waste Volume Pre-Retrieval gal (ft^3)	Waste Volume Retrieved gal (ft^3)	Residual Waste Remaining gal (ft^3)
C-201[a]	860 (115)	717 (95.8)	144 (19.2)
C-202[b]	1,400 (187)	1,253 (167)	147 (19.7)
C-203[c]	2,640 (353)	2,501 (334)	138 (18.5)
C-204[d]	1,489 (199)	1,346 (180)	137 (18.3)

[a] RPP-RPT-30181, "Retrieval Data Report for Single-Shell Tank 241-C-201."
[b] RPP-RPT-29095, "Retrieval Data Report for Single-Shell Tank 241-C-202."
[c] RPP-RPT-26475, "Retrieval Data Report for Single-Shell Tank 241-C-203."
[d] RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204."

4.3.5 Removal of Key Radionuclides from Ancillary Structures

Ancillary structures within WMA C consist of the C-301 Catch Tank, the 244-CR Process Vault with four small tanks, and the waste transfer system components (pipelines and diversion boxes). DOE plans to characterize and remove additional waste, including key radionuclides, from the C-301 Catch Tank and the 244-CR Process Vault using proven technologies. Consistent with those plans, the WMA C PA base case assumes that 90 percent of the waste will be retrieved from the catch tank and process vault.

Regarding the diversion boxes and transfer pipelines, operation records show that those transfer system components were previously well-flushed as part of routine operations. This flushing effectively removed waste and key radionuclides such that little or no residual waste remains, except as adsorbed onto surfaces, as discussed in Section 2.3.5 of this Draft WIR Evaluation.[51] Specifically with respect to the pipelines, the WMA C PA base case assumes, based on process knowledge and flushing history, that the pipelines are only 5 percent full, except for the cascade lines (which operated under gravity flow and had no practical means for flushing) and one transfer line, which is assumed to be plugged and therefore completely full.

From a risk-informed perspective, additional removal of waste and key radionuclides from the ancillary structures (beyond that discussed above) would not be technically practical

[51] DOE plans to inspect the diversion boxes, and based on that inspection, may decide to remove additional residual waste and key radionuclides. No further efforts to clean the pipelines are planned, given prior flushing operations and the very low quantity of remaining residual waste.

(i.e., sensible or useful), given that the residual waste, including that in the pipelines, is well below Class C concentration limits, as shown in Section 6.0 of this Draft WIR Evaluation. Similarly, the WMA C PA, which includes ancillary structures and their residuals, projects that future doses to the public and potential human intruder are well below the doses specified in the performance objectives and performance measures for LLW, as discussed in Section 5 of this Draft WIR Evaluation.[52]

Based on the above considerations, key radionuclides have been or will be removed from the ancillary structures to the maximum extent technically practical.

4.3.6 Conclusion for Removal of Key Radionuclides to the Maximum Extent Technically Practical

The Retrieval Data Reports (RDRs) submitted under the HFFACO for all WMA C tanks and the Practicability Evaluations for the WMA C tanks retrieved under the Consent Decrees provide data showing that the tanks have been retrieved to the limits of the technologies used.

The retrieval processes established under both the HFFACO and Consent Decrees have generated results that are similar to the WIR requirement that key radionuclides be removed to the maximum extent technically practical because of the following:

1. The waste retrieval technology was chosen specifically to address the waste type in the tanks, and the limitations inherent in retrieving waste from the tanks;
2. The chosen waste retrieval technology was then operated until it reached the limits of its ability to retrieve waste.

Based on the prior flushing of the transfer components (diversion boxes and pipelines) and the waste retrieval plans for the C-301 Catch Tank and the 244-CR Process Vault, waste and key radionuclides also have been or will be removed from the ancillary structures to the maximum extent technically practical. Therefore, the waste contained in the WMA C tanks and ancillary structures have been or will be processed to remove key radionuclides to the extent that is technically practical.

[52] The above discussion is not meant to suggest that DOE necessarily stops removing key radionuclides once performance objectives or Class C concentration limits are met.

4.4 REMOVAL OF KEY RADIONUCLIDES TO THE MAXIMUM EXTENT ECONOMICALLY PRACTICAL

As stated in Section 4.3 above, the first criterion in DOE M 435.1-1, Chapter II(B)(2)(a) is that the wastes "have been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical." Section 4.3 demonstrated that key radionuclides have been or will be removed from WMA C tanks and ancillary structures to the maximum extent that is technically practical. This section will demonstrate that key radionuclides have been or will be removed from WMA C tanks and ancillary structures to the maximum extent that is *economically* practical. Many of the elements of practicality were covered thoroughly in Section 4.3 and need not be repeated; this section will focus specifically on comparing the costs and benefits of removing additional wastes, including key radionuclides, from the WMA C tanks.

Various strategies could be envisioned to pursue additional waste removal from all WMA C tanks, or only select tanks. For the sake of this discussion, this Draft WIR Evaluation assumes an effort to remove an additional 90 percent of the residual waste from each of the twelve 100-series tanks, but also provides a range of values to bound other scenarios.

Regarding economic practicality, DOE G 435.1-1 states:

The economically practical part of this requirement is determined by the development of total lifecycle costs for an alternative, or unit costs, e.g., cost per curie removed. Some subjectivity will be present in determining whether these costs are economically practical; however in general, the goal should be to determine a relationship between costs and removal of the key radionuclides and identify the point in this relationship at which removal costs increase significantly and thus become impractical.

Section 3.4 of NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations*, provides guidance to NRC staff concerning appropriate elements and level of detail in a cost/benefit analysis for WIR evaluations. Table 3-1 of NUREG-1854 lists potential categories of costs and benefits for consideration in analyzing whether additional removal activities are justified.

The following subsections explore various elements of costs and benefits of additional waste removal activities, taking into account the above–referenced NRC and DOE guidance. The ensuing discussion is premised on data and rationale from a variety of sources, as well as informed judgment. For the reasons set forth below, the following subsections show that at closure of WMA C, DOE will have removed waste containing key radionuclides from the tanks and ancillary structures to the maximum extent economically practical, and that further removal efforts would not be economically practical, in terms of, for example, worker exposure, monetary costs, schedule delays, and potential doses to the public and human intruder.

Appendix C contains excerpts from the retrieval completion documents for several of the WMA C tanks, as representative examples. These evaluations describe the tank conditions (pre- and post-retrieval); the selected technologies and performance evaluations of each; which technologies were considered to perform additional retrieval; the recommended technology and its estimated effectiveness, cost estimate, estimated additional occupational radiation dose; and

schedule and waste treatment impacts. As noted above, the Retrieval Data Reports submitted under the HFFACO for all WMA C tanks and the Practicability Evaluations for the WMA C tanks retrieved under the Consent Decrees provided the DOE with data showing that the tanks have been retrieved to the limits of the technologies used, supporting DOE's determinations that retrieval of a particular tank was complete.

4.4.1 Costs of Further Waste Removal

Relevant costs include financial costs, schedule delays, increased radiological dose and other risks to site workers and the public, and system impacts such as secondary waste streams. These are discussed in the following paragraphs, and summarized in Table 4-9.

4.4.1.1 Financial Costs

Detailed cost estimates for implementing additional retrieval activities are not available for every WMA C tank. Representative cost estimates for several of the 100 series tanks are provided in Appendix C. These examples range from $6,500,000 to $20,000,000 per tank, with an average of $12,375,000. Therefore a total estimate for the twelve 100 series tanks would range between $78,000,000 and $240,000,000, with an average estimate of $148,500,000. [53] These estimates are additional direct monetary costs only, which do not include schedule delays, occupational exposure, or impacts to waste treatment. No detailed cost estimate was prepared for the 200-series tanks. [54]

4.4.1.2 Schedule Delays

Another potential cost of further waste removal is the associated delay in tank closure. While DOE does not consider schedule adherence to be the determining factor in tank closure planning, it is nevertheless important to both DOE and other stakeholders. DOE would not propose further delaying WMA C closure unless it can be shown that there would be significant benefit in doing so.

In addition to the direct dollar costs of additional retrieval efforts discussed above, schedule delays typically increase overall project costs due to the time value of money, increased maintenance needs for deteriorating facility infrastructure, and extension of on-going tank farm operations. Delays also increase the uncertainty of future appropriations to complete the mission.

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[53] The examples cited were developed at the time retrieval was considered complete in a given tank, but equipment had not yet been demobilized; the cost estimates relied in part on that existing equipment in deploying an additional technology. Much of that equipment has since been demobilized or decommissioned. Therefore, actual costs to deploy new technologies at this time would likely be several times higher. The existing numbers are used because they have a documented basis, but should be considered bounding minimums.

[54] The 55,000 gal 200 series tanks (C-201 through C-204) were not included in the evaluation because the removal of waste was very effective. These tanks were assumed to have leaked in the past and were retrieved with a vacuum retrieval system to an average waste volume of approximately 19 ft^3, with no more than 10 ft^3 considered removable by any means. As a result cost estimates for additional retrieval were not prepared. This approach is consistent with DOE G 435.1-1, at II-23, which explains: "An economic assessment may not be considered necessary if a technology option is not first considered to be technically practical."

The specific examples provided in Appendix C include representative estimates of 6 to 12 months for additional removal efforts at those tanks (3 to 5 years in one case). Extending this to all twelve of the 100-series tanks would result in an overall delay in WMA C closure of no less than six years from the current proposed plan. [55]

4.4.1.3 Increased Risks to Site Workers

The specific examples provided in Appendix C include representative estimates of additional occupational dose for continuing retrieval of the WMA C tanks ranging from 600 to 2,100 person mrem per tank. These estimates were based on actual data collected during previous retrieval operations in similar tanks. The extended total person mrem for the twelve tanks therefore ranges from 7,200 person mrem (7.2 person rem) to 25,200 person mrem (25.2 person rem), with an average estimate of 13,800 person mrem (13.8 person rem). [56]

While Hanford occupational illness and injury rates are very low, additional years of on-going tank farm operations would nevertheless also expose site workers to the industrial hazards associated with this complex work. The human and monetary costs of such additional exposures are difficult to quantify, but must be considered in the overall analysis in keeping with the as low as reasonably achievable (ALARA) concept.

4.4.1.4 System Impacts

No new waste streams would be expected to be created by additional waste retrieval efforts at WMA C, assuming use of similar technologies to those currently deployed. However, some additional waste volume would be created due to potential chemical additions, sluicing fluids, and flush water, which would require increased DST storage space and evaporator operations. These costs cannot be quantified without identifying the technologies to be used, but the DST and evaporator resources are already severely limited, and therefore would likely result in significant additional monetary costs and schedule delays to accommodate such activities.

Looking beyond the DST system, any additional waste retrieved from WMA C and added to the DST inventory would not be expected to have a significant impact on the overall future Waste Treatment Plant disposal mission.

4.4.1.5 Impacts to the Public and the Environment

No new public or environmental risks are associated specifically with additional retrieval activities in WMA C. Existing nuclear and industrial safety programs and access controls would continue. The potential exists for exacerbation of past leaks by additional in-tank activities, consistent with the analyses previously documented for current technologies. Such potential leaks would be evaluated in detail prior to implementation, but they would not be expected to have any measurable effect on the overall performance objectives for WMA C after closure (i.e., any such leak volumes would be well within the existing uncertainty ranges already accounted for in the WMA C PA analyses).

[55] As with the cost estimates, these time estimates assumed the existing retrieval technologies would remain largely intact for use in additional campaigns. Installing new equipment today would take much longer.
[56] Again, these are bounding minimum values, due to the additional work required to install new equipment.

4.4.2 Benefits of Further Waste Removal

Again referring to Table 3-1 of NUREG-1854, the potential benefits of additional waste removal from WMA C (primarily reduced long-term dose to the public) are discussed in the following paragraphs and summarized in

Table 4-10. Potential Benefits Associated With Additional Radionuclide Removal.

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4.4.2.1 Future Radiological Dose to the Public and Inadvertent Intruders

For perspective, the average annual radiological dose to individuals in the Hanford vicinity is approximately 625 mrem. About half of the annual dose is from ubiquitous, natural background sources (~311 mrem). Most of the remaining dose is from medical exposure to radiation (~300 mrem). Approximately 14 mrem per year comes from consumer products and other man-made sources (nuclear power, security, research, and occupational exposure) (NCRP 2009:12).

The WMC PA was developed to provide reasonable expectation that residual radioactive waste left in tanks and ancillary structures within the closed WMA C will meet defined performance objectives and measures for the protection of human health and the environment into the future. The WMA C PA considers the risk to two model populations – a hypothetical member of the public and a hypothetical inadvertent intruder. The WMA C PA base case is a deterministic analysis using best-estimate parameters, which evaluates the condition when the safety functions provide their expected contribution to the performance of the facility. The all-pathways analysis combines the groundwater pathway analysis and the air pathway analysis for the base case.

The peak dose for the all-pathways analysis in the compliance period is associated with the air pathway, with the peak dose of 2E-3 mrem/yr TEDE, primarily from ^{3}H releases. This peak occurs between 10 and 20 years after WMA C closure, and falls to near zero within the institutional control period when no unprotected member of the public should be exposed (RPP-ENV-58782). This value is over 12,000 times lower than the all-pathway performance objective of 25 mrem/yr. The peak all-pathways groundwater dose within the compliance time period to which a hypothetical member of the public could be exposed is even smaller – 4E-4 mrem/yr, or over 62,000 times lower than the performance objective of 25 mrem/yr.

DOE also performed additional modeling for a 10,000- year sensitivity period for making risk-informed decisions. The peak dose for the all-pathways analysis in the sensitivity period (i.e., 1,000 to 10,000 years after closure of WMA C) was 0.10 mrem/yr, dominated by ^{99}Tc from the groundwater pathway. Additional radionuclides contributing 95 percent of the all-pathways dose during the sensitivity period include ^{234}U, ^{238}U and ^{129}I. This peak-dose is 250 times lower than the performance objective of 25 mrem/yr.

Based on these values, the potential health risk to a future member of the public from this additional fraction of a single mrem is so small as to be incalculable. Further, if it is assumed that all other considerations are set aside and the goal of removing 90 percent of the current waste residuals from WMA C is accomplished, the net benefit of averting 90 percent of that negligible dose is also negligible.

The more likely inadvertent intruder scenarios in the WMA C PA are based upon breaching a buried waste transfer pipeline, rather than a tank. Due to prior flushing as shown by operation

history, little or no residual waste is assumed to remain in the pipelines other than waste adhered onto surfaces, with the exception of cascade lines (which operated by gravity and could not be flushed) and one presumably-plugged transfer line.[57] As discussed in Section 5.3 of this Draft WIR Evaluation, both the chronic and acute doses to the hypothetical human intruder who may intrude on a buried pipeline are very low (well below the applicable performance objective and performance measures), during both the 1,000-year compliance period and 10,000-year sensitivity period. Although no further efforts are planned to clean or remove waste transfer pipelines within WMA C, there would be negligible benefit (reduction in dose) to the hypothetical human intruder from additional waste removal, given the already low doses projected in the WMA C PA from the pipeline intruder scenarios. [58]

4.4.3 Summary of Removal to the Extent Economically Practical

The sections above describe the economic practicality assessment and demonstrate that removing additional radionuclides from WMA C tanks would not produce a net benefit. It would not be sensible nor useful in light of the overall benefit to human health, safety, and the environment. The additional financial costs, occupational radiation dose, and schedule impact lead to this conclusion. Key radionuclides have been removed to the extent economically practical based on the significant financial and other costs summarized in Table 4-9, and the insignificant benefits that may be realized, as summarized in

[57] This matter is discussed further in Sections 5.3.3 and 2.3.5 of this Draft WIR Evaluation, which explain that intrusion into a tank is unlikely, and that for the waste pipelines Base Case, the volume of the residuals in the pipelines is taken from RPP-PLAN-47559, which assumed the pipelines were only 5% full, except for the cascade lines and one transfer line which were assumed to be plugged and therefore completely full.

[58] While the tank intruder scenario is considered extremely unlikely, the PA provided an acute intruder dose for information purposes. The highest calculated dose is an order of magnitude below the relevant performance measure (PA Section 10.4 and PA Table 10-4). As risk is a product of likelihood and consequence, the benefit (reduction of risk) gained by further tank retrieval efforts, at any cost, would be negligible because the potential reduction in both dose and probability are extremely low.

Table 4-10. Potential Benefits Associated With Additional Radionuclide Removal.

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Table 4-9. Potential Costs Associated With Additional Radionuclide Removal.

Potential Costs	WMA C Tanks
Radiological dose to workers due to additional radionuclide removal activities	As discussed in Section 4.4.1.3 above, occupational dose would increase by an estimated 13.8 person rem.
Financial costs of additional radionuclide removal	As discussed in Section 4.4.1.1 above, financial costs would increase by an estimated $148,500,000.
Additional transportation risks	Not applicable. In-tank-farm pipelines would be used for additional waste retrieval.
Chemical and physical effects of removal activities on downstream waste processing or storage systems	As discussed in Section 4.4.1.4 above, negligible effects are noted in increased processing time.
Additional impacts on DOE's mission or schedule	As discussed in Section 4.4.1.2 above, the cumulative schedule impact to WMA C closure would be no less than 6 years.
Doses to the public due to additional removal activities	None expected; however, the dose to site workers would increase, as identified as in Table 4-10.
Environmental disruption due to additional removal activities	None identified.

Table 4-10. Potential Benefits Associated With Additional Radionuclide Removal.

Potential Benefits	WMA C Tanks
Potential averted long-term dose to members of the public and inadvertent intruders	As discussed in Section 4.4.2.1 above, the all pathways peak dose of 2E-3 mrem/yr to a member of the public during the compliance period occurs within two years of closure. Assuming the key radionuclides and resultant dose are reduced by an additional 90 percent, any benefit to hypothetical members of the public would be negligible given the already extremely low peak dose. As discussed in Section 4.2.2.1 above, the more likely inadvertent intruder scenarios are based upon breaching a buried waste transfer pipeline, rather than a tank. There would be negligible benefit (reduction in dose) to the hypothetical human intruder from additional waste removal from either pipelines or tanks.
Reduction in radiological dose to workers because of increased waste stabilization, decreased numbers of waste transfers in tank farms, or other similar considerations	As discussed in Section 4.4.1.3 above, there would be no worker radiation dose reduction, but rather an increase to current worker dose.
Decrease in costs of other entities, such as a reduction in costs incurred by public water supply utilities to meet the requirements of the Safe Drinking Water Act	As discussed in Section 4.4.2.1 above, the peak groundwater dose of 4E-4 mrem/yr to a member of the public during the compliance period which occurs during the compliance period is from radionuclides in the ground water. Assuming the key radionuclides are reduced by an additional 90 percent, any benefit to public water supply would be negligible.
Reduction of impact on natural resources, such as groundwater aquifers	There would be no significant benefit to the public water supply from additional retrievals and decreased inventory of Key Radionuclides from WMA C tanks.
Improvement of esthetics, changes in land use, and reduction in monitoring costs	There is no change to esthetics or future land use due to additional retrievals from WMA C. As discussed in Section 4.4.1.2 there will be additional cost for tank farm operations and monitoring.

As explained in the preceding sections and summarized in Tables 4-9 and 4-10, the cost / benefit analysis for additional waste retrieval efforts in WMA C tanks does not show a net benefit. The costs in dollars, worker dose, and closure delays far outweigh any potential reduction in dose to a future hypothetical member of the public. Therefore, the wastes contained in the WMA C tanks and ancillary structures have been or will be processed to remove key radionuclides to the extent that is economically practical.

4.5 CONCLUSION FOR REMOVAL OF KEY RADIONUCLIDES TO THE MAXIMUM EXTENT TECHNICALLY AND ECONOMICALLY PRACTICAL

Section 4.2 above identified the key radionuclides for this evaluation, as summarized in Table 4-3. Section 4.3 discusses the considerations involved in determining what is meant by "practical", and demonstrates that the waste and key radionuclides have been or will be removed from the tanks and ancillary structures to the maximum extent technically practical. Section 4.4 provides an analysis of the costs and benefits associated with additional removal efforts, and shows that additional removal would not be economically practical. Therefore, the preceding sections show that the first criterion in DOE M 435.1-1, Chapter II(B)(2)(a), concerning removal of key radionuclides to the maximum extent that is technically and economically practical, has or will be met at the time of closure of WMA C.

5.0 THE WASTE WILL BE DISPOSED OF IN ACCORDANCE WITH SAFETY REQUIREMENTS COMPARABLE TO THE PERFORMANCE OBJECTIVES SET OUT IN 10 CFR PART 61, SUBPART C

Section Purpose

The purpose of this section is to demonstrate that the stabilized residuals in the WMA C waste tanks and ancillary structures will be managed and disposed of to meet safety requirements comparable to the performance objectives for land disposal of LLW found in 10 CFR 61.41 through Title 10 CFR 61.44.

Section Contents

This section describes key parameters and results from the WMA C PA that demonstrate compliance with safety requirements comparable to the performance objectives in 10 CFR 61.41 and 10 CFR 61.42; DOE regulatory and contractual requirements which ensure compliance with safety requirements comparable to 10 CFR 61.43, Protection of individuals during operations (10 CFR 61.43); and relevant factors of WMA C siting, design, use, operation and closure that ensure compliance with safety requirements comparable to 10 CFR 61.44.

Key Points

- DOE is using an assumed institutional control period of 100 years for the purpose of analysis.
- A 100-m buffer zone around the WMA C boundary is assumed for the purpose of calculating doses to a member of the public.
- The WMA C PA analysis demonstrates compliance with safety requirements in DOE M 435.1-1 comparable to the performance objective in 10 CFR 61.41, including compliance with a 25 mrem/yr peak all-pathways total effective dose equivalent (TEDE) to a hypothetical member of the public.
- The WMA C PA analysis demonstrates compliance with performance measures in DOE M 435.1-1 comparable to the performance objective in 10 CFR 61.42, based on consideration of a dose of 100 mrem in a year and 500 mrem total effective dose equivalent excluding radon in air, for chronic and acute exposure scenarios, respectively, to a future hypothetical inadvertent intruder of the closed WMA C.
- The WMA C waste tanks and certain ancillary structures will be filled with grout to provide long-term stability.

5.1 BACKGROUND

The second criterion in DOE M 435.1-1, Chapter II.B.(2)(a) for determining whether waste is incidental to reprocessing, using the evaluation method, states in relevant part that the waste:

> *Will be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR 61 Subpart C.*

Sections 10 CFR 61.41 through 10 CFR 61.44 detail performance objectives established by the NRC for land disposal of radioactive waste for NRC licensees.[59] These performance objectives address protection of the general population from radioactivity releases (10 CFR 61.41); protection of individuals from inadvertent intrusion on the disposal site (10 CFR 61.42); protection of workers and the public during disposal facility operations (10 CFR 61.43); and the stability of the disposal site after closure (10 CFR 61.44).

Title 10, CFR, Part 61, Subpart C, § 61.40, General requirement (10 CFR 61.40) states:

> "Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in §§61.41 through 61.44."

A comparable provision is set forth in M 435.1-1, Chapter IV.P. (1) which provides:

> "Low-level waste disposal facilities shall be sited, designed, operated, maintained, and closed so that a reasonable expectation exists that the following performance objectives will be met for waste disposed of after September 26, 1988."

10 CFR 61.40 requires "reasonable assurance" that exposures are within the limits of the subsequent performance objectives for 10 CFR 61.41 through 10 CFR 61.44 for licensed disposal facilities. Similarly, DOE M 435.1-1 requires "reasonable expectation", analogous to "reasonable assurance", that the performance objectives set forth in M 435.1-1 will be met.[60] As explained later in this Draft WIR Evaluation, the DOE performance objectives and performance measures in M 435.1-1, Chapter IV.P. (1) set forth safety requirements comparable to the NRC performance objectives at 10 CFR Part 61, Subpart C. A summary comparison of the DOE and NRC disposal safety requirements is provided in Appendix B.

DOE has developed a WMA C PA that provides the technical basis and results demonstrating there is reasonable expectation that the 10 CFR 61.41 and 10 CFR 61.42 performance objectives and DOE M 435.1-1 performance objectives and performance measures will be met at WMA C closure. These analyses were performed using a variety of modeling codes including the STOMP© deterministic code and GoldSim© probabilistic code. As required by DOE M 435.1-1, maintenance of the WMA C PA will include future revisions as needed (e.g., to incorporate new information and update model codes).

[59] Disposal in situ of the tanks, residuals and ancillary equipment at the WMA C at closure will not be licensed by NRC or an Agreement State.

[60] This Draft WIR Evaluation uses the phrase "reasonable expectation" except when directly quoting the NRC language.

The PA modeling consisted of a hybrid approach using both deterministic modeling as well as probabilistic modeling for certain sensitivity and uncertainty analyses. The WMA C PA includes deterministic and probabilistic analyses for 10,000 years after WMA C closure. This approach envelopes both the 1,000-year compliance period after closure, as described in DOE M 435.1-1 for PAs for DOE facilities, as well as the 10,000-year period suggested in NUREG-1854.

The WMA C PA details the analyses performed to provide "reasonable expectation" that the stabilized residuals, waste tanks and ancillary structures will be disposed of in compliance with the 10 CFR 61.41 and 10 CFR 61.42 performance objectives and "reasonable expectation" of compliance with DOE M 435.1-1 performance objectives in conjunction with closure of the WMA C. The WMA C PA provides the development and calculation of the following doses:

- Potential radiological doses to a hypothetical member of the public
- Potential radiological doses to a hypothetical inadvertent intruder.

These calculations were performed to provide information regarding potential peak doses from the closed WMA C. In addition, uncertainty and sensitivity analyses were used to ensure reasonably conservative information is available to develop dose-informed conclusions related to the closure of WMA C.

5.2 PROTECTION OF THE GENERAL POPULATION FROM RELEASE OF RADIOACTIVITY

10 CFR 61.41, Protection of the General Population from Release of Radioactivity, provides as follows:

> "Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

DOE provides a similar requirement (see Appendix B) in DOE Manual 435.1-1, Section IV.P(1) as follows:

> (a) Dose to representative members of the public shall not exceed 25 millirem in a year total effective dose equivalent from all exposure pathways, excluding the dose from radon and its progeny in air.
> (b) Dose to representative members of the public via the air pathway shall not exceed 10 millirem in a year total effective dose equivalent, excluding the dose from radon and its progeny.

DOE Manual 435.1-1, Section IV.P(1) also has the following additional requirement that is discussed later in this section:

> (c) Release of radon shall be less than an average flux of 20 pCi/m2/s at the surface of the disposal facility. Alternatively, a limit of 0.5 pCi/L of air may be applied at the boundary of the facility.

5.2.1 General Approach

To demonstrate compliance with this performance objective, a 25 mrem/yr peak all-pathways TEDE is used, rather than individual organ doses. The NRC states in NUREG-1854 that the 25 mrem/yr all-pathways TEDE is used by the NRC in making the assessment for compliance with the whole body, thyroid, and any other organ limits in 10 CFR 61.41 and is protective of human health and the environment.

In addition, NUREG-1854 states the following:

> "… incidental waste determinations may use total effective dose equivalent (TEDE) without specific consideration of individual organ doses. Intruder calculations should be based on 5 mSv [500 mrem] TEDE limit, without specific consideration of individual organ doses, to ensure consistency between 10 CFR 61.41 and 10 CFR 61.43. Because of the tissue weighting factors and the magnitude of the TEDE limit, specific organ dose limits are not necessary for protection from deterministic effects."

The hypothetical future member of the public is assumed to be located at the boundary of the DOE-controlled area until the assumed active institutional control period ends (i.e., 100 years after closure), at which point the receptor is assumed to move to the point of maximum exposure at or outside of the WMA C 100-m buffer zone. For the purposes of demonstrating that the performance objective at 10 CFR 61.41 will be met and reasonable expectation of compliance with DOE M 435.1-1 performance objectives, the peak all-pathways dose at or outside of the 100-m buffer zone is used.

The pathways for release to a member of the public considered in the WMA C PA analyses are discussed in the following sections. The scenarios are not assumed to occur until after the assumed 100-year institutional control period ends.

5.2.2 Public Release All Pathways Dose Analysis

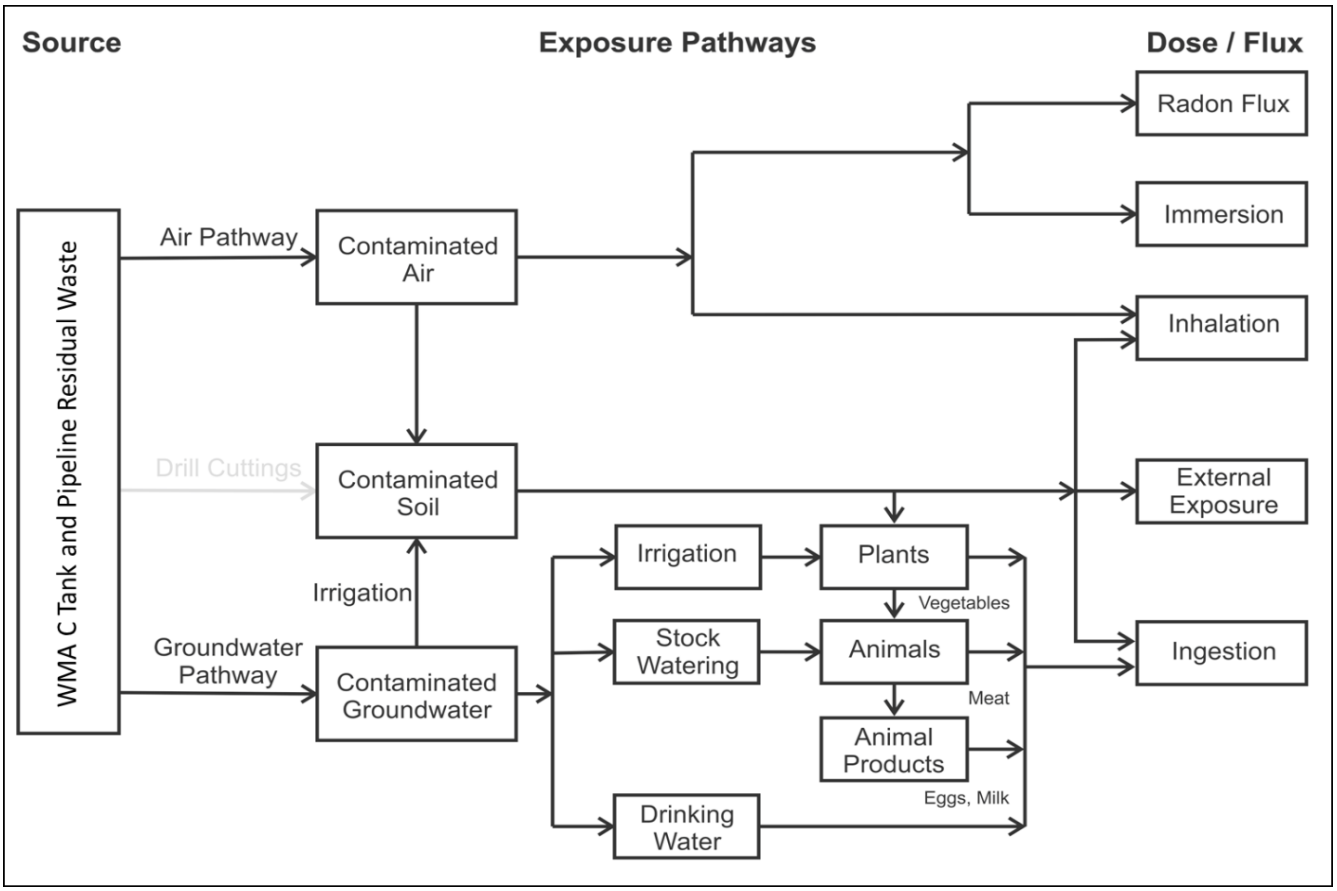
The all-pathways dose for the public in the WMA C PA is a combination of dose from the groundwater pathway and air pathway[61]. The receptor is considered to be a reasonably maximally-exposed individual and assumed to be located along the centerline of the air pathway plume and getting water from the well located at the highest concentration point in the aquifer at the 100 m boundary. The groundwater concentrations are used as the concentrations at the wellhead. This approach has been taken to maintain consistency between the groundwater protection performance objectives and the all-pathways dose performance objective in the WMA C PA, but does not take account of any dilution that may occur in the well as it is pumped.

For the all pathways scenario, the individual who receives dose is a Representative Person (ICRP 2006, "ICRP Publication 101a: Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public") who resides near WMA C and draws contaminated water from a well downgradient of WMA C. The all-pathways representative

[61] Under DOE M 435.1-1 requirements the air pathway excludes dose from radon and its progeny in air. The air pathway has a dose limit of 10 mrem/yr, excluding radon and progeny. Doses from radon are discussed later in this Draft WIR Evaluation.

person is assumed to use the water to drink, irrigate crops, and water livestock. The exposed representative person is assumed to receive dose by the exposure pathways shown in Figure 5-1.

Figure 5-1. Overview of Dose Calculations for Exposure Along the Groundwater and Air Pathways for the All-Pathways Scenario.



Current DOE and International Commission on Radiological Protection (ICRP) guidance recommends the use of a representative person for describing the hypothetical member of the public for use in projecting future doses. The representative person is described as a person who is representative of the more highly-exposed individuals in the population (DOE O 458.1, Radiation Protection of the Public and the Environment; ICRP 2006; ICRP 2007, "ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection"). The concept of the representative person replaces the concept of an average member of the critical group used in older radiation protection guidance.

Internal doses to the representative person are calculated using the dose factors provided in DOE-STD-1196-2011, and external doses are calculated using dose factors in EPA-402-R-93-081, Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil, Office of Radiation and Indoor Air. These dose factors represent effective dose coefficients calculated to a reference person in the manner of ICRP 1996, "ICRP Publication 72: Age-dependent Doses to the Members of the Public from Intake of

Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients." The reference person is a hypothetical aggregation of human (male and female) physical and physiological characteristics arrived at by international consensus for the purpose of standardizing radiation dose calculations (DOE-STD-1196-2011; "Environmental Dosimetry" [Jannik 2014]).

The source of contamination for the all-pathways scenario is the portion of the inventory transported by groundwater to the well location and drawn through the well. The exposed individual is assumed to use the water to drink, shower, irrigate crops, and water livestock. Exposure occurs through the following pathways:

- Ingestion of water
- Ingestion of fruits and vegetables grown on the farm
- Ingestion of beef raised on the farm
- Ingestion of milk from cows raised on fodder grown on the farm
- Ingestion of eggs from poultry fed with fodder grown on the farm
- Ingestion of poultry fed with fodder grown on the farm
- Ingestion of contaminated soil
- Inhalation of contaminated soil in the air
- External exposure to radiation.

An atmospheric pathway scenario is considered in which an individual is exposed to radionuclides that are diffused to the surface from the wastes disposed at WMA C and are transported 100 m downwind. Three exposure mechanisms are considered for the atmospheric pathway:

- Air immersion
- Inhalation
- External exposure to the contaminated ground surface.

External exposure results from a fraction of the waste in the air that settles on the ground via dry and wet depositions as they are transported by wind.

In addition to the deterministic all-pathways peak dose Base Case analysis, additional analyses are provided in the WMA C PA to characterize the context of uncertainty and sensitivity surrounding the WMA C PA all-pathways peak dose results. These evaluations focused on the key uncertainties and sensitivities identified during calculation of the member of the public dose. The uncertainty analyses provide information regarding how collective uncertainty in model input parameters is propagated through the model to the various model results. The sensitivity analyses provide information as to how various individual input parameters affect dose results. Together the uncertainty and sensitivity analyses provide assurance that the impacts of variability and uncertainty in the member of the public dose analyses are understood and addressed.

A full uncertainty analysis for the all-pathways scenario was undertaken in the WMA C PA by performing multi-realization simulations in the probabilistic mode using the GoldSim©-based system model. The uncertainties are propagated using the Monte Carlo sampling methodology and utilizing the inbuilt Latin hypercube sampling scheme. In the Monte Carlo simulation, the entire system is simulated a large number of times; each simulation is equally likely and is referred to as a *realization* of the system. For each realization, all of the uncertain parameters are

sampled, and the system is simulated through time (with the given set of input parameters) such that the performance of the system can be computed.

The results of the WMA C all-pathways analysis for both the deterministic and uncertainty analysis are provided in the following sections.

5.2.3 Results of the Analyses

WMA C PA modeling was used to determine an all-pathways dose to a member of the public for comparison with the 10 CFR 61.41 and the DOE M. 435.1-1, Chapter IV.P. (1) performance objectives. The deterministic Base Case analysis in the WMA C PA projected the peak all-pathways dose to the WMA C public receptor (i.e., individual greater than or equal to 100 m from WMA C) to be less than the 25 mrem/yr performance objective.

The WMA C PA all-pathways dose results for the groundwater and the air pathway are presented in Figure 5-2 for all radionuclides that produced a nonzero dose result within 10,000 years. Also shown on the figure are the DOE M 435.1-1 compliance time and compliance dose, for comparison. The peak dose summed over all radionuclides within the compliance time period is 2×10^{-3} mrem/yr, primarily from ^{3}H release. Within the compliance time period, the early dose is due to contribution of ^{3}H and ^{129}I from the air pathway, but after ~800 years the dose is dominated by ^{99}Tc contribution from the groundwater pathway. Within the sensitivity/uncertainty analysis time period (1,000 to 10,000 years), the peak dose summed over all radionuclides is 0.10 mrem/yr, which occurs ~1,500 years after closure.

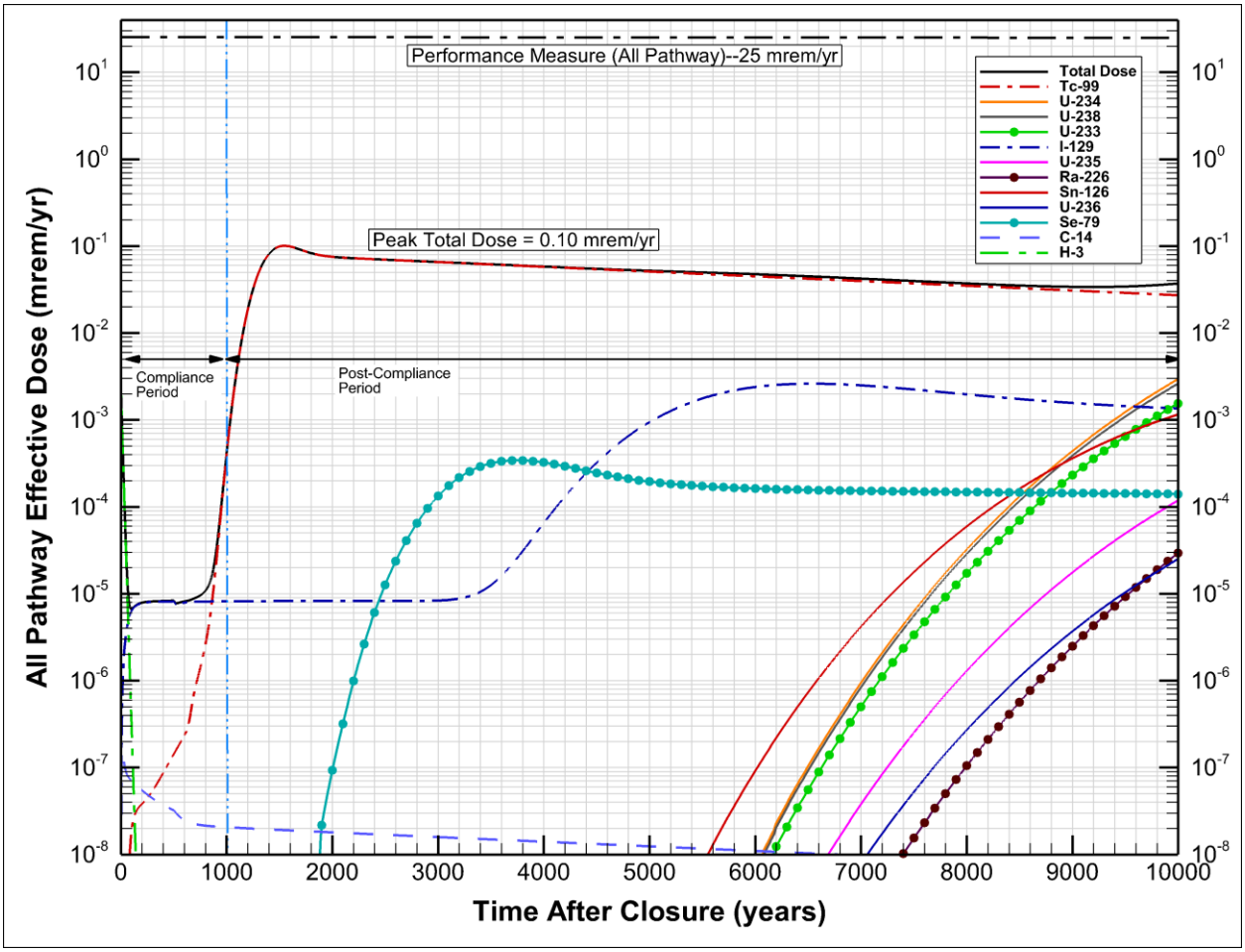
The dose resulting from exposure along the groundwater pathway is by far the dominant dose in the sensitivity/uncertainty analysis time period (1,000 to 10,000 years) and is presented separately in Figure 5-3 along with the major dose-contributing radionuclides. The highest total dose from the groundwater pathway within the compliance time period is 4×10^{-4} mrem/yr and within the sensitivity/uncertainty analysis time period is 0.10 mrem/yr resulting from release of ^{99}Tc. Minor contributors to the total dose at long times are ^{79}Se, ^{129}I, ^{126}Sn, and uranium isotopes (^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U) and their progeny. A summary of the peak doses and time of peak occurrence is presented in Table 5-1.

Doses from radionuclides that may potentially be released in gaseous form are presented in Figure 5-4 along with the 10 mrem/yr air pathway dose performance objective from DOE M 435.1. Doses are orders of magnitude below the dose performance objective at all times. The peak dose of 2×10^{-3} mrem/yr occurs within the first two years with ^{3}H being the primary dose contributor. Around 100 years, ^{129}I takes over as the primary dose contributor as ^{3}H dose declines due to its short half-life. Iodine-129 persists within the tank due to its long half-life and retention in the grout (from sorption), leading to a slow continuous diffusive flux. By about 500 years the ^{129}I dose reaches a steady value, indicating that the concentration gradient in the air phase from the tank to the surface has reached a steady state.

The GoldSim©-based system model is run for 300 realizations in the WMA C PA for the all-pathways uncertainty analysis. The results are presented in Figure 5-5 in terms of mean of total dose (from all radionuclides from the groundwater and atmospheric transport pathways) along with the mean dose contribution of individual radionuclides. The early dose (from 100 to 600 years) primarily results from the release of ^{3}H and ^{129}I to the air pathway, and the late dose

(past 1,000 years) results primarily from the release of ^{99}Tc to the groundwater pathway. The mean dose reaches a peak value of ~0.17 mrem/yr at ~3,400 years (post-closure time) and then declines gradually. Although the contribution of ^{99}Tc steadily declines, the mean total dose remains virtually unchanged beyond 7,000 years until the end of the analysis time. This is because of increasing dose contributions from uranium isotopes (primarily, ^{234}U, ^{238}U, and ^{233}U) that have relatively long half-lives and are relatively mobile (low K_d value).

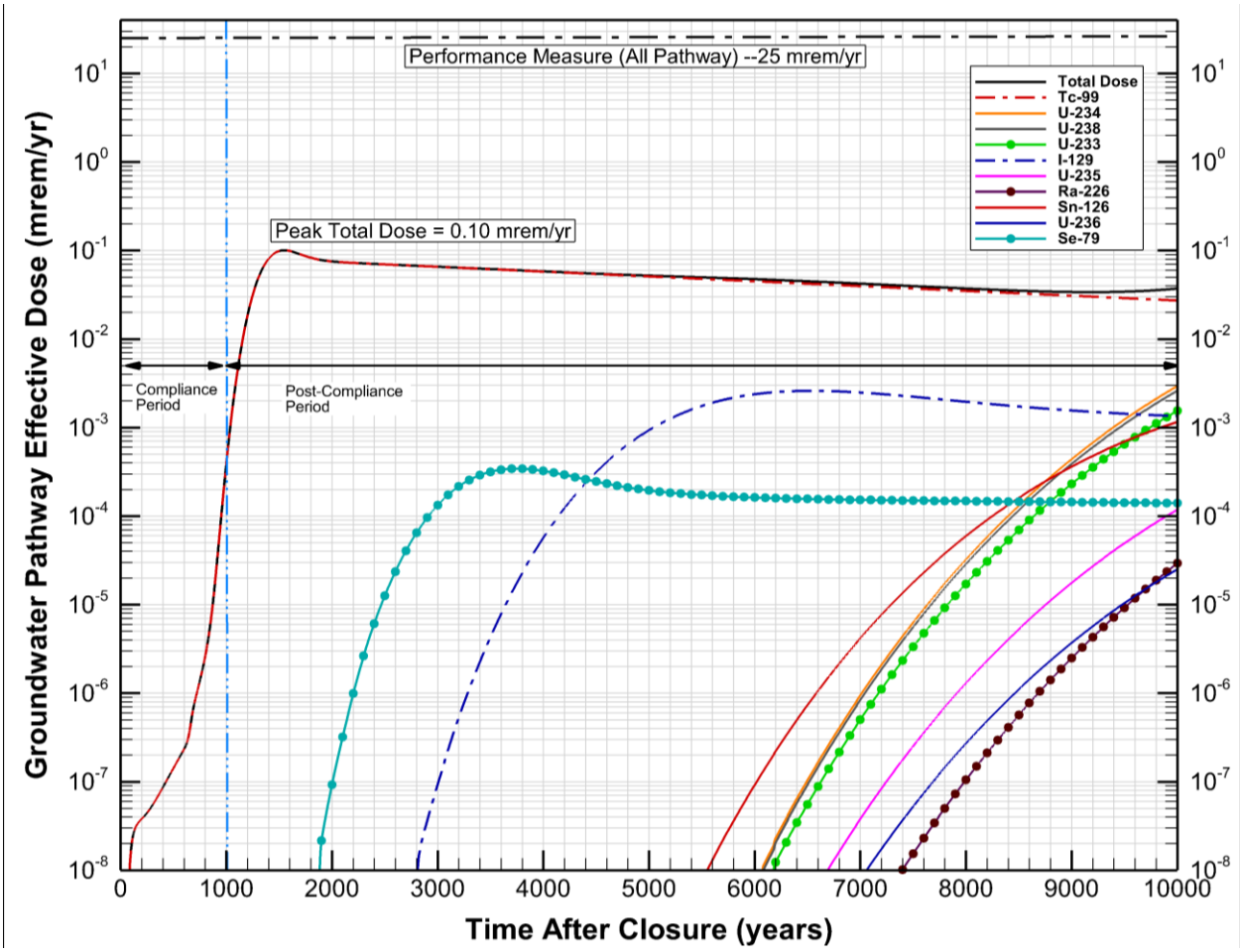
Figure 5-2. All-Pathways Dose Results that Includes Air and Groundwater Pathway Contributions at the Maximum Point of Concentration.



Note: The DOE M435.1,Radioactive Waste Management, compliance time (1,000 years) is shown as a vertical blue dashed line, and the compliance dose (25 mrem/yr) is shown as a black horizontal dashed line. Note the logarithmic vertical axis.

Other radionuclides of interest besides ^{99}Tc and uranium isotopes are ^{129}I, ^{226}Ra, ^{126}Sn, and ^{79}Se. The dose contribution of ^{129}I in the first 1,000 years is primarily from the atmospheric pathway, and beyond that primarily from the groundwater pathway. Radium-226 dose results from it being in secular equilibrium with the uranium decay series, and therefore—although it has a high K_d by itself—it appears at the 100-m point of compliance. Tin-126 and ^{79}Se are relatively mobile (low K_d) and have relatively long half-lives (greater than 200,000 years) and, therefore, show breakthrough at the 100-m point of compliance within the simulated time period.

Figure 5-3. Results of the Groundwater Pathway Dose Analysis at the Maximum Point of Concentration.



5.2.4 All-Pathways Dose for Revised Inventories Based on Post-Retrieval Sampling

After the completion of the all-pathways modeling for WMA C PA, six additional SSTs have been retrieved (C-101, C-102, C-105, C-107, C-111, and C-112)[62] and the post-retrieval samples have been obtained for all tanks except C-105. The discussion below provides a comparison of the all-pathways dose based on the WMA C PA inventory estimates and the all-pathways dose based on the BBI inventory estimates updated with post-retrieval samples for the five SSTs for which post-retrieval samples have been obtained.

The potential change in the all-pathways dose from the revision of the inventory due to the BBI update based on post-retrieval samples would be negligible. The all-pathways dose in the WMA C PA consisted of two media components, the air and groundwater. The air pathway was

[62] Retrieval has recently been completed for tank C-105, but final sampling and volume analysis have not yet been completed and are anticipated in the near future. Because more waste was retrieved from C-105 than assumed in the PA, the PA analysis remains bounding for C-105.

dominated by ^{3}H and ^{129}I and the groundwater pathway was dominated by ^{99}Tc. A summary of the updated post-retrieval inventory is provided in Table 2-6.

Table 5-1. Summary of Peak Doses (mrem/yr) for the Groundwater Pathway and Time of Occurrence for All Radionuclides Giving Nonzero Doses in the Base Case Analysis.

Radionuclide	Peak Dose (mrem/yr)	Post-Closure Time of Peak Dose (year)	Peak Dose within 1,000 years Post-Closure (mrem/yr)
^{99}Tc	0.1	1,500	4E-04
^{79}Se	3.4E-4	3,800	0
^{129}I	2.6E-3	6,500	0
^{126}Sn	1.2E-3	10,000	0
^{238}U	2.6E-3	10,000	0
^{236}U	2.5E-5	10,000	0
^{235}U	1.2E-4	10,000	0
^{234}U	3.0E-3	10,000	0
^{233}U	1.6E-3	10,000	0
^{230}Th	1.3E-7	10,000	0
$^{226+D}Ra$*	2.8E-5	10,000	0

*Radium-226+D includes doses associated with all its progeny, excluding inhalation doses from ^{222}Rn, as required in DOE M 435.1, Radioactive Waste Management.

The total inventory for tanks C-101, C-102, C-107, C-111 and C-112 decreased from 3.56×10^{5} Ci (WMA C PA inventory) to 1.43×10^{5} Ci (post-retrieval inventory update). The total ^{3}H inventory for tanks C-101, C-102, C-107, C-111 and C-112 decreased from 2.63 to 1.89×10^{-1} Ci. Therefore, the post-retrieval inventories do not change the dose results provided in the WMA C PA, which are considered bounding of the post-retrieval inventories for ^{3}H.

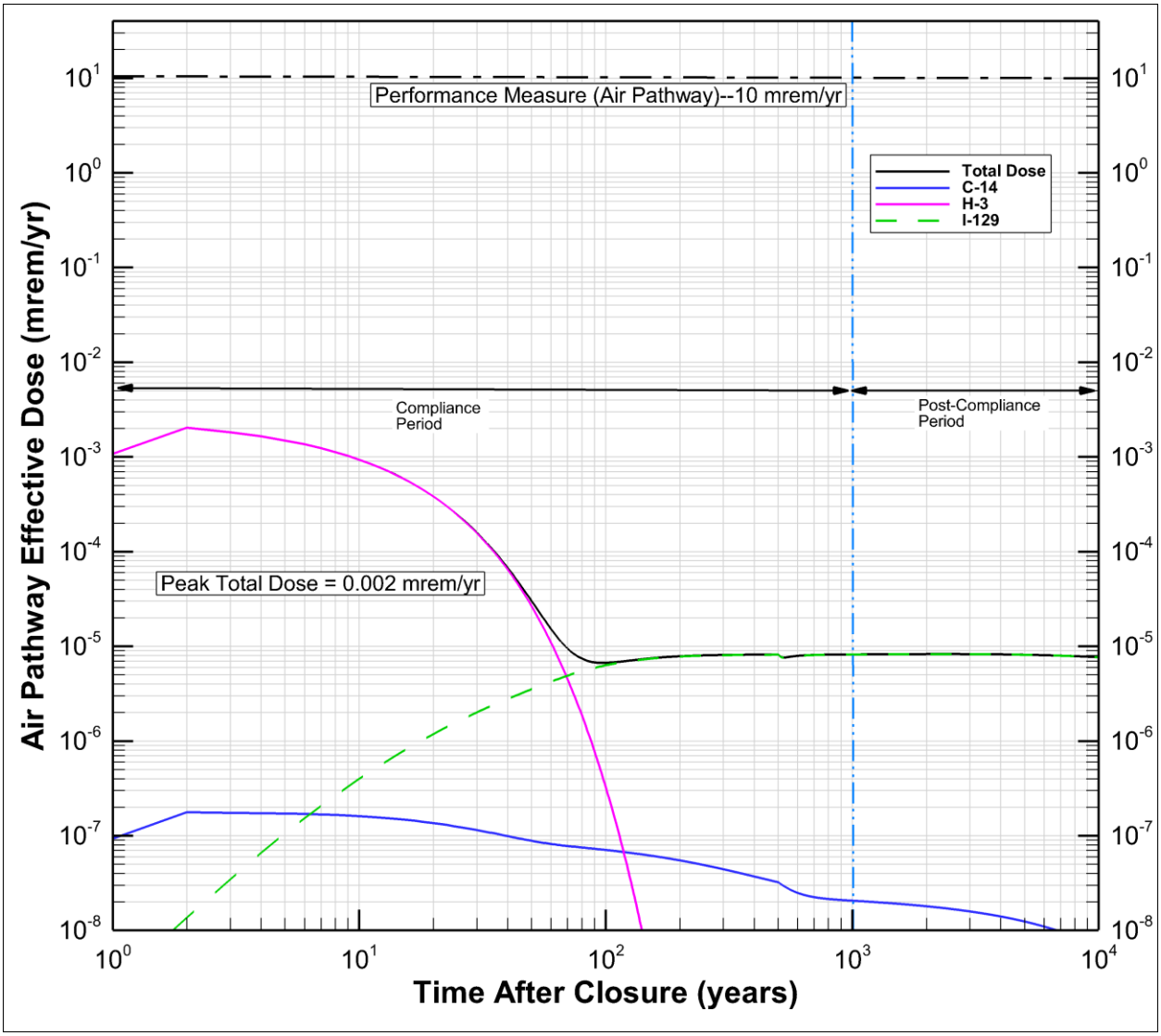
The total ^{129}I inventory for tanks C-101, C-102, C-107, C-111, and C-112 decreased from 5.75×10^{-2} to 7.37×10^{-3} Ci. Therefore, the post-retrieval inventories do not change the dose results provided in the WMA C PA, which are considered bounding of the post-retrieval inventories for ^{129}I.

The total ^{99}Tc inventory for tanks C-101, C-102, C-107, C-111 and C-112 decreased from 6.07 to 1.63 Ci. Therefore, the post-retrieval inventories do not change the dose results provided in the WMA C PA, which are considered bounding of the post-retrieval inventories for ^{99}Tc.

Based on the post-retrieval inventory update for tanks C-101, C-102, C-107, C-111 and C-112 presented above, the potential change in the all-pathways dose from the revision of the inventory due to the BBI update based on post-retrieval samples would be negligible. The radionuclides that contributed the majority of the doses to the all-pathways dose in the WMA C PA (i.e., ^{3}H, ^{129}I, and ^{99}Tc) all decreased in the WMA C. These radionuclides inventories did increase in comparison to their PA inventories in individual tanks as noted in Section 2.3.6 of this Draft

WIR Evaluation; however, the increase in a particular tank was far less than the maximum inventory modeling in the PA for that radionuclide. Therefore, the doses reported in the PA are considered bounding of the post-retrieval inventories for tanks C-101, 102, 107, 111 and 112.

Figure 5-4. Air Pathway Dose Analysis Results.



Note the logarithmic vertical and horizontal axes.

5.2.5 Radon Flux Analysis

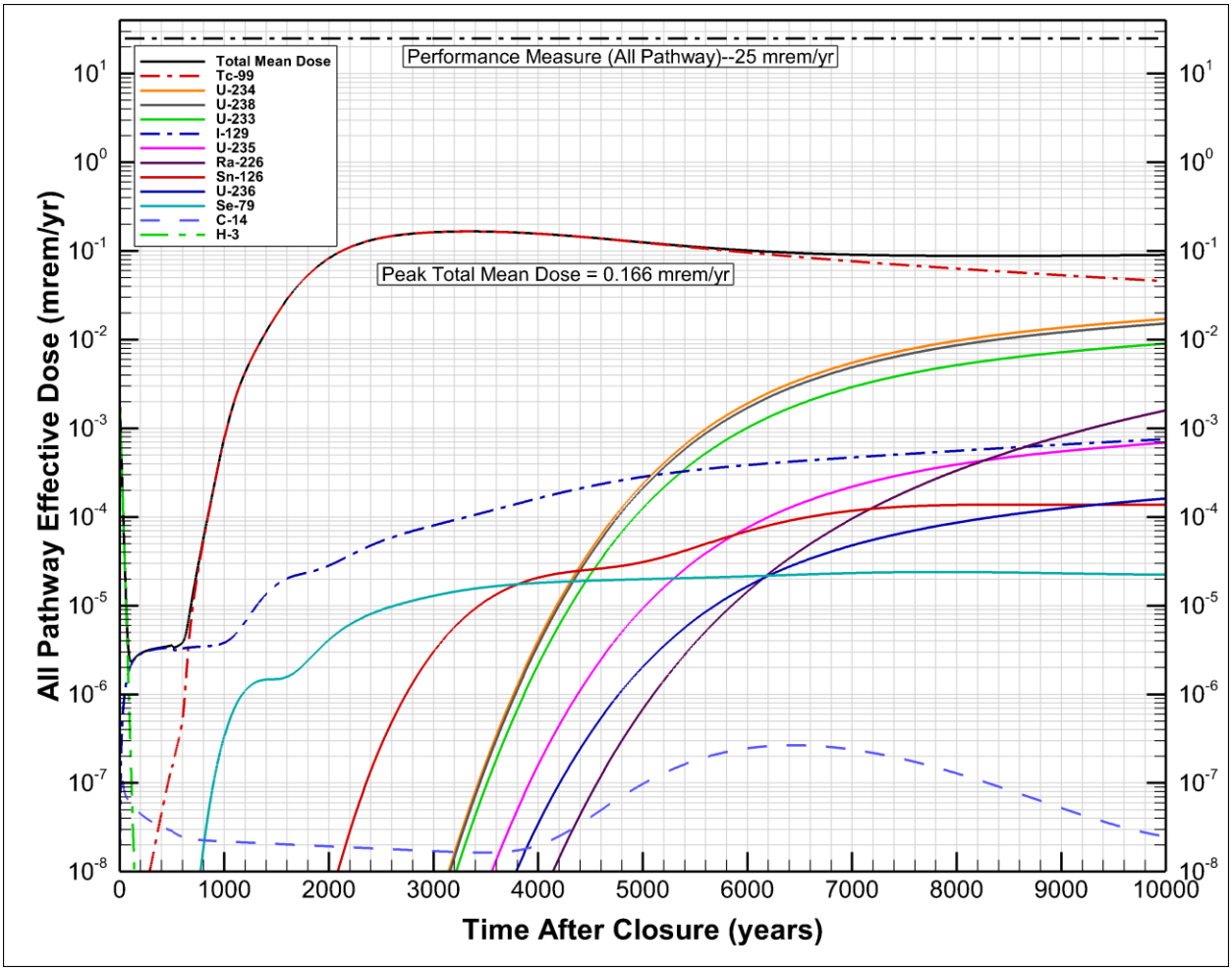
DOE Manual 435.1-1, Section IV.P(1) has the following requirement:

> (c) Release of radon shall be less than an average flux of 20 pCi/m2/s at the surface of the disposal facility. Alternatively, a limit of 0.5 pCi/L of air may be applied at the boundary of the facility.

Releases of radon from the WMA C were evaluated and compared to the 20 pCi/m2/s radon flux performance objective in DOE M 435.1. The inventory of ^{226}Ra (the parent of ^{222}Rn) in WMA C

residual waste is small, and initial radon fluxes are very low compared to the performance objectives. Ingrowth of ^{226}Ra from decay of the ^{238}U decay chain leads to increasing radon fluxes at longer times. However, the fluxes remain many orders of magnitude below the performance objective at all times, as presented in Figure 5-6 (RPP-ENV-58782).

Figure 5-5. All-Pathways Mean Dose Calculation Results Based on 300 Realizations.



5.2.6 As Low As Reasonably Achievable

The NRC performance objective in 10 CFR 61.41 also provides that reasonable effort shall be made to maintain releases of radioactivity in effluents to the environment ALARA. The WMA C PA was developed in accordance with the comparable requirement in DOE M 435.1-1:

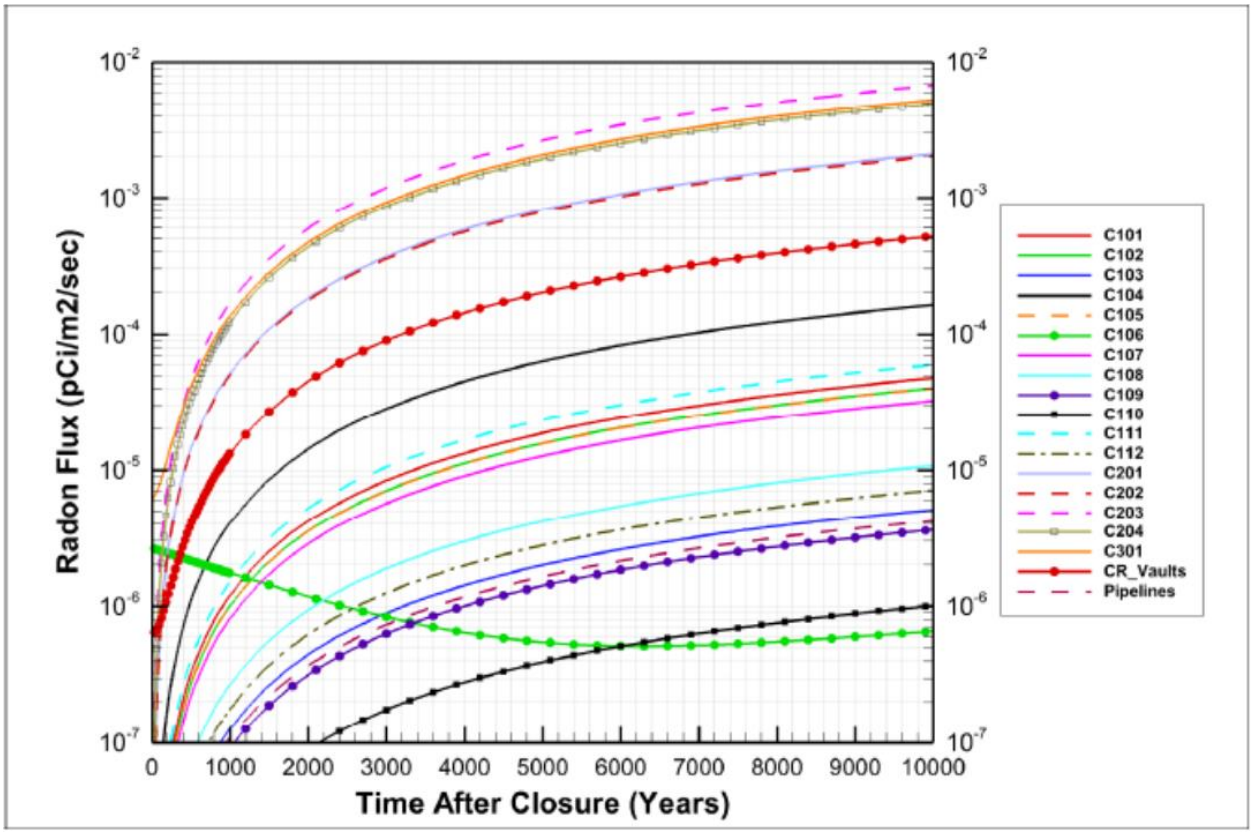
> "Performance assessments shall include a demonstration that projected releases of radionuclides to the environment shall be maintained as low as reasonably achievable (ALARA)."

As discussed previously, the WMA C PA provides the information to demonstrate compliance with the 25 mrem all-pathways dose performance objective, including stabilization of the residual waste using grout to minimize releases to the environment. Section 4.0 of this Draft

WIR Evaluation provides the information to show that key radionuclides in the waste tanks and ancillary structures will have been removed to the maximum extent technically and economically practical at closure.

In addition to removal of key radionuclides to the maximum extent technically and economically practical, other WMA C closure design features also serve to support the ALARA objective set forth in 10 CFR 61.41. The WMA C closure design stabilizes the residual waste, minimizes infiltration of water through the waste tanks and ancillary structures, and provides long-term stability. These features serve to impede release of stabilized contaminants into the general environment.

Figure 5-6. Radon Flux at Surface of Waste Management Area C.



The residual material remaining in the waste tanks after key radionuclides have been removed to the maximum extent technically and economically practical will be stabilized with grout. The waste tank fill grout will also have low permeability, which will enhance its ability to limit the migration of contaminants after closure.

There are multiple elements of the WMA C design that will serve to minimize infiltration of water through the waste tanks and ancillary structures. The waste tank concrete vaults and steel liners will serve to significantly retard water flow through the waste tanks. In addition, the waste tank liners, where applicable, will be filled with cementitious material, which will further serve to limit the amount of water infiltration into the waste tanks. The concrete structures, steel wall liners, if applicable, and transfer line encasements will serve to significantly retard water flow

into ancillary structures. In addition, the waste tanks and ancillary structures are expected to be covered with a closure barrier, which will further limit water infiltration.

Final WMA C closure will also support long-term stability consistent with the ALARA objective set forth in 10 CFR 61.41. Because the waste tanks will be filled with grout at closure, significant structural failure (i.e., collapse) is not likely. Ancillary structures such as diversion boxes, pump pits, and tanks are expected to be filled with appropriate fill materials, as necessary, to prevent subsidence. The engineered closure barrier will also provide physical stabilization of the closed site.

The design features described above serve to impede the release of stabilized contaminants into the general environment. These features, along with the removal of key radionuclides to the maximum extent technically and economically practical, are consistent with the ALARA objective in 10 CFR 61.41 to maintain releases of radioactivity in effluents to the general environment ALARA.

Sections 5.4.10 and 5.4.11 provide discussion relative to compliance with the ALARA objective set forth in 10 CFR 61.43.

5.2.7 Conclusion for Protection of the Public

The highest total projected dose for the groundwater pathway within the compliance time period (i.e., 1,000 years after closure of WMA C) was 4×10^{-4} mrem/yr, and the peak dose for the air pathway was 2×10^{-3} mrem/yr. DOE also performed additional modeling for a 10,000-year sensitivity period for making risk-informed decisions. The peak dose for the all-pathways analysis in the sensitivity period (i.e., 10,000 years after WMA C closure) was 0.10 mrem/yr; this potential dose would be dominated by ^{99}Tc from the groundwater pathway, which, along with additional radionuclides (including ^{234}U, ^{238}U and ^{129}I) would contribute 95 percent of the potential, all-pathways dose (0.10 mrem/yr) during the sensitivity period. Therefore, reasonable expectation is provided that the performance objective of 25 mrem/yr from 10 CFR 61.41 and DOE Manual 435.1-1 will not be exceeded. The additional performance requirements in DOE Manual 435.1-1 for (1) the air pathway dose limit of 10 millirem in a year total effective dose equivalent, excluding the dose from radon and its progeny and (2) that the release of radon shall be less than an average flux of 20 pCi/m2/s at the surface of the disposal facility, also will not be exceeded.

5.3 PROTECTION OF INDIVIDUALS FROM INADVERTENT INTRUSION

Provisions in 10 CFR 61.42 5.3, *Protection of Individuals from Inadvertent Intrusion*, require the following:

> "Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

A comparable provision is set forth in M 435.1-1, Chapter IV.P. (2)(h), which provides for protection of individuals from inadvertent intrusion as follows:

> "For purposes of establishing limits on the concentration of radionuclides that may be disposed of near-surface, the performance assessment shall include an assessment of impacts calculated for a hypothetical person assumed to inadvertently intrude for a temporary period into the low-level waste disposal facility. For intruder analyses, institutional controls shall be assumed to be effective in deterring intrusion for at least 100 years following closure. The intruder analyses shall use performance measures for chronic and acute exposure scenarios, respectively, of 100 millirem (1 mSv) in a year and 500 millirem (5 mSv) total effective dose equivalent excluding radon in air."

5.3.1 General Approach

DOE Manual 435.1-1, Section IV.P(2)(h) states that the intruder analyses shall use performance measures for chronic and acute exposure scenarios, respectively, of 100 millirem (1 mSv) in a year and 500 millirem (5 mSv) total effective dose equivalent excluding radon in air. 10 CFR 61.42 exhibits the NRC intent to protect persons who inadvertently intrude on the waste. While the performance objective does not establish quantitative limits on exposure, the 10 CFR 61 Final EIS suggests a dose limit of 500 mrem/yr for the waste classification scheme in 10 CFR 61.55. By way of guidance, the NRC uses 500 mrem/yr dose limit for evaluating impacts to an inadvertent intruder for purposes of 10 CFR 61.42 (NUREG-0945, Final Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste"; NUREG-1854). To demonstrate reasonable expectation that the performance objective at 10 CFR 61.42 will be met, the 500 mrem/yr NRC peak intruder dose limit is used.

Neither DOE M 435.1-1 nor the 10 CFR 61.42 regulations specify use of a particular scenario to demonstrate compliance. In developing intruder scenarios, DOE assumes that humans will continue land use activities that are consistent with past (e.g., recent decades) and present regional practices after the end of the assumed active institutional control period.

Two types of exposure scenarios are considered in the WMA C PA to estimate dose to the hypothetical intruder: (1) acute scenarios and (2) chronic scenarios. Acute scenarios evaluate the dose received from well drilling and subsequent exposure to residual waste in the drill cuttings; exposure is evaluated over a short time period. Chronic scenarios evaluate the dose received from spreading the drill cuttings over a specific area while living and/or working on that area. One acute exposure scenario and three chronic exposure scenarios are evaluated in the WMA C PA; brief descriptions of each scenario are provided in Table 5-2.

Intruder scenarios were evaluated for each of 19 waste sources (twelve 100-series tanks, four 200-series tanks, CR vault, catch tank C-301, and pipelines). The dose calculations were based on the emplaced radionuclide inventory in WMA C (considering radioactive decay and ingrowth), but conservatively ignoring any depletion due to transport of radionuclides from the waste site. The best-estimate inventory as provided in Table 5-2 is used in the WMA C PA for the intruder dose calculation. For all inadvertent intruder scenarios, the emplaced wastes were assumed to be distributed uniformly throughout the bottom area of the waste source.

According to RPP-PLAN-47559, there are ~7 mi of pipelines at WMA C, with the majority of pipelines being pumped waste transfer pipelines (98 percent by length) and the remaining being gravity-fed cascade lines between the 100-series SSTs (including one known plugged pipeline, V122). The waste transfer pipelines are assumed to be 5 percent full, while the cascade lines (including pipeline V122) are assumed to be fully plugged and the residual inventory is estimated using average BBI concentration for retrieved tanks. The waste transfer pipelines are more likely to be intruded as they cover 98 percent of the total pipeline length and correspondingly the area over which pipelines are distributed within WMA C. For the purpose of analysis, intrusion is considered through the 3-in. diameter waste transfer pipeline (the most common pipe diameter) that is assumed to be 5 percent full of waste. Impact of improbable intrusion through a fully plugged cascade pipeline is evaluated in the WMA C PA as part of the sensitivity analysis to estimate the bounding dose.

Table 5-2. Descriptions of the Inadvertent Intruder Scenarios Evaluated in the Waste Management Area C Performance Assessment.

Scenario	Description
Acute Exposure: Well Driller	Dose is the result of drilling through Waste Management Area C. Exposure pathways include external exposure, inhalation of soil particulates, and incidental soil ingestion. Exposure occurs during the drilling operation while in contact with the drill cuttings. Exposure does not depend on the borehole diameter.
Chronic Exposure: Rural Pasture	Dose is the result of drilling a well that serves a rural pasture. Contaminated drill cuttings are mixed with the soil over the pasture area. Exposure pathways include external exposure, inhalation of soil particulates, incidental soil ingestion, and milk consumption.
Chronic Exposure: Suburban Garden	Dose is the result of drilling a well that serves a suburban garden. Contaminated drill cuttings are mixed with the soil over the area where a residence and a garden are constructed. Exposure pathways include external exposure, inhalation of soil particulates, incidental soil ingestion, and fruit and vegetable consumption.
Chronic Exposure: Commercial Farm	Dose is the result of drilling a well that serves a commercial farm. Contaminated drill cuttings are mixed with the soil over the commercial farm area. Exposure pathways are external exposure, inhalation of soil particulates, and incidental soil ingestion.

Source: RPP-ENV-58813, "Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington."

5.3.2 Intruder Pathway Analysis

5.3.2.1 Acute Well Driller Scenario

A single acute hypothetical inadvertent intruder exposure scenario is evaluated in the WMA C PA. This scenario evaluates the short-term exposure of a well driller to drill cuttings that are exhumed from a well that is installed to the depth of the water table for the supply of water. As the well is drilled through the WMA C waste residuals, the driller will be exposed to the radiation dose from the drill cuttings. The well driller is assumed to be exposed to drill cuttings for a total of five days (8 hours per day for a total of 40 hours). The dose is calculated assuming that the cuttings are uniformly spread across the drill pad, and the pad is small enough that concentrations are not diluted by mixing with clean soil.

The borehole diameter is not a factor in determining dose for this scenario because the radionuclide concentrations in the drill cuttings are independent of the size of the borehole, and because the cuttings are assumed to be distributed over the drill pad with no mixing with clean soil. For the purpose of calculating dose from external exposure, the thickness and lateral extent of the contaminated layer is assumed to be infinite. Exposure pathways evaluated for the well driller scenario are incidental soil ingestion, inhalation of soil particulates, and direct external exposure. Details of the exposure scenario, including parameter values used in the analysis, are provided in the WMA C PA.

5.3.2.2 Chronic Rural Pasture Scenario

The rural pasture scenario evaluates the long-term exposure to an individual who uses the land as a residence, with a pasture used for milk production from dairy cows. In this scenario, a well diameter of 26.67 cm (10.5 in.) is assumed, the drill cuttings are spread over a pasture area of 5,000 m^2, and the cuttings are tilled to a depth of 15 cm. This scenario represents an individual who resides and has a pasture on the target field area. The pasture is used to raise dairy cattle that eat fodder grown from the pasture, and the resident subsequently drinks the pasture cows' milk. In addition to exposure from milk consumption, the resident is exposed by incidental soil ingestion, inhalation of the soil particulates, and external exposure. Details of the exposure scenario, including parameter values used in the analysis, are provided in the WMA C PA.

5.3.2.3 Chronic Suburban Garden Scenario

The suburban garden scenario evaluates the long-term exposure to an individual who uses the target field as a home construction lot with a garden. In this scenario, a well diameter of 16.51 cm (6.5 in.) is assumed that was drilled prior to the construction of the house and garden, and the drill cuttings are spread over the 2,500 m^2 lot and tilled to a depth of 15 cm. The size of the home garden was chosen to be 100 m^2 based on the discussions presented in HNF-SD-WM-TI-707, "Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment," where this garden size is deemed reasonable to provide 25 percent of the daily vegetable diet for a family of four living in the home. In addition to exposure from fruit and vegetable consumption, the resident is exposed by incidental soil ingestion, inhalation of the soil particulates, and external exposure. Details of the exposure scenario, including parameter values used in the analysis, are provided in the WMA C PA.

5.3.2.4 Chronic Commercial Farm Scenario

The commercial farm scenario evaluates the long-term exposure to an individual who uses the target field as a commercial farm. In this scenario, a well diameter of 41.91 cm (16.5 in.) is assumed and the drill cuttings are spread over a farm area of 647,000 m^2 (160 ac) for growing food crops. This scenario represents an individual who works on the commercial farm and grows and tends to the crops but does not consume what is produced. The commercial farm worker is exposed by incidental soil ingestion, inhalation of soil particulates, and external exposure. Details of the exposure scenario, including parameter values used in the analysis, are provided in the WMA C PA.

5.3.3 Results of Analysis

Doses associated with hypothetical inadvertent human intrusion were calculated for all sources in the WMA C PA, Section 7.0, and compared to the acute and chronic performance measures in DOE M 435.1. However, as explained in the WMA PA, the calculated doses do not take into account the likelihood of intrusion into the various sources, and there are significant differences between them.

As discussed previously in this Draft WIR Evaluation, the tank domes are constructed of reinforced concrete, which are still in good condition and will likely provide a very substantial barrier to a drilling intrusion. Furthermore, upon closure the tanks will be filled with grout, which will add a second and very significant barrier to drilling intrusion. As a result of these barriers, the WMA C PA explains that intrusion into grouted tanks is not regarded as a credible event, as the tank domes and infill grout form very substantial and long-lasting barriers to the intrusion. The WMA C PA further explains that "Consequently, while the potential doses that might arise from intrusion into a tank are the highest calculated, the likelihood of occurrence of intrusion into a tank is regarded as very small. As a result, the intrusion analyses for tanks should be regarded as informational, and should not be compared to the performance measures."

By contrast, barriers are much less robust or nonexistent for pipelines and other ancillary structures. As a result, the primary potential for intrusion is considered to be into ancillary structures. The likely event for ancillary structures would be intrusion into a waste transfer pipeline, as discussed in the WMA C PA, Section 7.0. This event was used to represent intrusion into any ancillary structures, and these results are used for comparison with performance measures.

The calculated doses associated with the acute and chronic exposure scenarios for intrusion into a waste transfer pipeline are summarized in Table 5-3 for the compliance time period and for the sensitivity/uncertainty analysis period. The calculated doses for acute and chronic exposure scenarios from potential intrusion into a waste transfer pipeline remain below the DOE M 435.1-1 performance measure for the time period evaluated beyond 100 years after closure. The acute scenario dose is dominated by ^{137}Cs and ^{239}Pu, while chronic scenario doses are dominated by ^{90}Sr, ^{137}Cs and ^{239}Pu. The total dose generally shows a steep decline, compared to the timescales evaluated in the WMA C PA, due to short half-lives of ^{90}Sr and ^{137}Cs but becomes stable once long-lived ^{239}Pu becomes the dominant dose contributor. The dominant exposure condition for the assessment is the acute scenario, which has higher doses than the chronic exposure scenarios at 100 years after closure. At longer times (greater than ~500 years after closure), the acute scenario also produced higher calculated doses for the intrusion into waste transfer pipelines, mainly because long-lived ^{239}Pu plays a more important role in the dose calculation. (RPP-ENV-58782).

5.3.4 Conclusion for Intruder Analysis

The projected dose for an inadvertent intruder is 36 mrem (acute) and 8.2 mrem/yr (chronic). Therefore, there is reasonable expectation that the DOE M 435.1-1 performance measures (100 mrem in a year and 500 mrem total effective dose equivalent excluding radon in air, for chronic and acute exposure scenarios respectively), and, for additional information, the

10 CFR 61.42 performance objective (500 mrem/yr) will not be exceeded during both the 1,000-year and 10,000-year periods after WMA C closure.

Table 5-3. Summary of Inadvertent Human Intrusion Analyses for Intrusion into Ancillary Structures.

Exposure Scenario	Compliance Period (<1,000 yr)		Sensitivity/Uncertainty Period (1,000 – 10,000 yr)	
	Peak Dose (mrem/yr)	Time of Peak (years after closure)	Peak Dose (mrem/yr)	Time of Peak (years after closure)
Acute inadvertent intruder Performance Measure – 500 mrem	36.0	100	11.1	1,000
Chronic inadvertent intruder Performance Measure – 500 mrem/yr	8.2	100	0.07	1,000

5.4 RADIATION PROTECTION DURING OPERATIONS

Provisions in 10 CFR 61.43, *Radiation Protection During Operations*, for NRC licensees states the following:

> "Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by §61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

A comparable provision is set forth in M 435.1-1, Section I.E(13), which provides for protection of individuals during operations as follows:

> "Radioactive waste management facilities, operations, and activities shall meet the requirements of 10 CFR Part 835, Occupational Radiation Protection, and DOE [Order] 5400.5 [now DOE Order 458.1], Radiation Protection of the Public and the Environment."

This requirement references Title 10 CFR, Part 20, "Standards for Protection Against Radiation" (10 CFR 20), which contains radiological protection standards for workers and the public. DOE requirements for occupational radiological protection are provided in Title 10 CFR, Part 835, "Occupational Radiation Protection" (10 CFR 835), and those for radiological protection of the public and the environment are provided in DOE O 458.1.

The cross-referenced "standards for radiation protection" in 10 CFR 20 that are considered in detail in this Draft WIR Evaluation are the dose limits for the public and the workers during disposal operations set forth in Title 10, CFR, Part 20, Subpart B—Radiation Protection Programs, § 20.1101, Radiation protection programs, item (d); Title 10, CFR, Part 20, Subpart C—Occupational Dose Limits, § 20.1201, Occupational dose limits for adults, items (a)(1)(i), (a)(1)(ii), (a)(2)(i), and (a)(2)(ii); Title 10, CFR, Part 20, Subpart C, § 20.1208, Dose equivalent to an embryo/fetus, item (a); and Title 10, CFR, Part 20, Subpart D—Radiation

Dose Limits for Individual Members of the Public, § 20.1301, Dose limits for individual members of the public, items (a)(1), (a)(2), and (b).[63] Consistent with NUREG-1854, the following sections explain that these dose limits correspond to the dose limits in 10 CFR 835 and relevant DOE orders that establish DOE regulatory and contractual requirements for DOE facilities and activities.

The following sections show that the WMA C closure meets these dose limits and that doses will be maintained ALARA. Table 5-4 provides a crosswalk between DOE requirements and the relevant standards set forth in 10 CFR 20.

5.4.1 Air Emissions Limit for Individual Member of the Public [NRC 10 CFR 20.1101(d); DOE O 458.1, Admin Chg 3]

The NRC regulation at 10 CFR 20.1101(d) provides in relevant part the following:

> "[A] constraint on air emissions of radioactive material to the environment, excluding Radon-222 and its daughters, shall be established … such that the individual member of the public likely to receive the highest dose will not be expected to receive a total effective dose equivalent in excess of 10 mrem (0.1 mSv) per year from these emissions."

DOE similarly limits effective dose equivalent from air emissions to the public at 10 mrem/yr in DOE O 458.1 to comply with the EPA requirement in Title 40, CFR, Part 61, "National Emission Standards for Hazardous Air Pollutants," Subpart H—National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities, § 61.92 Standard (40 CFR 61.92), which has the same limit. The estimated dose per year from airborne emissions to the maximally exposed individual member of the public located at or beyond the Hanford Site boundary from all operations at the Site ranged from 0.0079 to 0.12 mrem from 2004 through 2013 (PNNL-15222, "Hanford Site Environmental Report for Calendar Year 2004"; PNNL-15892, "Hanford Site Environmental Report for Calendar Year 2005"; PNNL-16623, "Hanford Site Environmental Report for Calendar Year 2006"; PNNL-17603, "Hanford Site Environmental Report for Calendar Year 2007"; PNNL-18427, "Hanford Site Environmental Report for Calendar Year 2008"; PNNL-19455, "Hanford Site Environmental Report for Calendar Year 2009"; PNNL-20548, "Hanford Site Environmental Report for

[63] The NRC performance objectives at 10 CFR Part 61, Subpart C apply, by their terms, to NRC licensees. However, neither DOE nor DOE's WMA C is or will be licensed by the NRC or an Agreement State, and such licensing and related regulatory authority is not conveyed to NRC or any Agreement State by the Atomic Energy Act of 1954, as amended (42 USC 2011 et seq.), Section 202 of the Energy Reorganization Act of 1974, as amended (42 USC 5842, 42 USC 5801 et seq.), or any other law. It therefore follows that the "standards for radiation protection" in 10 CFR Part 20 (cross-referenced in the performance objective at 10 CFR 61.43), which are relevant in the context of WIR evaluations for non-licensed DOE facilities, are the dose limits for radiation protection of the public and the workers during disposal operations, and not those which address general licensing, administrative, programmatic, or enforcement matters administered by NRC for NRC licensees. Accordingly, this Draft WIR Evaluation addresses in detail the dose limits for the public and workers during disposal operations set forth in 10 CFR Part 20, and like provisions in DOE regulations and Orders. Although 10 CFR 20.1206 (e) contains limits for planned special exposures for adult workers, there will not be any such planned special exposures for closure operations at the WMA C. Therefore, this limit is not discussed further in the Draft WIR Evaluation. Likewise, 10 CFR 20.1207 specifies dose limits for minors. However, there will not be minors working at WMA C who will receive an occupational dose. Therefore, this limit is not discussed further in this Draft WIR Evaluation.

Calendar Year 2010"; DOE/RL-2011-119, "Hanford Site Environmental Report for Calendar Year 2011"; DOE/RL-2013-18, "Hanford Site Environmental Report for Calendar Year 2012"; DOE/RL-2013-47, "Hanford Site Environmental Report for Calendar Year 2013"). These values (0.0079 to 0.12 mrem from 2004 to 2013) are for all Hanford Site operations, not only WMA C closure operations, and are well below the dose limit specified in 10 CFR 20.1101(d) of 10 mrem (0.1 mSv) per year.

Table 5-4. Crosswalk Between Applicable 10 CFR 20 Standards and U.S. Department of Energy Requirements.

10 CFR 20 Standard	U.S. Department of Energy Requirement	Basis Document Section	Title
10 CFR 20.1101(d)	DOE O 458.1	5.4.1	Air Emissions Limit for Individual Member of the Public
10 CFR 20.1201(a)(1)(i)	10 CFR 835.202 (a)(1)	5.4.2	Total Effective Dose Equivalent Limit for Adult Workers
10 CFR 20.1201(a)(1)(ii)	10 CFR 835.202 (a)(2)	5.4.3	Any Individual Organ or Tissue Dose Limit for Adult Workers
10 CFR 20.1201(a)(2)(i)	10 CFR 835.202 (a)(3)	5.4.4	Annual Dose Limit to the Lens of the Eye for Adult Workers
10 CFR 20.1201(a)(2)(ii)	10 CFR 835.202 (a)(4)	5.4.5	Annual Dose Limit to the Skin of the Whole Body and to the Skin of the Extremities for Adult Workers
10 CFR 20.1208(a)	10 CFR 835.206 (a)	5.4.6	Dose Equivalent to an Embryo/Fetus
10 CFR 20.1301(a)(1)	DOE O 458.1	5.4.7	Total Effective Dose Equivalent Limit for Individual Members of the Public
10 CFR 20.1301(a)(2)	10 CFR 835.602 10 CFR 835.603	5.4.8	Dose Limits for Individual Members of the Public in Unrestricted Areas
10 CFR 20.1301(b)	10 CFR 835.208	5.4.9	Dose Limits for Individual Members of the Public in Controlled Areas

References:

10 CFR 20, "Standards for Protection Against Radiation," Subpart B—Radiation Protection Programs, § 20.1101, Radiation protection programs.

10 CFR 20, "Standards for Protection Against Radiation," Subpart C—Occupational Dose Limits, § 20.1201, Occupational dose limits for adults

10 CFR 20, "Standards for Protection Against Radiation," Subpart C—Occupational Dose Limits, § 20.1208, Dose equivalent to an embryo/fetus.

10 CFR 20, "Standards for Protection Against Radiation," Subpart D—Radiation Dose Limits for Individual Members of the Public, § 20.1301, Dose limits for individual members of the public.

10 CFR 835, "Occupational Radiation Protection," Subpart C—Standards for Internal and External Exposure, § 835.202, Occupational dose limits for general employees.

10 CFR 835, "Occupational Radiation Protection," Subpart C—Standards for Internal and External Exposure, § 835.206, Limits for the embryo/fetus.

10 CFR 835, "Occupational Radiation Protection," Subpart C—Standards for Internal and External Exposure, § 835.208, Limits for members of the public entering a controlled area.

10 CFR 835, "Occupational Radiation Protection," Subpart G—Posting and Labeling, § 835.602, Controlled areas.

10 CFR 835, "Occupational Radiation Protection," Subpart G—Posting and Labeling, § 835.603, Radiological areas and radioactive material areas.

DOE O 440.1B, Worker Protection Program for DOE (Including the National Nuclear Security Administration) Federal Employees.

DOE O 458.1, Radiation Protection of the Public and the Environment.

5.4.2 Total Effective Dose Equivalent Limit for Adult Workers [NRC 10 CFR 20.1201(a)(1)(i); DOE 10 CFR 835.202(a)(1)]

The NRC regulation at 10 CFR 20.1201(a) concerning occupational dose limits for adults provides in relevant part the following:

> "(a) … [C]ontrol the occupational dose to individual adults, except for planned special exposures … to the following dose limits.
> (1) An annual limit, which is the more limiting of—
> (i) The total effective dose equivalent being equal to 5 rems (0.05 Sv)."

The DOE regulation in Title 10, CFR, Part 835, Subpart C—Standards for Internal and External Exposure, § 835.202, Occupational dose limits for general employees (10 CFR 835.202), item (a)(1) has the same annual dose limit for the annual occupational dose to general employees. For the occupational dose to adults during WMA C closure, the total effective dose (TED) per year will be controlled using the ALARA principles, and will be below 5 rem as described in HNF-5183, "Tank Farm Radiological Control Manual," Chapter 2, "Radiological Standards." Occupational doses to workers have been well below the annual limits specified in 10 CFR 20.1201(a)(1)(i) for all Hanford Site work activities. The TED to workers from TOC closure is expected to remain well below the DOE/NRC limit.

5.4.3 Any Individual Organ or Tissue Dose Limit for Adult Workers [NRC 10 CFR 20.1201(a)(1)(ii); DOE 10 CFR 835.202(a)(2)]

The NRC regulation at 10 CFR 20.1201(a) concerning occupational dose limits for adults provides in relevant part the following:

> "(a) … [C]ontrol the occupational dose to individual adults, except for planned special exposures … to the following dose limits.
> (1) An annual limit, which is the more limiting of—
> …
> (ii) The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems (0.5 Sv)."

The dose limit specified in 10 CFR 20.1201(a)(1)(ii) is similar to the dose limit specified in 10 CFR 835.202(a)(2). For the occupational dose to adults during WMA C closure, the sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye will be controlled to ALARA, below a maximum of 50 rem/yr. TOC procedure TFC-ESHQ-RP_ADM-C-26, "Radiological Design Review Process," provides that the design basis annual occupational exposure limits for any organ or tissue, other than the eye, cannot exceed 10 rem/yr, which is well below the DOE and NRC regulatory limit of 50 rem/yr (HNF-5183 Chapter 2).

5.4.4 Annual Dose Limit to the Lens of the Eye for Adult Workers [NRC 10 CFR 20.1201(a)(2)(i); DOE 10 CFR 835.202(a)(3)]

The NRC regulation at 10 CFR 20.1201(a) concerning occupational dose limits for adults provides in relevant part the following:

> "(a) … [C]ontrol the occupational dose to individual adults, except for planned special exposures … to the following dose limits.
>
> …
>
> (2) The annual limits to the lens of the eye, to the skin of the whole body, and to the skin of the extremities, which are:
>
> (i) A lens dose equivalent of 15 rems (0.15 Sv)."

The dose limit specified in 10 CFR 20.1201(a)(2)(i) is the same as that specified in the DOE regulation at 10 CFR 835.202(a)(3). For the occupational dose to adults during WMA C closure, the annual dose limit to the eye lens will be controlled using the ALARA principles, and will be below 15 rem/yr. TOC procedure TFC-ESHQ-RP_ADM-C-26 provides that the design basis annual occupational exposure limits for the eye lens cannot exceed 3 rem/yr, which is well below the DOE and NRC regulatory limit of 15 rem/yr (HNF-5183 Chapter 2).

5.4.5 Annual Dose Limit to the Skin of the Whole Body and to the Skin of the Extremities for Adult Workers [NRC 10 CFR 20.1201(a)(2)(ii); DOE 10 CFR 835.202(a)(4)]

The NRC regulation at 10 CFR 20.1201(a) concerning occupational dose limits for adults provides in relevant part the following:

> "(a) [C]ontrol the occupational dose to individual adults, except for planned special exposures … to the following dose limits.
>
> …
>
> (2) The annual limits to the lens of the eye, the skin of the whole body, or to the skin of the extremities, which are:
>
> …
>
> (ii) A shallow-dose equivalent of 50 rem (0.5 Sv) to the skin of the whole body or to the skin of any extremity."

This NRC dose limit specified in 10 CFR 20.1201(a)(2)(ii) is the same as the DOE dose limit specified at 10 CFR 835.202(a)(4). For the occupational dose to adults during WMA C closure that involve limited hands-on activity, the annual dose limit to the skin of the whole body or to the skin of any extremity will be controlled using the ALARA principles and will be below a shallow-dose equivalent of 50 rem/yr (HNF-5183 Chapter 2).

5.4.6 Dose Equivalent to an Embryo/Fetus [NRC 10 CFR 20.1208(a); DOE 10 CFR 835.206(a)]

The NRC regulation at 10 CFR 20.1208(a) concerning the dose equivalent to an embryo/fetus provides in relevant part the following:

> "(a) … [E]nsure that the dose equivalent to the embryo/fetus during the entire pregnancy, due to the occupational exposure of a declared pregnant woman, does not exceed 0.5 rem (5 mSv)."

The DOE regulation at Title 10 CFR Part 835, Subpart C, § 835.206, Limits for the embryo/fetus (10 CFR 835.206), item (a) has the same dose limit. For the embryo/fetus occupational dose during WMA C closure, doses will be controlled so the dose equivalent to the embryo/fetus during the entire pregnancy for a declared pregnant worker will not exceed 0.5 rem. Furthermore, after pregnancy declaration, DOE provides a mutually agreeable assignment option of work tasks, without loss of pay or promotional opportunity, such that further occupational radiation exposure during the remainder of the gestation period is unlikely. In addition, personnel dosimetry is provided and used to carefully track exposure as controlled by HNF-5183 Chapter 2.

5.4.7 Total Effective Dose Equivalent Limit for Individual Members of the Public [NRC 10 CFR 20.1301(a)(1); DOE O 458.1, Admin Chg 3]

The NRC regulation at 10 CFR 20.1301(a) concerning dose limits for individual members of the public provides in relevant part the following:

> "(a) … [C]onduct operations so that—
> (1) The total effective dose equivalent to individual members of the public … does not exceed 0.1 rem (1 mSv) in a year, exclusive of the dose contributions from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released … from voluntary participation in medical research programs, and from the … disposal of radioactive material into sanitary sewerage[.]"

Provisions in DOE O 458.1 similarly limit public doses to less than 100 mrem/yr. However, the DOE application of the limit is more restrictive, in that it requires DOE to make a reasonable effort to ensure multiple sources (e.g., DOE sources and NRC regulated sources) do not combine to cause the limit to be exceeded. For individual members of the public during WMA C closure, the TED limit to an individual member of the public will be controlled to less than 0.1 rem/yr (HNF-5183 Chapter 2).

5.4.8 Dose Limits for Individual Members of the Public in Unrestricted Areas [NRC 10 CFR 20.1301(a)(2); DOE 10 CFR 835.602 and 603]

The NRC regulation at 10 CFR 20.1301(a) concerning dose limits for individual members of the public provides in relevant part the following:

> "(a) … [C]onduct operations so that—
> …
> (2) The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released … does not exceed 0.002 rem (0.02 millisievert) in any one hour."

The DOE regulation at Title 10 CFR, Part 835, Subpart G—Posting and Labeling, § 835.602, Controlled areas (10 CFR 835.602) establishes the expectation that TED in controlled areas will be less than 0.1 rem/yr. For individual members of the public during WMA C closure, operations will be conducted such that the dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material, will be less than 0.00005 rem/hr above background. HNF-5183 Chapter 2 also restricts the TED in

controlled areas to less than 0.1 rem/year. To ensure these dose limits are met, the following measures have been instituted within controlled areas. Per Title 10 CFR Part 835, Subpart G, § 835.603, Radiological areas and radioactive material areas (10 CFR 835.603), radioactive materials areas have been established for radioactive material accumulation possibly resulting in a radiation dose of greater than or equal to 100 mrem in a year. In addition, TOC has established radiological buffer areas (RBAs) around posted radiological areas. Standard TOC practice is to assume a 2,000 hr/yr continuous occupancy at the outer boundary of these areas; therefore, the dose rate at an RBA boundary is 0.05 mrem/hr (100 mrem/2,000 hr = 0.05 mrem/hr or 0.00005 rem/hr). Because the controlled area encompasses an RBA, it is ensured the dose in the controlled area (but outside of radioactive material areas and RBA) will be less than 0.1 rem/yr (HNF-5183 Chapters 2 and 3). Therefore, TOC implementation of the provisions at 10 CFR 835.602 and 10 CFR 835.603 provides limits protective of the dose limit specified in 10 CFR 20.1301(a)(2). Training is required for individual members of the public for entry into controlled areas. In addition, to ensure no member of the public exceeds radiation exposure limits, use of dosimetry is required if a member of the public is expected to enter a controlled area and receive a dose that may exceed 0.05 rem/yr (HNF-5183 Chapter 5).

5.4.9 Dose Limits for Individual Members of the Public in Controlled Areas [NRC 10 CFR 20.1301(b); DOE 10 CFR 835.208]

The NRC regulation at 10 CFR 20.1301(b) concerning dose limits for individual members of the public provides in relevant part the following:

> "(b) If … members of the public *[are permitted]* to have access to controlled areas, the limits for members of the public continue to apply to those individuals."

The DOE regulation at Title 10 CFR Part 835, Subpart C, § 835.208, Limits for members of the public entering a controlled area (10 CFR 835.208) has the same dose limit. The TED limit to an individual member of the public granted access to controlled areas during WMA C closure will be controlled to 0.1 rem/yr. Furthermore, training is required for individual members of the public for entry into controlled areas. In addition, to ensure no member of the public exceeds radiation exposure limits, use of dosimetry is required if a member of the public is expected to enter a controlled area and receive a dose that may exceed 0.05 rem/yr (HNF-5183 Chapter 5).

5.4.10 As Low As Reasonably Achievable (NRC 10 CFR 20.1003; DOE 10 CFR 835.2)

The NRC regulation at Title 10 CFR, Part 20, Subpart A—General Provisions, § 20.1003, Definitions (10 CFR 20.1003) defines ALARA in relevant part as follows:

> "*ALARA* … means making every reasonable effort to maintain exposures to radiation as far below the dose limits … as is practical consistent with the purpose for which the … activity is undertaken …[.]"

The DOE has a similar requirement, and the DOE regulation at Title 10 CFR Part 835, Subpart A—General Provisions, § 835.2, Definitions (10 CFR 835.2) defines ALARA as "… the approach to radiation protection to manage and control exposures (both individual and collective) to the work force and to the general public to as low as is reasonable…" For radiological work activities during WMA C closure, every reasonable effort will be made to

maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the activity is undertaken. Furthermore, the DOE regulation at Title 10 CFR Part 835, Subpart B—Management and Administrative Requirements, § 835.101, Radiation protection programs (10 CFR 835.101), item (c) requires the contents of each radiation protection program to include formal plans and measure for applying the ALARA process to occupational exposure as further discussed in Section 5.4.11.1.

5.4.11 Reasonable Expectation

Measures that provide reasonable expectation that WMA C closure will comply with the applicable dose limits and with the ALARA provisions include the documented radiation protection program, the Documented Safety Analysis (RPP-13033), design, regulatory, and contractual enforcement mechanisms, and access controls, training, and dosimetry. These measures are discussed in the following sections.

5.4.11.1 Tank Operations Contractor Radiation Protection Program

DOE regulates occupational radiation exposure at its facilities through 10 CFR 835, which establishes exposure limits and other requirements to ensure DOE facilities are operated in a manner such that occupational exposure to workers is maintained within acceptable limits and as far below these limits as is reasonably achievable. The requirements in 10 CFR 835, if violated, provide a basis for the assessment of civil penalties under Section 234A of the AEA.

Pursuant to 10 CFR 835, TOC activities including WMA C closure operations must be conducted in compliance with the documented TOC radiation protection program as approved by DOE (HNF-5183). The key radiation protection program elements include monitoring of individuals and work areas, access control to areas containing radiation and radioactive materials, use of warning signs and labels, methods to control the spread of radioactive contamination, radiation safety training qualification, objectives for the design of facilities, criteria for radiation and radioactive material workplace levels, and continually updated records to document compliance with the provisions of 10 CFR 835. The radiation protection program also includes formal plans and measures for applying the ALARA process.

The 10 CFR 835 requirements, as contained in the radiation protection program, are incorporated in the standards/requirement identification document system. The system links the requirements of 10 CFR 835 to the company-level and lower-level implementing policies and procedures that control radiological work activities conducted across the Site. These procedures control the planning of radiological work, the use of radiation monitoring devices by employees, the bioassay program, the air monitoring program, the contamination control program, the ALARA program, the training of general employees, radiological workers, radiological control inspectors, and health physics professionals and technicians and the other aspects of an occupational radiation protection program as required by 10 CFR 835.

5.4.11.2 Documented Safety Analysis

WMA C is an operating Hazard Category 2 nuclear facility. The existing approved safety basis covers the operational activities in WMA C, including waste storage and monitoring, and waste retrieval.

Operating procedures and work control documents are screened for compliance with the safety basis and technical safety requirements. This process ensures that all credible hazards and accidents are analyzed, and controls put in place to prevent or mitigate them.

Post-retrieval closure activities (e.g., tank grouting, above-grade demolition and decommissioning, and construction of the final engineered barrier over the facility) are not specifically addressed in the current safety basis. As WMA C transitions to closure, these activities will be evaluated through the process hazard analysis and unreviewed safety question processes. These processes will determine how the safety basis needs to be amended to support closure activities. There is an expectation that the safety basis hazards and controls will be reduced as closure activities progress, and at the completion of closure there is an expectation that no safety basis controls will be required.

5.4.11.3 Radiological Design for Protection of Occupational Workers and the Public

The WMA C radiological facilities and facility modifications are designed to meet the requirements of 10 CFR 835 Subpart K—Design and Control. TOC procedure TFC-ESHQ-RP_ADM-C-26 provides the requirements necessary to ensure compliance with 10 CFR 835. The procedure refers to 10 CFR 835, DOE orders, DOE standards, DOE handbooks, national consensus standards, TOC manuals, TOC engineering standards, TOC engineering guides, and Hanford Site operating experience to meet the 10 CFR 835 specific requirements and additional requirements to ensure the design provides for protection of the workers and the environment.

The standard covers the full spectrum of radiological design requirements and not just radiation exposure limits. The following are the specific areas addressed in the procedure: radiation exposure limits, facility and equipment layout, area radiation levels, radiation shielding, internal radiation exposure, radiological monitoring, confinement, and ventilation.

The facility design also incorporates radiation zoning criteria to ensure exposure limits are met by providing adequate radiation shielding. Areas in which non-radiological workers are present are assumed to have continuous occupancy (2,000 hr/yr) and are designed to a dose rate less than 0.05 mrem/hr to ensure the annual dose is less than 100 mrem. Other zoning criteria are established to ensure radiological worker doses are ALARA and less than 1,000 mrem/yr to meet the Title 10 CFR Part 835, Subpart K, § 835.1002, Facility design and modifications (10 CFR 835.1002) design requirements.

The design is also required to provide necessary radiological monitoring or sampling for airborne and surface contamination to ensure the engineered controls are performing their function and, in the event of a failure or upset condition, workers are warned and exposures avoided.

Radiological protection personnel ensure applicable requirements of the standard are addressed and presented in design summary documentation. The incorporation of radiological design criteria in the engineering standard ensures the requirements of 10 CFR 835 are met and the design provides for the radiological safety of the workers and environment.

5.4.11.4 Regulatory and Contractual Enforcement

Any violation of the 10 CFR 835 requirements is subject to civil penalties pursuant to AEA Section 234A, as implemented by DOE regulations in Title 10 CFR Part 820, "Procedural Rules for DOE Nuclear Activities" (10 CFR 820). In addition, the requirements in 10 CFR 835 and all applicable DOE orders are incorporated into all contracts with DOE contractors. DOE enforces these contractual requirements through contract enforcement measures, including the reduction of contract fees (Title 48 CFR Part 970, "DOE Management and Operating Contracts" [48 CFR 970]).

5.4.11.5 Access Controls, Training, Dosimetry and Monitoring

Training or an escort is required for individual members of the public for entry into controlled areas. In addition, use of dosimetry is required if a member of the public is expected to enter a controlled area and exceed 0.05 rem/yr to ensure no member of the public exceeds radiation exposure limits (HNF-5183 Chapters 5 and 6).

In addition, worker radiation exposure monitoring is performed for all workers expected to receive 100 mrem/yr from internal and external sources of radiation to provide assurance no worker exceeds radiation exposure limits and all radiation dose are maintained as far below the limits as is reasonably achievable (HNF-5183 Chapter 5).

5.4.11.6 Occupational Radiation Exposure History for Tank Operations Contractor

The effectiveness of the radiation protection program, including the effectiveness of oversight programs to ensure they are implemented properly, is demonstrated by the occupational radiation exposure results. Hanford Site TOC quarterly radiological performance reports consistently demonstrate that the program is effective. For the period 2011 to 2015, the average dose for an exposed worker was 52.2 mrem/yr (WRPS-1603585, "Third Quarter Fiscal Year 2016 Radiological Control Performance Report"), compared to the DOE maximum Administrative Control Limit of 2,000 mrem/yr and the 10 CFR 835 limit of 5,000 mrem/yr. The TOC strives to maintain doses well below the 2,000 mrem DOE annual administrative limit by using 500 mrem as the initial administrative limit for each employee. This administrative limit is only increased following an analysis of the worker dose and subsequent actions to keep the worker dose ALARA.

5.4.12 Conclusion for Radiation Protection

Based on the previous discussion, operations at the WMA C are conducted in compliance with the standards for radiation protection set out in 10 CFR 20 and 10 CFR 835. Every reasonable effort continues to be made at the WMA C to maintain radiation exposures as low as is reasonably achievable.

Measures that provide reasonable expectation that WMA C closure will comply with the applicable dose limits and with the ALARA provisions include the documented radiation protection program, the Documented Safety Analysis (RPP-13033), design, regulatory, and contractual enforcement mechanisms, and access controls, training, and dosimetry.

5.5 STABILITY OF THE DISPOSAL SITE AFTER CLOSURE

10 CFR 61.44, *Stability of the Disposal Site after Closure*, states the following:

> "The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

A comparable provision is set forth in M 435.1-1, Sections IV.Q(1)(a) and (b) and IV.Q(2)(c), stability of the disposal site after closure, as follows:

> "Disposal Facility Closure Plans (DOE Manual 435.1, Section IV.Q(1)(a) and (b)). A preliminary closure plan shall be developed and submitted to Headquarters for review with the performance assessment and composite analysis. The closure plan shall be updated following issuance of the disposal authorization statement to incorporate conditions specified in the disposal authorization statement. Closure plans shall:
>
> (a) Be updated as required during the operational life of the facility.
>
> (b) Include a description of how the disposal facility will be closed to achieve long-term stability and minimize the need for active maintenance following closure and to ensure compliance with the requirements of DOE 5400.5, Radiation Protection of the Public and the Environment [now DOE Order 458.1]."
>
> "Disposal Facility Closure (DOE Manual 435.1, Section IV.Q(2)(c)). Institutional control measures shall be integrated into land use and stewardship plans and programs, and shall continue until the facility can be released pursuant to DOE Order 5400.5, Radiation Protection of the Public and the Environment [now DOE Order 458.1]."

This section outlines the relevant factors of WMA C siting, design, use, operation and closure, which ensure compliance with 10 CFR 61.44 and DOE Manual 435.1-1 for the purpose of this Draft WIR Evaluation.

5.5.1 Siting

A Hanford Site characteristics review of demography, geography, meteorology, climatology, ecology, geology, seismology, and hydrogeology is presented in the WMA C PA and Section 2.0 of this Draft WIR Evaluation, and is briefly summarized in the following paragraphs.

The gross pattern of seismic activity around the Hanford Site is consistent with current understanding of regional tectonic characteristics of the Northwest. That is, the flood basalts form a large and relatively competent block of rock that is surrounded by numerous complex zones of active faults where large-scale stresses, imposed primarily by the ongoing subduction of the Pacific and Juan de Fuca Plates underneath the North American Plate, are mostly relieved. Consequently, relatively minimal stress relief occurs in the Columbia Plateau and earthquake energy is correspondingly small. This means that potential ground motion that accompanies these earthquakes is also relatively small.

Relative movement is commonly quantified as some fraction of gravitational acceleration (g) and has been usually correlated with earthquake magnitude. For the range of earthquake magnitudes

suggested by data summarized above for the Hanford Site (less than 3 to 6), peak accelerations between less than 0.0017 and 0.18 *g* are proposed. The associated range of motion is generally imperceptible compared to clearly felt movement that can result in minimal building damage. A probabilistic seismic hazard analysis (WHC-SD-W236A-TI-002) estimated that a 0.1 *g* horizontal acceleration would occur every 500 years and a 0.2 *g* acceleration would occur every 2,500 years.

Field and laboratory studies that have been completed at many of the tank farm sites are summarized in WHC-SD-GN-ER-30009. These studies reveal that there are no areas of potential surface or subsurface subsidence, uplift, or collapse at the Hanford Site, with the minor exceptions of the Cold Creek and Wye Barricade depressions, neither of which are close to WMA C. With the exception of the loose superficial wind-deposited silt and sand in some locations, the in-place soils are competent and form good foundations.

Liquefaction is the sudden decrease of shearing resistance of a cohesionless soil, caused by the collapse of the structure by shock or strain, and is associated with a sudden but temporary increase of the pore fluid pressure. Saturated or near-saturated soil (sediments) are required for liquefaction to occur. The average volumetric moisture content at WMA C is less than 10 percent (WMA C PA Section 3.2.1.3.2). Therefore, liquefaction of soils beneath the tank farms would not present a credible hazard because the water table is greater than 213 ft bgs.

Two types of volcanic hazards have affected the Hanford Site in the past 20 million years. The hazards were (1) continental flood basalt volcanism that produced the CRBG and (2) volcanism associated with the Cascade Range. Several volcanoes in the Cascade Range are currently considered to be active, but activity associated with flood basalt volcanism has ceased.

The flood basalt volcanism that produced the CRBG occurred between 17 and 6 million years ago. Most of the lava was extruded during the first 2 to 2.5 million years of the 11-million-year volcanic episode. Volcanic activity has not recurred during the last 6 million years, suggesting that the tectonic processes that created the episode have ceased. The recurrence of CRBG volcanism is not considered to be a credible volcanic hazard (DOE/RW-0164).

Volcanism in the Cascade Range was active throughout the Pleistocene Epoch and has remained active through the Holocene Epoch. The eruption history of the current Holocene Epoch best characterizes the most likely types of activity in the next 100 years. Many of the volcanoes have been active in the last 10,000 years, including Mount Mazama (Crater Lake) and Mount Hood in Oregon; and Mount Saint Helens, Mount Adams, and Mount Rainier in Washington. The Hanford Site is ~93 mi from Mount Adams, 109 mi from Mount Rainier, and 124 mi from Mount Saint Helens, the three closest active volcanoes. At these distances, the deposition of tephra (ash) is the only potential hazard. Mount Saint Helens has been considerably more active throughout the Holocene Epoch than Mount Rainier or Mount Adams, which is the least active of the three. WHC-SD-GN-ER-30038 concludes that the Hanford Site is sufficiently distant from the Cascade Range volcanoes that hazards from lava flows, pyroclastic flows and surges, landslides, lahars, and ballistic projectiles are below a probability of concern.

Columbia River flow is regulated by three upstream dams in Canada and by seven upstream dams in the United States. The Hanford Reach, ~50 mi long, extends from Priest Rapids Dam to just north of the 300 Area. Flow through the Hanford Reach fluctuates significantly and is

controlled at Priest Rapids Dam. The three dams with the largest reservoirs upstream from the Hanford Site are the Mica and Hugh Keenleyside dams in Canada and the Grand Coulee Dam in the United States. The controlled flow of the Columbia River caused by these dams results in a lower flood hazard for high-probability floods (e.g., 100-yr floods); however, dam-failure scenarios are significant potential contributors that result in high flood flows.

The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 1.4 million ft^3/sec and is greater than the 500 year flood. This flood would inundate parts of the 100 Area adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected [DOE/RW-0070, Nuclear Waste Policy Act (Section 112), Environmental Assessment, Reference Repository Location, Hanford Site]. The USACE has derived the Standard Project Flood with both regulated and unregulated peak discharges given for the Columbia River downstream of Priest Rapids Dam ("Water Control Manual for McNary Lock and Dam, Columbia River, Oregon and Washington" [USACE 1989]). The regulated Standard Project Flood for this part of the river is given as 54,000 ft^3/sec and the 100 year regulated flood as 440,000 ft^3/sec. Impacts to the Hanford Site are negligible and would be less than the probable maximum flood.

The USACE evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions on the order of 400,000 ft^3/sec. The discharge resulting from a 50 percent breach at the outfall of Grand Coulee Dam was determined to be 21 million ft^3/sec. In addition to the areas inundated by the probable maximum flood, the remainder of the 100 Area, the 300 Area, and nearly all of Richland would be flooded (DOE/RW-0070). No determinations were made for breaches greater than 50 percent of Grand Coulee Dam, for failures of dams upstream, or for associated failures downstream of Grand Coulee. Based on "Artificial Flood Possibilities on the Columbia River" (USACE 1951), the 50 percent breach scenario was believed to represent the largest realistically conceivable flow resulting from either a natural or human-induced breach (DOE/RW-0070). It was also assumed that a scenario such as the 50 percent breach would occur only as the result of direct explosive detonation, and not because of a natural event such as an earthquake, and that even a 50 percent breach under these conditions would indicate an emergency situation in which there might be other overriding major concerns.

A flood scenario of a 50 percent breach of Grand Coulee Dam results in a flood level of ~470 ft above mean sea level at Columbia River mile 365; this low point is the closest flood route to the 200 Areas Plateau. River mile 365 is ~150 ft bgs of the lowest elevation tank farm. The 50 percent breach of the Grand Coulee Dam would not impact the areas occupied by tank farm facilities. Therefore, this scenario bounds all other Columbia River flood scenarios. UCRL-21069, "Probabilistic Flood Hazard Assessment for the N Reactor, Hanford, Washington" provides a detailed hazard assessment of other flood scenarios.

The Yakima River is ~12 mi south of and greater than 200 ft in elevation below the 200 East and 200 West Areas. The Yakima River is not a flood hazard for the tank farm facilities. During 1980, a flood risk analysis of Cold Creek was conducted as part of the characterization of a basaltic geologic repository for high-level radioactive waste. In lieu of 100- and 500-year floodplain studies, a probable maximum flood evaluation was performed based on a large rainfall or combined rainfall/snowmelt event in the Cold Creek and Dry Creek watershed

(RHO-BWI-C-120/PNL-4219, "Flood Risk Analysis of Cold Creek near the Hanford Site"). The probable maximum flood discharge rate for the lower Cold Creek Valley was 80,000 ft^3/sec compared to 19,900 ft^3/sec for the 100-year flood. Modeling indicated that State Route 240, along the Hanford Site southwestern and western areas, would not be usable. Based on the information presented in this section, flooding of WMA C would not be a credible scenario.

5.5.2 Design

The closure design of the WMA C waste tanks and ancillary structures will provide long-term stability, with no active systems that would require maintenance, which is consistent with the performance objective.

There are multiple elements of the WMA C design that will serve to minimize infiltration of water through the waste tanks and ancillary structures. The waste tank structures and grout fill will serve to significantly retard water flow through the waste tanks. The WMA C design features are described in detail in the WMA C PA. In addition, the waste tanks and ancillary structures are expected to be covered with a closure barrier as discussed in Section 2.3.8 of this Draft WIR Evaluation, which further limits the water infiltration into the waste tanks and ancillary structures.

Because the waste tanks will be filled with grout at closure, significant structural failure (i.e., collapse) is not likely. The impact of potential waste tank degradation (e.g., cracking or corrosion leading to increased water infiltration) is considered in the WMA C PA. Applicable ancillary structures also will be filled with grout, preventing subsidence. As previously noted, the transfer piping will not be filled with grout, but will be covered by the planned closure barrier. The WMA C closure barrier, tank structures and waste tank grout are considered sufficient barriers to prevent drilling into the waste tanks, given regional well drilling practices and the presence of nearby land without underground rock or concrete obstructions. The closed tanks, ancillary structures, and final surface barrier will be passive structures, which require no active maintenance under foreseen conditions. Conceptual designs include no active systems (such as sumps, pumps, ventilation, instrumentation, etc.) which would require on-going maintenance other than surveillance, monitoring, or minor custodial care.

5.5.3 Use/Operation

Prior to closure, the use/operation of WMA C waste tanks and ancillary structures will support long-term stability consistent with the performance objective. During waste storage and retrieval operations, corrosion control and structural integrity programs were implemented to maintain design features utilized for waste containment (e.g., waste tanks and ancillary structures) (RPP-PLAN-45082, "Implementation Plan for the Single-Shell Tank Integrity Project"). These programs ensure that tanks are monitored for structural integrity via mechanisms such as a tank inspection program and a tank leak detection system. As described in the following paragraphs, isolation and stabilization (grouting) of tanks and applicable ancillary structures will eliminate the need for these active programs.

5.5.4 Closure

Final WMA C closure will support long-term stability consistent with this performance objective. In this context, long-term stability of the closed WMA C site means that the stabilized residuals in the waste tanks and ancillary structures maintain structural integrity under the closure conditions for hundreds to thousands of years following closure. A stable closure system prevents subsidence of, and minimizes water intrusion into, the closed site and mitigates migration of residual material into the environment. In addition, a carefully designed closure site minimizes the likelihood of inadvertent intrusion into the system and disturbance of the stabilized residuals.

Closure of the individual SSTs and of WMA C as a whole occurs in three major steps as identified in RPP-RPT-41918: (1) SST waste retrieval, (2) tank isolation and stabilization, and (3) surface barrier placement. A general description of these steps follows.

As discussed in Section 4.3, for closure of WMA C to occur, DOE must retrieve tank waste in accordance with DOE and HFFACO/Consent Decree requirements. DOE will also meet the performance objectives for the disposal of Class C LLW provided in 10 CFR 61 Subpart C, as discussed in Section 5.1. In addition, because the tank waste residual is mixed waste, it has to meet Washington State dangerous waste requirements for closure (WAC 173-303). HFFACO Action Plan Appendix I closure plans will be incorporated into the Hanford Site-Wide Permit (WA7 89000 8967).

The next closure action process after Ecology and DOE approval will be to fill the tanks with grout to stabilize and immobilize the residual waste, to prevent further long-term degradation of the SSTs, and to discourage intruder access as required for a near-surface disposal facility. As explained previously, grout will be formed from materials such as cement, fly ash, fine aggregate, and water to create a free-flowing material, which will be used to fill the tanks and applicable ancillary structures after waste retrieval is completed. The grout will harden in the tanks and ancillary structures to stabilize the residual waste and provide structural stability for closure of the tank farm. The grout will also serve to immobilize the residuals, minimize water infiltration, and discourage human intrusion. The specific formulation of the grout has not yet been established. DOE will tailor and finalize the specific formulation of the grout, before it is added to the tanks and applicable ancillary structures.

The final closure activity will be placement of an engineered surface barrier. This surface barrier will provide protection from infiltration and intrusion. The specific design of the closure barrier has not been finalized, but it is likely to be based on the Modified RCRA Subtitle C barrier concept (RPP-RPT-49701, “Waste Management Area C Closure – Conceptual Design Report”), as discussed in Section 2.3.8 of this Draft WIR Evaluation. This barrier is a passive system requiring no active maintenance.

Future land use is discussed in Section 2.1.1 of this Draft WIR Evaluation. The plans referenced in that section are consistent with the long-term stability of the closed site.

5.5.5 Conclusion for Site Stability

As discussed in detail in Section 2.0 of this Draft WIR Evaluation, and summarized in the preceding paragraphs, site conditions do not present hazards that impact WMA C stability. The

WMA C closure methods will result in a facility closure that does not require active maintenance. Therefore, closure of WMA C will comply with DOE M 435.1-1 and 10 CFR 61.44 performance objectives.

6.0 RADIONUCLIDE CONCENTRATIONS OF STABILIZED RESIDUALS, TANKS AND ANCILLARY STRUCTURES

Section Purpose

The purpose of this section is to demonstrate that the WMA C stabilized tanks, ancillary structures and their residuals at closure of WMA C will meet concentration limits for Class C LLW as set out in 10 CFR 61.55.

Section Contents

This section provides the methodology and assumptions to demonstrate that the WMA C stabilized tanks, ancillary structures and residuals at closure meet Class C concentration limits.

Key Points

- DOE is using the NRC guidance in NUREG-1854 Category 3 in its approach to determining whether the stabilized tanks, ancillary structures and residuals meet Class C concentration limits.
- The Category 3 approach involves the use of the Site-specific intruder-driller scenarios analyzed in the WMA C PA.
- DOE has derived site-specific concentration averaging expressions for WMA C waste based upon the site-specific intruder-driller scenarios and the guidance in NUREG-1854.

6.1 BACKGROUND

DOE M 435.1-1 states in relevant part that waste resulting from reprocessing SNF that is determined to be incidental to reprocessing is not HLW, and shall be managed under DOE regulatory authority in accordance with the requirements for LLW.

The third criterion in DOE M 435.1-1 provides in relevant part that such wastes:

> "3. …[W]ill 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."

6.2 WASTE CONCENTRATIONS

Under DOE disposal plans, the stabilized tanks, ancillary structures and residuals will be incorporated into a solid physical form and covered by a closure barrier at the time of closure of WMA C, as explained previously. As demonstrated below, the emplaced wastes are not expected to exceed concentration limits for Class C LLW.

The methodology for comparison to the Class C concentration limits for radionuclides included in 10 CFR 61.55 is presented in the following sections, which reflect information in the WMA C PA and its references. The radionuclides and their associated limits are specified in two separate tables within 10 CFR 61.55 which are reproduced in Table 6-1 and Table 6-2.

Table 6-1. 10 CFR 61.55 Table 1 Class C Concentration Limits.

Radionuclides (long lived)	Concentration
C-14	8 Ci/m^3
C-14 in activated metal	80 Ci/m^3
Ni-59 in activated metal	220 Ci/m^3
Nb-94 in activated metal	0.2 Ci/m^3
Tc-99	3 Ci/m^3
I-129	0.08 Ci/m^3
Alpha-emitting transuranic nuclides with half-life >5 years	100 nCi/g
Pu-241	3,500 nCi/g
Cm-242	20,000 nCi/g

Reference: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

6.3 APPROACH TO WASTE CONCENTRATIONS FOR WASTE MANAGEMENT AREA C RESIDUALS

Prior NRC guidance to determine concentrations for comparison with Class C concentration limits of 10 CFR 61.55 was based on excavation of a basement as the likely pathway to expose an inadvertent intruder to waste in a commercial, shallow land burial site (NUREG-1854). Due to the disposal depth of the stabilized tanks, ancillary structures and residuals at WMA C, the basement excavation scenario associated with development of 10 CFR 61.55 Tables 1 and 2 is not an appropriate scenario for WMA C. As explained in the WMA C PA, the more appropriate and credible scenario for potential human intrusion and calculation of radionuclide concentrations is one that assumes that a hypothetical intruder inadvertently drills a well through a waste tank or ancillary structure after the assumed period of institutional control ends.[64]

[64] The WMA C PA evaluates intrusion scenarios for each of the 19 waste sources at WMA C (twelve 100-series tanks, four 200-series tanks, CR-vaults, C-301 catch tank and pipelines). In the WMA C PA, hypothetical intrusion into a pipeline is assumed to occur 100 years after closure of WMA C, and 500 years after closure for the more highly stabilized tanks and grouted ancillary structures. All of these intrusion scenarios are considered to be very unlikely, with the likelihood of intrusion into a pipeline many times higher than intrusion into a tank, as explained in the WMA C PA.
The WMA C PA assumes, for the purposes of analysis,that the period of institutional control will last 100 years after closure of WMA C. This approach is consistent with M 435.1-1 and NUREG 1854. As noted in the PA however, DOE anticipates that institutional control will continue well after that period.

Consistent with more recent NRC staff guidance, this Draft WIR Evaluation follows the Category 3 site-specific averaging approach set forth in NUREG-1854, using the intruder-drilling scenario. This approach utilizes a risk-informed approach that takes into consideration such things as the specific conditions of the WMA C site, the final form of the stabilized residuals, site-specific parameters and the final closure configuration.

Table 6-2. 10 CFR 61.55 Table 2 Class C Concentration Limits.

Radionuclides (short lived)	Concentration (Ci/m^3)		
	Column 1 (Class A)	Column 2 (Class B)	Column 3 (Class C)
Total of all nuclides with <5 year half-life	700	*	*
H-3	40	*	*
Co-60	700	*	*
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7,000
Sr-90	0.04	150	7,000
Cs-137	1	44	4,600

* There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in the table determine the waste to be Class C independent of these nuclides.

Reference: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

The following sections present the methodology, inputs and assumptions DOE used to compare the radionuclide concentration of the waste at closure of WMA C to the Class C concentration limits.

6.4 METHODOLOGY

The Category 3 approach to concentration averaging reflects site-specific conditions of WMA C and the final form of the stabilized tanks, ancillary structures and residuals to account for the volume, concentration, and accessibility of the material. In order to account for the site-specific conditions relative to WMA C, DOE has developed, consistent with the Category 3 methodology, averaging expressions for WMA C based on the results of the inadvertent intruder analysis performed within the WMA C PA. As discussed in the following sections, the radionuclide concentrations have been compared utilizing these averaging expressions against the concentration limits for Class C LLW as set out in 10 CFR 61.55 Tables 1 and 2. For the waste tanks and the ancillary structures, this comparison was based on the projected inventories at closure in the WMA C PA.

For purposes of comparison to the Class C concentration limits, and to align with the inputs used in developing the averaging expressions for WMA C, the residual inventory used for these calculations are decayed to the inventory that will be present at the time of closure (assumed to be 2020 for the purposes of analysis in the WMA C PA). As discussed below, the radionuclide concentrations of the stabilized residuals are compared, using the sum-of-fractions (SOF) methodology and the WMA C averaging expressions, to the concentration limits for Class C LLW as set out in 10 CFR 61.55 Tables 1 and 2.

To demonstrate compliance with, among other things, the performance objectives set out in 10 CFR 61 Subpart C, DOE developed a PA covering closure activities within WMA C. To demonstrate compliance with 10 CFR 61.42, the WMA C PA is used to demonstrate that there is reasonable expectation that the dose to an inadvertent intruder will remain below 500 mrem/yr, taking into consideration a variety of intruder scenarios. In the WMA C PA, DOE utilized the inadvertent human intruder analysis to develop the WMA C averaging expressions used for comparison to the concentration limits for Class C LLW in 10 CFR 61.55.

The WMA C PA models used to simulate the performance of the WMA C closure system take into account the release of radiological contaminants from the waste tanks and the associated ancillary structures in WMA C and simulate transport of the radiological contaminants through soil and groundwater to the assessment point. The models use numerous WMA C-specific input parameters to represent the WMA C closure system behavior over time. Many of the input parameters are based on site-specific data (e.g., soil and cementitious materials K_d) used in transport modeling. In addition, site-specific information is used to model the behavior of individual barriers within WMA C, such as the waste tank and cementitious barriers. Numerous bioaccumulation factors (e.g., soil-to-plant transfer factors), human health exposure parameters (e.g., vegetable consumption data), and dose conversion factors are used in the computer modeling to calculate doses for each of the exposure pathways. All of these parameters factor into development of the WMA C averaging expressions. A detailed discussion of the WMA C PA intruder analyses is provided in the PA.

The stabilized contaminant materials after WMA C closure will be primarily located in areas protected by significant materials (e.g., grouted waste tanks and ancillary structures) that are clearly distinguishable from the surrounding soil and make drilling an unlikely scenario based on regional drilling practices. Regional drilling conditions are such that a barrier such as the closure erosion barrier, tank top or grout fill are situations that would cause drillers to stop operations and move drilling location. The most vulnerable location for waste residuals is in the pipelines which may be near grade-level prior to closure, are of a small size (typically a 3-in. diameter or less) and will not be grouted, which makes them the most credible stabilized contaminants vulnerable during any intruder drilling operations, although the probability of hitting a pipeline is small due to the small surface area of pipelines versus the large WMA C footprint. However, for the purposes of developing averaging expressions for WMA C, it is assumed that the structures would be penetrated and that construction of the well would be completed.

The following sections describe how the SOF is calculated for the WMA C waste tanks and ancillary structures.

6.4.1 Methodology Inputs

The residual inventory used for the concentration calculations is the total inventory of the residual material within the waste tank or ancillary structure. The residual material layer in the waste tanks and ancillary structures, with the exception of the pipelines, is assumed to be spread evenly across the floor of the waste tank or ancillary structure. The residual material within pipelines is assumed to be spread evenly over the internal surface of the pipelines.

Site-specific averaging expressions for WMA C, as described in Section 6.4.2, are utilized for comparison against the concentration limits for Class C LLW as set out in 10 CFR 61.55 Tables 1 and 2.

Table 6-3 provides the input data used for the calculations presented in the remainder of this section.

Table 6-3. Alternative Class C Calculation Input Parameter Values.

Parameter	Notation	Value	Units
Radionuclide inventory	I_R	See Table 2-5	Ci
Waste volume	V_R	See Table 4-7 and Table 4-8	m^3
Waste density	ρ_{ws}	2.05 (RPT-ENV-58782 Table 9.2)	g/cm^3
10 CFR 61.55 limits	Table $value_i$	See Table 6-1 and Table 6-2	Ci/m^3 or nCi/g
Intruder doses	$Dose_i$	See Table 6-6 and Table 6-7	mrem/yr

References:
10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."
RPT-ENV-58782, "Performance Assessment of Waste Management Area C, Hanford Site, Washington."

6.4.2 Site-Specific Waste Management Area C Waste Concentration Calculation Averaging Expressions

As described above, the Category 3 approach to concentration averaging contemplates consideration of site-specific conditions of WMA C and the stabilized residuals. In development of 10 CFR 61.55 Tables 1 and 2, the underlying assumption was that the concentration limits and disposal requirements ensure that an inadvertent intruder (e.g., assuming excavation to a depth of 10 ft for construction of a house) would not receive a dose exceeding an equivalent of 500 mrem to the whole body. At closure, the depth of the stabilized residuals within the WMA C waste tanks and ancillary structures will be well below (i.e., greater than 10 ft) the WMA C closure surface barrier and a robust intruder barrier consisting of grouted tanks and ancillary structures, as described in the WMA C PA, will be in place. Therefore, the intruder-construction scenario is considered inapplicable. Based on the depth to the stabilized residuals and the presence of a robust intruder barrier, the "Deep waste, intruder barrier" scenario from NUREG-1854 Table 3-2 is being utilized; see Table 6-4. The WMA C pipelines will be located greater than 10 ft below the WMA C closure barrier; however, the pipelines will not be grouted and are not considered to

provide a robust intruder barrier. Therefore, the pipelines are evaluated according to the "Deep waste, no intruder barrier" scenario from NUREG-1854 Table 3-2; see Table 6-4.

Table 6-4. NUREG-1854 Assumed Conditions for the Four Scenarios Used to Develop Averaging Expressions.

Scenario	Typical Waste Access Time (yr)	Waste Disruption Process	Receptor Type
Shallow waste (<5 m), no intruder barrier	100	Residential construction	Acute construction worker or chronic resident
Shallow waste (<5 m), intruder barrier	500	Residential construction	Acute construction worker or chronic resident
Deep waste (>5 m), no intruder barrier	100	Well drilling	Acute well driller or chronic resident
Deep waste (>5 m), intruder barrier	500	Well drilling	Acute well driller or chronic resident

Reference: NUREG-1854, NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use.

To account for the site-specific conditions relative to WMA C, site-specific averaging expressions for WMA C, based on the results of the inadvertent intruder analyses performed within the WMA C PA, have been developed.

The WMA C PA provides the estimated dose to an intruder who resides within the boundary of WMA C after the period of institutional control (assumed for the purposes of analysis to be 100 years after closure of WMA C). The intruder is assumed to be exposed via various pathways from drill cuttings. The acute intruder scenario involves the exposure of a driller that pulls up contamination from striking tank waste or ancillary structures waste (e.g., catch tank C-301, 244-CR vault, pipeline) which are deposited on the ground surface. The chronic scenarios were evaluated for three exposure scenarios: (1) commercial farm, (2) rural pasture, and (3) suburban garden.

The WMA C PA Base Case groundwater transport modeling indicated that only contaminants with K_d values equal to zero in the natural system reach groundwater within the DOE M 435.1-1 compliance period of 1,000 years. The only radionuclide in the analyses producing nonzero concentrations at the 100-m compliance boundary in the compliance period was ^{99}Tc. Other mobile contaminants such as ^{3}H, ^{60}Co, and ^{93m}Nb decay to insignificant quantities before reaching the water table. The maximum concentration of ^{99}Tc in groundwater during this period is 0.1 pCi/L, which is more than a factor of 5,000 less than the maximum contamination level. The peak dose for ^{99}Tc within the 1,000-year compliance period is 5.0×10^{-4} mrem/yr and the peak dose from 1,000 to 10,000 years post-closure is 0.13 mrem/yr. Due to the very low groundwater concentrations and doses, the groundwater pathway was not included in the intruder analysis in the PA.

Because the stabilized residuals in WMA C at closure are expected to have multiple radionuclides from 10 CFR 61.55 Tables 1 and 2, the SOF approach for comparing to Class C

concentration limits was applied. The SOF approach requires that the concentration of each of the Table 1 and Table 2 radionuclides contained in the stabilized residuals be divided by the appropriate Table 1 or Table 2 Class C concentration limit. The resulting fractions for each radionuclide are then totaled for the applicable 10 CFR 61.55 Table 1 or Table 2 radionuclides. If the SOF is less than 1.0 for the individual tables, the waste is below the Class C concentration limits set out in 10 CFR 61.55. Consistent with the Category 3 approach, the averaging expression used to determine the individual radionuclide contribution to the SOF is represented by the following equation:

$$SOF_i = \frac{C_R}{Table\_Value_i} \; x \; Site \; Factor_i$$

Where:

- SOF_i = Radionuclide "i" contribution to the sum of fractions.
- C_R = Concentration of the drilled source for radionuclide "i" at closure (Ci/m^3 or nCi/g) [see equations in Sections 6.4.2.1 and 6.4.2.2 for calculation of C_R. The concentration terms are derived from the $\frac{I_R}{V_R}$ ratios as explained in the following sections].
- *Table Value*$_i$ = Class C concentration limit from 10 CFR 61.55 Table 1 or Table 2 for radionuclide "i".
- *Site Factor*$_i$ = Site-specific factor for radionuclide "i" based on site-specific conditions within WMA C after closure [see calculation in Section 6.4.2.3].

The WMA C averaging expressions, based on the above equation that DOE is utilizing, are shown in the following sections.

6.4.2.1 Waste Management Area C Waste Tank Waste Concentration Calculation Averaging Expressions

For WMA C waste tanks, individual radionuclide concentrations for the SOF calculations are determined with the following equations.

For volume-based concentrations:

$$SOF_i = \frac{1}{Table\_Value_i} \; x \; \frac{I_R}{V_R} \; x \; Site \; Factor_i$$

Where:

- SOF_i = Radionuclide "i" contribution to the sum of fractions.
- *Table Value*$_i$ = Class C concentration limit in Ci/m^3 from 10 CFR 61.55 Table 1 or Table 2 for radionuclide "i".
- I_R = Total tank residuals inventory for radionuclide "i" decayed to date of closure (i.e., 2020), units in curies.
- V_R = Total volume of residuals remaining in the waste tank, units in m^3.
- *Site Factor*$_i$ = Site-specific factor for radionuclide "i" at closure (see Section 6.4.2.3 for derivation of site-specific factors).

For mass-based concentrations:

$$SOF_i = \frac{1}{Table\_Value_i} \; x \; \frac{I_R}{(V_R) \; x \; (\rho_{ws}) \; x \; (1{,}000{,}000)} \; x \; Site \; Factor_i$$

Where:

- SOF_i = Radionuclide "i" contribution to the sum of fractions.
- $Table\ Value_i$ = Class C concentration limit in nCi/g from 10 CFR 61.55 Table 1 for radionuclide "i".
- I_R = Total tank residuals inventory for radionuclide "i" decayed to date of closure (i.e., 2020), units in nanocuries.
- V_R = Total volume of residuals remaining in the waste tank, units in m^3.
- ρ_{ws} = Density of waste, units in g/cm^3.
- $Site\ Factor_i$ = Site-specific factor for radionuclide "i" at closure (see Section 6.4.2.3 for derivation of site-specific factors).

The calculated fractions are totaled for the applicable 10 CFR 61.55 Table 1 or Table 2 radionuclides. If the SOF is less than 1.0 for the individual tables, the waste is below the 10 CFR 61.55 Class C concentration limits.

6.4.2.2 Waste Management Area C Pipeline Waste Concentration Calculation Averaging Expressions

For WMA C pipelines, the individual radionuclide concentrations for the SOF calculations are determined with the following equations.

For volume-based concentrations:

$$SOF_i = \frac{1}{Table\_Value_i} \; x \; \frac{I_R}{V_R} \; x \; Site \; Factor_i$$

Where:

- SOF_i = Radionuclide "i" contribution to the sum of fractions.
- $Table\ Value_i$ = Class C concentration limit in Ci/m^3 from 10 CFR 61.55 Table 1 or Table 2 for radionuclide "i".
- I_R = Pipeline residuals inventory for radionuclide "i" decayed to date of closure (i.e., 2020), units in Ci
- V_R = Total volume of waste in the piping, units in m^3.
- $Site\ Factor_i$ = Site-specific factor for radionuclide "i" at closure (see Section 6.4.2.3 for derivation of site-specific factors).

For mass-based concentrations:

$$SOF_i = \frac{1}{Table\_Value_i} \; x \; \frac{I_R}{(V_R) \; x \; (\rho_{ws}) \; x \; (1{,}000{,}000)} \; x \; Site \; Factor_i$$

Where:

SOF_i = Radionuclide "i" contribution to the sum of fractions.
$Table\ Value_i$ = Class C concentration limit in nCi/g from 10 CFR 61.55 Table 1 for radionuclide "i".
I_R = Pipeline residuals inventory for radionuclide "i" decayed to date of closure (i.e., 2020), units in nCi.
V_R = Total volume of residuals remaining in the piping, units in m^3.
ρ_{ws} = Density of waste, units in g/cm^3.
$Site\ Factor_i$ = Site-specific factor for radionuclide "i" at closure (Table 6-8; see Section 6.4.2.3 for derivation of site-specific factors).

The calculated fractions are totaled for the applicable 10 CFR 61.55 Table 1 or Table 2 radionuclides. If the SOF is less than 1.0 for the individual tables, the waste is below the Class C concentration limits set out in 10 CFR 61.55.

6.4.2.3 Site-Specific Factors for Use in Waste Management Area C Averaging Expressions

The site-specific factors in the WMA C averaging expressions discussed previously were developed to account for site-specific conditions while ensuring the same protection as the concentration limits in Tables 1 and 2 and as the 10 CFR 61.55 analysis provides. To develop the site-specific factors, the results of the WMA C PA inadvertent intruder analyses, along with the WMA C PA inventory at closure, were utilized. The WMA C PA deterministic model and its associated dose calculation methodology were utilized to determine the dose to the acute and chronic intruder. The acute intruder drilling scenario resulted in the maximum intruder dose in the WMA C PA; therefore, this scenario was utilized for comparison to the Class C concentration limits (Table 6-5).

The peak intruder dose for each radionuclide, regardless of the time of the peak, was determined (Table 6-6 and Table 6-7) and site-specific factors were developed based on the assumed concentrations at closure from the drill cutting source. For the catch tank C-301 and 244-CR vault analyses, the time period evaluated started at 500 years after closure, while the pipeline time period started at 100 years after closure.

To determine, based on the inadvertent intruder analysis performed within the WMA C PA, the individual radionuclide site-specific factors that would result in an inadvertent intruder under the WMA C site-specific conditions receiving an equivalent dose (500 mrem) to that used in developing the 10 CFR 61.55 concentration limits, the following equation was used:

$$Site\ Factor_i = \frac{Table\_Value_i}{C_{PA}}\ x\ \frac{\mathrm{Dose}_i}{500\ mrem}$$

Where:

$Site\ Factor_i$ = Site-specific factor for radionuclide "i" at closure.
$Table\ Value_i$ = Class C concentration limit from 10 CFR 61.55 Table 1 or Table 2 for radionuclide "i".

C_{PA} = Concentration, based on the WMA C PA inventory at closure, of the drilled source for radionuclide "i" (Ci/m^3 or nCi/g) [see Sections 6.4.2.1 and 6.4.2.2].

$Dose_i$ = Peak dose, based on results of the WMA C PA, that occurs beyond 100 years (for pipelines) or beyond 500 years (for waste tanks, catch tank C-301 and 244-CR vault) after closure, for radionuclide "i", units in mrem/yr.

Table 6-5. Effective Dose for the Inadvertent Intruder Scenarios at 100 Years and 500 Years Post-Closure for All Residual Waste Sources.

Source	Well Driller Acute Dose (mrem)	Commercial Farm Chronic Dose (mrem/yr)	Rural Pasture Chronic Dose (mrem/yr)	Suburban Garden Chronic Dose (mrem/yr)
	500 yr	500 yr	500 yr	500 yr
C-101	1.24E+00	2.17E-03	1.44E-01	3.22E-01
C-102	4.59E+00	8.09E-03	5.37E-01	1.20E+00
C-103	4.09E-01	7.25E-04	6.14E-02	1.10E-01
C-104	5.77E-01	1.10E-03	1.21E-01	1.70E-01
C-105	3.80E+00	6.69E-03	7.18E-01	1.23E+00
C-106	3.47E+00	8.75E-03	8.93E-01	9.57E-01
C-107	1.49E+01	2.66E-02	1.82E+00	3.90E+00
C-108	5.80E-02	1.05E-04	1.09E-02	1.71E-02
C-109	3.10E-02	5.57E-05	7.63E-03	9.33E-03
C-110	8.24E-02	1.78E-04	1.99E-02	2.44E-02
C-111	7.47E+00	1.32E-02	1.40E+00	2.13E+00
C-112	3.48E-01	6.10E-04	9.17E-02	1.41E-01
C-201	1.45E+01	2.52E-02	1.58E+00	3.75E+00
C-202	1.28E+01	2.22E-02	1.39E+00	3.32E+00
C-203	4.61E-01	8.51E-04	7.25E-02	1.26E-01
C-204	5.60E-02	1.77E-04	2.97E-02	2.49E-02
C-301	2.12E+01	3.86E-02	2.69E+00	5.57E+00
244-CR vault	3.91E+00	7.10E-03	4.96E-01	1.03E+00
Pipeline*	3.60E+01	1.13E-03	8.21E+00	3.92E+00

Reference: RPT-ENV-58782, Table 9-7.

* Alternative Class C calculations for pipelines were at 100 years post-closure.

Table 6-6. Waste Management Area C Intruder Doses for Alternative Class C Calculations for Table 1 Radionuclides.

Table 1 Radionuclide	Intruder Doses (mrem/yr)																		
	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204	C-301	CR Vault	Pipelines
^{14}C	5.26E-08	1.88E-08	1.33E-07	5.87E-08	9.27E-07	1.57E-07	4.12E-07	1.56E-07	1.46E-08	2.88E-08	1.98E-06	3.05E-07	2.05E-07	5.44E-08	4.45E-08	5.04E-08	5.55E-07	1.02E-07	3.24E-07
^{59}Ni	1.69E-09	3.78E-07	2.62E-07	2.02E-07	1.03E-06	2.45E-05	2.76E-09	2.17E-09	1.51E-09	4.27E-10	3.27E-06	2.03E-09	1.34E-07	1.37E-07	1.12E-07	1.04E-07	1.38E-05	2.54E-06	7.70E-06
^{99}Tc	1.54E-06	1.27E-07	1.59E-06	1.08E-05	2.78E-04	5.83E-06	7.61E-05	1.73E-06	3.12E-07	1.59E-06	7.78E-05	6.01E-05	1.31E-06	1.25E-06	1.16E-06	1.59E-06	1.85E-05	3.41E-06	1.03E-05
^{129}I	2.26E-07	1.04E-05	1.22E-05	1.97E-06	3.65E-05	2.59E-06	1.67E-04	1.55E-07	1.08E-07	1.08E-06	5.78E-05	1.46E-07	2.62E-08	4.23E-07	8.43E-07	2.05E-08	1.20E-05	2.23E-06	6.72E-06
^{237}Np	1.60E-04	3.06E-04	1.17E-03	6.67E-03	4.00E-04	5.30E-03	4.92E-03	1.43E-05	5.82E-05	9.04E-05	1.39E-03	2.53E-05	4.46E-03	3.62E-03	3.87E-05	2.50E-02	3.43E-02	6.32E-03	1.90E-02
^{238}Pu	1.03E-04	1.35E-03	1.19E-03	5.39E-04	6.87E-04	2.18E-03	7.31E-04	4.00E-06	1.43E-05	1.43E-05	1.56E-03	3.29E-05	5.69E-03	5.14E-03	1.75E-04	3.55E-06	9.68E-03	1.78E-03	1.26E-01
^{239}Pu	9.31E-01	3.30E+00	2.54E-01	2.62E-01	2.69E+00	8.50E-01	6.62E+00	3.40E-02	2.04E-02	5.95E-02	4.81E+00	2.95E-01	1.13E+01	1.02E+01	3.48E-01	7.04E-03	1.55E+01	2.86E+00	8.74E+00
^{240}Pu	9.60E-02	7.59E-01	5.09E-02	7.59E-02	5.09E-01	1.75E-01	6.95E-01	3.56E-03	2.13E-03	6.22E-03	9.06E-01	3.08E-02	2.34E+00	2.12E+00	7.23E-02	1.46E-03	3.22E+00	5.93E-01	1.87E+00
^{241}Pu	4.86E-14	1.54E-12	5.69E-14	3.60E-13	5.53E-13	5.81E-13	3.31E-13	2.50E-15	1.61E-14	1.13E-14	1.12E-12	1.55E-14	3.71E-12	3.34E-12	1.15E-13	2.31E-15	5.46E-12	1.01E-12	7.13E-04
^{242}Pu	1.32E-06	4.41E-05	1.59E-06	9.66E-04	1.54E-05	2.04E-05	9.66E-06	4.95E-08	2.98E-08	8.68E-08	3.21E-05	4.29E-07	1.10E-04	1.00E-04	3.41E-06	6.88E-08	9.10E-04	1.67E-04	5.05E-04
^{241}Am	2.03E-01	4.66E-01	9.96E-02	1.80E-01	5.90E-01	1.31E+00	7.53E+00	1.93E-02	7.91E-03	1.26E-03	1.72E+00	1.95E-02	7.86E-01	4.20E-01	1.16E-02	9.56E-04	1.73E+00	3.19E-01	1.83E+00
^{243}Am	1.24E-04	6.85E-05	3.20E-06	4.53E-04	5.81E-05	2.63E-04	3.33E-03	8.45E-06	3.38E-06	4.78E-07	9.93E-04	8.40E-06	1.19E-03	5.72E-04	1.48E-05	1.48E-06	1.69E-03	3.12E-04	9.76E-04
^{243}Cm	8.14E-12	2.72E-11	3.35E-13	1.59E-09	3.99E-12	2.43E-08	2.15E-10	6.57E-13	2.23E-13	3.16E-14	7.97E-10	5.52E-13	1.91E-08	9.24E-09	2.39E-10	2.38E-11	3.33E-08	6.14E-09	2.52E-04
^{244}Cm	4.63E-14	1.79E-13	2.12E-15	9.33E-12	2.18E-14	1.03E-10	1.20E-12	4.13E-15	1.27E-15	1.80E-16	4.55E-12	3.14E-15	1.09E-10	5.26E-11	1.36E-12	1.36E-13	1.71E-10	3.16E-11	4.16E-04

Reference: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

Note: Only the 10 CFR 61.55 Table 1 radionuclides in the tank inventory are listed.

1
2

Table 6-7. Waste Management Area C Intruder Doses for Alternative Class C Calculations for Table 2 Radionuclides.

Table 2 Radionuclide	Intruder Doses (mrem/yr)																		
	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204	C-301	CR Vault	Pipelines
^{63}Ni	1.04E-08	3.78E-07	3.49E-06	1.87E-05	4.00E-04	1.23E-05	2.72E-08	5.26E-07	1.65E-07	7.66E-08	2.12E-05	2.03E-08	2.20E-06	5.28E-07	1.46E-07	3.86E-08	2.56E-05	4.71E-06	2.26E-04
^{90}Sr	4.65E-05	4.16E-06	9.58E-05	6.91E-05	4.09E-04	6.36E-04	3.34E-04	1.77E-05	3.29E-05	3.70E-05	4.31E-03	3.22E-06	3.40E-05	6.58E-05	3.10E-05	2.05E-05	6.18E-04	1.14E-04	5.17E+00
^{137}Cs	6.86E-04	1.53E-04	1.15E-03	1.18E-03	9.65E-03	1.90E-03	4.31E-03	1.63E-04	8.18E-05	3.84E-05	1.36E-02	1.45E-03	1.87E-04	1.65E-04	2.43E-04	1.10E-04	3.28E-03	6.05E-04	1.78E+01

Reference: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

Note: Only the 10 CFR 61.55 Table 2 radionuclides in the tank inventory are listed.

3
4

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Using values for the WMA C PA closure inventory along with the mass (for mass-based limits) and volume (for volume-based limits) of the residual material, the radionuclide concentrations at closure were determined. The calculated concentration for each radionuclide, the peak dose for each radionuclide and the equation developed above, were then used to determine the site-specific factors, on a radionuclide basis, to be used in the site-specific averaging expression as shown in Sections 6.4.2.1 and 6.4.2.2.

Table 6-8 and Table 6-9 provide the WMA C site-specific factors for 10 CFR 61.55 Table 1 and Table 2 radionuclides, respectively, which are used in the WMA C averaging expressions.

6.5 WASTE CONCENTRATION CALCULATIONS

The following sections provide calculations of radionuclide concentrations and compare those concentrations to the Class C concentration limits set out in 10 CFR 61.55.

6.5.1 Waste Tank Concentration Calculation

The contribution of each radionuclide to the SOF was calculated using the WMA C averaging expressions presented in Section 6.4.2.1 for a mass or volume basis as necessary. For example, using the tank C-107 inventory values for ^{99}Tc and ^{239}Pu, the mass- and volume-based averaging expressions from Section 6.4.2.1 become the following.

For the volume-based ^{99}Tc fraction of Class C concentration limit:

$$SOF_{[Tc-99]} = \frac{1}{3\ Ci/m^3}\ x\ \frac{2.14\ Ci}{53.0\ m^3}\ x\ \ 1.13E-05 = 1.52E-07$$

For the mass-based ^{239}Pu fraction of Class C concentration limit:

$$SOF_{[Pu-239]} = \frac{1}{100\frac{nCi}{g}}\ x\ \frac{1.3E+11\ nCi}{(53.0\ m^3)\ x\ \left(2.05\frac{g}{cm^3}\right)\ x\ \left(1.0E+06\frac{cm^3}{m^3}\right)}\ x\ 1.11E-03$$
$$= 1.32E-02$$

The remainder of the 10 CFR 61.55 Tables 1 and 2 radionuclides are calculated similarly and the results for each tank and ancillary structures (e.g., catch tank C-301, 244-CR vault) are presented in Tables 6-10 and 6-11.

Table 6-10 shows the sum of ratios for 10 CFR 61.55 Table 1 radionuclides; the maximum value occurs for tank C-107 at an SOF of 2.97×10^{-2}. Table 6-11 shows the sum of ratios for 10 CFR 61.55 Table 2 radionuclides; the maximum value occurs for tank C-111 at an SOF of 3.58×10^{-5}. Using the inventory values assumed for this calculation, the stabilized residuals would not exceed Class C concentration limits.

6.5.2 Waste Tank Concentration Comparison for Revised Inventories Based on Post-Retrieval Sampling

After the completion of the modeling for WMA C PA, waste from six additional SSTs have been retrieved and the post-retrieval samples have been obtained for five of those tanks (C-101,

C-102, C-107, C-111 and C-112).[65] The discussion below provides a comparison of the Class C limits based on the WMA C PA inventory estimates and the Class C limits based on the BBI inventory estimates updated with post-retrieval samples for the five SSTs for which post-retrieval samples have been obtained.

The evaluation of the Class C limits was based on the increase in the inventory for each 10 CFR 61.55 Tables 1 and 2 radionuclides based on:

$$Inventory\ Factor = \frac{Post\ Retrieval\ Inventory\ (Ci)}{WMA\ C\ PA\ Inventory\ (Ci)}$$

The inventories for both the post-retrieval inventory and the WMA C PA inventory are provided in Table 2-6.

The fraction of the Class C limit for each radionuclide provided in Tables 6-10 and 6-11 were multiplied by the inventory factor to obtain the new fraction of the Class C limit. A sum of these fractions that was less than 1.0 indicated compliance with 10 CFR 61.55 for the new post-retrieval inventories.

The fraction of the Class C limits for the post-retrieval inventory for tanks C-101, C-102, C-107, C-111, and C-112 are provided in Table 6-12 through Table 6-16. The sum of fractions for the post-retrieval inventory Class C limits were all significantly less than 1.0 for the 10 CFR 61.55 Tables 1 and Table 2 radionuclides. Therefore, the post-retrieval inventory for tanks C-101, C-102, C-107, C-111, and C-112 meet the Class C concentration limits of 10 CFR 61.55.

6.5.3 Pipeline Concentration Calculation

The contribution of each radionuclide to the SOF was calculated using the averaging expressions presented in Section 6.4.2.2 for a mass or volume basis as necessary. For example, using the inventory values for ^{99}Tc and ^{239}Pu, the mass- and volume-based averaging expressions from Section 6.4.2.2 become:

$$SOF_{[Tc-99]} = \frac{1}{3\ Ci/m^3}\ x\ \frac{5.61E-02\ Ci}{6.1\ m^3}\ x\ 6.73E-06 = 2.06E-08$$

For the mass-based ^{239}Pu fraction of Class C concentration limit:

$$SOF_{[Pu-239]} = \frac{1}{100\frac{nCi}{g}}\ x\ \frac{3.28E \mp 10\ nCi}{(6.1\ m^3)\ x\ \left(2.05\frac{g}{cm^3}\right)\ x\ \left(1.0E+06\frac{cm^3}{m^3}\right)}\ x\ 6.66E-04$$
$$= 1.75E-02$$

[65] Post-retrieval sampling has been completed for five tanks (C-101, C-102, C-107, C-111 and C-112) and is anticipated in the near future for C-105. As explained previously, more waste was retrieved from tank C 105 that was assumed for the WMA C PA, so the inventory and analysis in the WMA C PA for C-105 is considered to be bounding.

Table 6-8. Waste Management Area C Site-Specific Factors for 10 CFR 61.55 Table 1 Radionuclides.

Table 1 Radionuclide	Site-Specific Factor																		
	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204	C-301	CR Vault	Pipelines
^{14}C	5.77E-06	3.11E-06	2.92E-06	2.20E-06	1.46E-05	3.20E-06	1.62E-05	3.93E-06	2.32E-06	2.44E-06	4.03E-05	4.03E-05	2.57E-06	2.57E-06	2.14E-06	2.14E-06	1.74E-05	1.81E-06	1.01E-05
^{59}Ni	1.94E-05	1.05E-05	9.83E-06	7.40E-06	4.93E-05	1.08E-05	5.45E-05	1.33E-05	7.81E-06	8.22E-06	1.36E-04	1.36E-04	8.67E-06	8.67E-06	7.23E-06	7.23E-06	5.88E-05	6.10E-06	3.24E-05
^{99}Tc	4.03E-06	2.18E-06	3.18E-09	1.54E-06	1.02E-05	2.24E-06	1.13E-05	2.75E-06	1.62E-06	1.71E-06	2.82E-05	2.82E-05	1.80E-06	1.80E-06	1.50E-06	1.50E-06	1.22E-05	1.27E-06	6.73E-06
^{129}I	1.23E-05	6.65E-06	2.45E-08	4.70E-06	3.13E-05	6.88E-06	3.47E-05	8.41E-06	4.96E-06	5.22E-06	8.65E-05	8.61E-05	5.50E-06	5.53E-06	4.59E-06	4.59E-06	3.72E-05	3.89E-06	2.07E-05
^{237}Np	3.60E-03	2.48E-02	2.35E-06	2.47E-04	4.07E-02	4.21E-04	5.14E-01	3.50E-03	2.81E-04	2.72E-04	2.27E-02	8.91E-03	3.21E-04	3.07E-04	2.94E-04	2.37E-04	1.99E-03	2.07E-04	1.10E-03
^{238}Pu	7.09E-06	3.83E-06	2.38E-06	2.70E-06	1.80E-05	3.94E-06	1.97E-05	4.84E-06	2.85E-06	3.00E-06	4.95E-05	4.95E-05	3.17E-06	3.17E-06	2.64E-06	2.64E-06	2.15E-05	2.24E-06	2.77E-04
^{239}Pu	3.94E-04	2.13E-04	5.08E-04	1.50E-04	1.00E-03	2.19E-04	1.11E-03	2.69E-04	1.59E-04	1.67E-04	2.75E-03	2.75E-03	1.76E-04	1.76E-04	1.47E-04	1.47E-04	1.20E-03	1.24E-04	6.66E-04
^{240}Pu	3.79E-04	2.05E-04	1.02E-04	1.45E-04	9.64E-04	2.11E-04	1.06E-03	2.59E-04	1.53E-04	1.61E-04	2.65E-03	2.65E-03	1.69E-04	1.69E-04	1.41E-04	1.41E-04	1.15E-03	1.19E-04	6.60E-04
^{241}Pu	8.57E-15	4.62E-15	1.14E-16	3.26E-15	2.18E-14	4.76E-15	2.29E-14	5.85E-15	3.45E-15	3.63E-15	5.98E-14	5.98E-14	3.82E-15	3.82E-15	3.19E-15	3.19E-15	2.59E-14	2.70E-15	3.36E-06
^{242}Pu	3.80E-04	2.05E-04	3.18E-09	1.45E-04	9.65E-04	2.11E-04	1.07E-03	2.59E-04	1.53E-04	1.61E-04	2.65E-03	2.65E-03	1.70E-04	1.70E-04	1.41E-04	1.41E-04	1.15E-03	1.19E-04	6.31E-04
^{241}Am	1.59E-04	9.18E-05	1.99E-04	6.29E-05	4.09E-04	8.84E-05	4.42E-04	1.08E-04	6.64E-05	8.34E-05	1.12E-03	1.12E-03	7.86E-05	8.54E-05	7.51E-05	6.20E-05	5.13E-04	5.31E-05	5.36E-04
^{243}Am	6.69E-04	3.61E-04	6.39E-09	2.55E-04	1.70E-03	3.72E-04	1.88E-03	4.57E-04	2.69E-04	2.83E-04	4.67E-03	4.67E-03	2.99E-04	2.99E-04	2.49E-04	2.49E-04	2.02E-03	2.11E-04	1.16E-03
^{243}Cm	3.39E-09	1.83E-09	1.72E-09	1.29E-09	8.62E-09	1.88E-09	9.29E-09	2.32E-09	1.36E-09	1.44E-09	2.37E-08	2.37E-08	1.51E-09	1.51E-09	1.26E-09	1.26E-09	1.02E-08	1.07E-09	7.68E-05
^{244}Cm	1.08E-12	5.83E-13	5.47E-13	4.12E-13	2.75E-12	6.00E-13	2.92E-12	7.38E-13	4.35E-13	4.58E-13	7.55E-12	7.55E-12	4.83E-13	4.83E-13	4.02E-13	4.02E-13	3.27E-12	3.40E-13	7.88E-06

Reference: 10 CFR 61, “Licensing Requirements for Land Disposal of Radioactive Waste,” Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, “Waste classification.”

Note: Only the 10 CFR 61.55 Table 1 radionuclides in the tank inventory are listed.

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Table 6-9. Waste Management Area C Site-Specific Factors for 10 CFR 61.55 Table 2 Radionuclides.

Table 2 Radionuclide	Site-Specific Factor																		
	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204	C-301	CR Vault	Pipelines
^{63}Ni	4.97E-06	3.97E-07	2.52E-06	1.89E-06	7.44E-04	2.76E-06	1.38E-05	3.39E-06	2.00E-06	2.10E-06	3.47E-05	3.47E-05	2.22E-06	2.22E-06	1.85E-06	1.85E-06	1.50E-05	1.56E-06	1.31E-04
^{90}Sr	3.74E-06	2.02E-06	1.89E-06	1.43E-06	9.50E-06	2.08E-06	1.02E-05	2.55E-06	1.50E-06	1.58E-06	2.61E-05	2.61E-05	1.67E-06	1.67E-06	1.39E-06	1.39E-06	1.13E-05	1.18E-06	9.39E-02
^{137}Cs	3.30E-04	1.78E-04	1.67E-04	1.26E-04	8.39E-04	1.83E-04	9.05E-04	2.25E-04	1.33E-04	1.40E-04	2.31E-03	2.31E-03	1.47E-04	1.47E-04	1.23E-04	1.23E-04	9.99E-04	1.03E-04	5.34E+00

Reference: 10 CFR 61, “Licensing Requirements for Land Disposal of Radioactive Waste,” Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, “Waste classification.”

Note: Only the 10 CFR 61.55 Table 2 radionuclides in the tank inventory are listed.

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Table 6-10. Waste Management Area C Sum of Fractions for 10 CFR 61.55 Table 1 Radionuclides.

Table 1 Radionuclide	Fraction of Class C Concentration Limit																		
	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204	C-301	CR Vault	Pipelines
^{14}C	1.05E-10	3.77E-11	2.67E-10	1.17E-10	1.85E-09	3.13E-10	8.24E-10	3.12E-10	2.92E-11	5.76E-11	3.97E-09	6.10E-10	4.10E-10	1.09E-10	8.90E-11	1.01E-10	1.11E-09	2.04E-10	6.48E-10
^{59}Ni	3.38E-12	7.57E-10	5.23E-10	4.04E-10	2.06E-09	4.90E-08	5.51E-12	4.34E-12	3.02E-12	8.55E-13	6.54E-09	4.06E-12	2.67E-10	2.73E-10	2.23E-10	2.09E-10	2.77E-08	5.09E-09	1.54E-08
^{99}Tc	3.09E-09	2.53E-10	3.18E-09	2.16E-08	5.57E-07	1.17E-08	1.52E-07	3.46E-09	6.23E-10	3.17E-09	1.56E-07	1.20E-07	2.63E-09	2.50E-09	2.32E-09	3.18E-09	3.70E-08	6.83E-09	2.06E-08
^{129}I	4.52E-10	2.09E-08	2.45E-08	3.95E-09	7.30E-08	5.17E-09	3.33E-07	3.11E-10	2.16E-10	2.16E-09	1.16E-07	2.91E-10	5.24E-11	8.47E-10	1.69E-09	4.09E-11	2.40E-08	4.45E-09	1.34E-08
^{237}Np	3.20E-07	6.12E-07	2.35E-06	1.33E-05	7.99E-07	1.06E-05	9.84E-06	2.87E-08	1.16E-07	1.81E-07	2.78E-06	5.07E-08	8.93E-06	7.25E-06	7.74E-08	5.00E-05	6.86E-05	1.26E-05	3.81E-05
^{238}Pu	2.07E-07	2.71E-06	2.38E-06	1.08E-06	1.37E-06	4.36E-06	1.46E-06	8.00E-09	2.86E-08	2.86E-08	3.11E-06	6.57E-08	1.14E-05	1.03E-05	3.50E-07	7.11E-09	1.94E-05	3.57E-06	2.53E-04
^{239}Pu	1.86E-03	6.61E-03	5.08E-04	5.24E-04	5.37E-03	1.70E-03	1.32E-02	6.80E-05	4.08E-05	1.19E-04	9.62E-03	5.89E-04	2.26E-02	2.05E-02	6.96E-04	1.41E-05	3.11E-02	5.71E-03	1.75E-02
^{240}Pu	1.92E-04	1.52E-03	1.02E-04	1.52E-04	1.02E-03	3.50E-04	1.39E-03	7.12E-06	4.27E-06	1.24E-05	1.81E-03	6.16E-05	4.68E-03	4.24E-03	1.45E-04	2.92E-06	6.45E-03	1.19E-03	3.74E-03
^{241}Pu	9.73E-17	3.08E-15	1.14E-16	7.20E-16	1.11E-15	1.16E-15	6.62E-16	5.00E-18	3.22E-17	2.26E-17	2.24E-15	3.10E-17	7.43E-15	6.68E-15	2.29E-16	4.63E-18	1.09E-14	2.01E-15	1.43E-06
^{242}Pu	2.65E-09	8.82E-08	3.18E-09	1.93E-06	3.08E-08	4.08E-08	1.93E-08	9.90E-11	5.95E-11	1.74E-10	6.41E-08	8.59E-10	2.21E-07	2.00E-07	6.81E-09	1.38E-10	1.82E-06	3.35E-07	1.01E-06
^{241}Am	4.06E-04	9.31E-04	1.99E-04	3.60E-04	1.18E-03	2.62E-03	1.51E-02	3.86E-05	1.58E-05	2.51E-06	3.44E-03	3.90E-05	1.57E-03	8.41E-04	2.32E-05	1.91E-06	3.47E-03	6.38E-04	3.66E-03
^{243}Am	2.47E-07	1.37E-07	6.39E-09	9.07E-07	1.16E-07	5.27E-07	6.67E-06	1.69E-08	6.75E-09	9.57E-10	1.99E-06	1.68E-08	2.37E-06	1.14E-06	2.96E-08	2.96E-09	3.38E-06	6.24E-07	1.95E-06
^{243}Cm	1.63E-14	5.45E-14	6.71E-16	3.19E-12	7.98E-15	4.86E-11	4.29E-13	1.31E-15	4.46E-16	6.32E-17	1.59E-12	1.10E-15	3.82E-11	1.85E-11	4.78E-13	4.77E-14	6.66E-11	1.23E-11	5.03E-07
^{244}Cm	9.26E-17	3.57E-16	4.24E-18	1.87E-14	4.35E-17	2.06E-13	2.40E-15	8.26E-18	2.54E-18	3.60E-19	9.10E-15	6.28E-18	2.18E-13	1.05E-13	2.73E-15	2.73E-16	3.43E-13	6.32E-14	8.32E-07
SOF	**2.46E-03**	**9.06E-03**	**8.14E-04**	**1.05E-03**	**7.58E-03**	**4.69E-03**	**2.97E-02**	**1.14E-04**	**6.11E-05**	**1.34E-04**	**1.49E-02**	**6.90E-04**	**2.89E-02**	**2.56E-02**	**8.64E-04**	**6.89E-05**	**4.11E-02**	**7.55E-03**	**2.52E-02**

Reference: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

SOF = sum of fractions

Table 6-11. Waste Management Area C Sum of Fractions for 10 CFR 61.55 Table 2 Radionuclides.

Table 2 Radionuclide	Fraction of Class C Concentration Limit																		
	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112	C-201	C-202	C-203	C-204	C-301	CR Vault	Pipelines
^{63}Ni	2.08E-11	7.57E-10	6.98E-09	3.74E-08	7.99E-07	2.45E-08	5.44E-11	1.05E-09	3.30E-10	1.53E-10	4.24E-08	4.06E-11	4.40E-09	1.06E-09	2.93E-10	7.71E-11	5.12E-08	9.42E-09	4.53E-07
^{90}Sr	9.30E-08	8.31E-09	1.92E-07	1.38E-07	8.17E-07	1.27E-06	6.68E-07	3.53E-08	6.59E-08	7.41E-08	8.62E-06	6.45E-09	6.80E-08	1.32E-07	6.20E-08	4.10E-08	1.24E-06	2.27E-07	1.03E-02
^{137}Cs	1.37E-06	3.07E-07	2.31E-06	2.36E-06	1.93E-05	3.80E-06	8.61E-06	3.25E-07	1.64E-07	7.67E-08	2.71E-05	2.91E-06	3.74E-07	3.30E-07	4.86E-07	2.21E-07	6.57E-06	1.21E-06	3.56E-02
SOF	**1.46E-06**	**3.16E-07**	**2.50E-06**	**2.54E-06**	**2.09E-05**	**5.09E-06**	**9.28E-06**	**3.62E-07**	**2.30E-07**	**1.51E-07**	**3.58E-05**	**2.92E-06**	**4.47E-07**	**4.63E-07**	**5.48E-07**	**2.62E-07**	**7.86E-06**	**1.45E-06**	**4.59E-02**

Reference: 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, "Waste classification."

SOF = sum of fractions

Table 6-12. Tank C-101 Class C Limit Comparison for the Waste Management Area C Performance Assessment Inventory Versus Post-Retrieval Inventory.

Table 1 Radionuclides	Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit	Post-Retrieval Inventory Change Factor	Post-Retrieval Inventory Fraction of Class C Limit
^{14}C	1.05E-10	1.27E+00	1.33E-10
^{59}Ni	3.38E-12	1.27E+00	4.29E-12
^{99}Tc	3.09E-09	1.81E+01	5.59E-08
^{129}I	4.52E-10	4.90E+01	2.22E-08
^{237}Np	3.20E-07	7.19E+01	2.30E-05
^{238}Pu	2.07E-07	2.68E+00	5.55E-07
^{239}Pu	1.86E-03	1.05E+00	1.95E-03
^{240}Pu	1.92E-04	1.05E+00	2.02E-04
^{241}Pu	9.73E-17	5.52E+00	5.37E-16
^{242}Pu	2.65E-09	1.05E+00	2.77E-09
^{241}Am	4.06E-04	5.79E-01	2.35E-04
^{243}Am	2.47E-07	4.16E-01	1.03E-07
^{243}Cm	1.63E-14	4.16E-01	6.77E-15
^{244}Cm	9.26E-17	4.16E-01	3.85E-17
Sum of Fractions	**2.46E-03**		**2.41E-03**
Table 2 Radionuclides	**Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit**	**Post-Retrieval Inventory Change Factor**	**Post-Retrieval Inventory Fraction of Class C Limit**
^{63}Ni	2.08E-11	9.98E+02	2.07E-08
^{90}Sr	9.30E-08	2.78E+00	2.58E-07
^{137}Cs	1.37E-06	5.46E+00	7.48E-06
Sum of Fractions	**1.46E-06**		**7.76E-06**

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Table 6-13. Tank C-102 Class C Limit Comparison for the Waste Management Area C Performance Assessment Inventory Versus Post-Retrieval Inventory.

Table 1 Radionuclides	Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit	Post-Retrieval Inventory Change Factor	New Fraction of Class C Limit
^{14}C	3.77E-11	8.33E+00	3.14E-10
^{59}Ni	7.57E-10	1.60E-02	1.21E-11
^{99}Tc	2.53E-10	1.20E+02	3.03E-08
^{129}I	2.09E-08	6.25E-01	1.30E-08
^{237}Np	6.12E-07	7.81E+01	4.78E-05
^{238}Pu	2.71E-06	3.64E-01	9.85E-07
^{239}Pu	6.61E-03	9.71E-01	6.41E-03
^{240}Pu	1.52E-03	3.82E-01	5.80E-04
^{241}Pu	3.08E-15	4.41E-01	1.36E-15
^{242}Pu	8.82E-08	2.22E-03	1.96E-10
^{241}Am	9.31E-04	7.97E-01	7.42E-04
^{243}Am	1.37E-07	1.54E+00	2.11E-07
^{243}Cm	5.45E-14	2.52E-01	1.37E-14
^{244}Cm	3.57E-16	2.19E-01	7.81E-17
Sum of Fractions	**9.06E-03**		**7.78E-03**
Table 2 Radionuclides	**Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit**	**Post-Retrieval Inventory Change Factor**	**New Fraction of Class C Limit**
^{63}Ni	7.57E-10	4.14E+01	3.13E-08
^{90}Sr	8.31E-09	1.69E+00	1.41E-08
^{137}Cs	3.07E-07	7.09E+00	2.17E-06
Sum of Fractions	**3.16E-07**		**2.22E-06**

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Table 6-14. Tank C-107 Class C Limit Comparison for the Waste Management Area C Performance Assessment Inventory Versus Post-Retrieval Inventory.

Table 1 Radionuclides	Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit	Post-Retrieval Inventory Change Factor	New Fraction of Class C Limit
^{14}C	8.24E-10	1.46E+00	1.20E-09
^{59}Ni	5.51E-12	1.46E+00	8.03E-12
^{99}Tc	1.52E-07	4.13E-02	6.28E-09
^{129}I	3.33E-07	7.32E-02	2.44E-08
^{237}Np	9.84E-06	1.15E+02	1.14E-03
^{238}Pu	1.46E-06	1.23E-01	1.80E-07
^{239}Pu	1.32E-02	1.23E-01	1.63E-03
^{240}Pu	1.39E-03	1.23E-01	1.70E-04
^{241}Pu	6.62E-16	1.23E-01	8.13E-17
^{242}Pu	1.93E-08	1.23E-01	2.37E-09
^{241}Am	1.51E-02	3.57E-02	5.37E-04
^{243}Am	6.67E-06	3.50E-02	2.33E-07
^{243}Cm	4.29E-13	3.51E-02	1.51E-14
^{244}Cm	2.40E-15	3.51E-02	8.43E-17
Sum of Fractions	**2.97E-02**		**3.47E-03**
Table 2 Radionuclides	**Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit**	**Post-Retrieval Inventory Change Factor**	**New Fraction of Class C Limit**
^{63}Ni	5.44E-11	2.05E+03	1.12E-07
^{90}Sr	6.68E-07	3.46E-01	2.31E-07
^{137}Cs	8.61E-06	9.35E-02	8.05E-07
Sum of Fractions	**9.28E-06**		**1.15E-06**

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Table 6-15. Tank C-111 Class C Limit Comparison for the Waste Management Area C Performance Assessment Inventory Versus Post-Retrieval Inventory.

Table 1 Radionuclides	Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit	Post-Retrieval Inventory Change Factor	New Fraction of Class C Limit
^{14}C	3.97E-09	3.75E-02	1.49E-10
^{59}Ni	6.54E-09	2.71E-04	1.77E-12
^{99}Tc	1.56E-07	2.27E-02	3.53E-09
^{129}I	1.16E-07	1.11E-03	1.28E-10
^{237}Np	2.78E-06	3.95E-01	1.10E-06
^{238}Pu	3.11E-06	4.95E-02	1.54E-07
^{239}Pu	9.62E-03	2.68E-02	2.58E-04
^{240}Pu	1.81E-03	1.49E-02	2.69E-05
^{241}Pu	2.24E-15	6.07E-03	1.36E-17
^{242}Pu	6.41E-08	5.86E-03	3.76E-10
^{241}Am	3.44E-03	9.30E-02	3.20E-04
^{243}Am	1.99E-06	3.70E-03	7.34E-09
^{243}Cm	1.59E-12	3.04E-04	4.84E-16
^{244}Cm	9.10E-15	3.03E-04	2.76E-18
Sum of Fractions	**1.49E-02**		**6.05E-04**
Table 2 Radionuclides	**Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit**	**Post-Retrieval Inventory Change Factor**	**New Fraction of Class C Limit**
^{63}Ni	4.24E-08	3.04E-02	1.29E-09
^{90}Sr	8.62E-06	1.33E-01	1.15E-06
^{137}Cs	2.71E-05	2.03E-02	5.51E-07
Sum of Fractions	**3.58E-05**		**1.70E-06**

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Table 6-16. Tank C-112 Class C Limit Comparison for the Waste Management Area C Performance Assessment Inventory Versus Post-Retrieval Inventory.

Table 1 Radionuclides	Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit	Post-Retrieval Inventory Change Factor	New Fraction of Class C Limit
^{14}C	6.10E-10	1.09E+00	6.63E-10
^{59}Ni	4.06E-12	1.60E+00	6.49E-12
^{99}Tc	1.20E-07	1.67E-01	2.01E-08
^{129}I	2.91E-10	1.60E+00	4.65E-10
^{237}Np	5.07E-08	1.40E+02	7.11E-06
^{238}Pu	6.57E-08	1.02E+01	6.70E-07
^{239}Pu	5.89E-04	1.08E+00	6.38E-04
^{240}Pu	6.16E-05	1.08E+00	6.68E-05
^{241}Pu	3.10E-17	2.10E+01	6.51E-16
^{242}Pu	8.59E-10	1.16E+03	1.00E-06
^{241}Am	3.90E-05	2.11E+01	8.25E-04
^{243}Am	1.68E-08	1.59E+00	2.68E-08
^{243}Cm	1.10E-15	1.60E+00	1.77E-15
^{244}Cm	6.28E-18	1.60E+00	1.01E-17
Sum of Fractions	**6.90E-04**		**1.54E-03**
Table 2 Radionuclides	**Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit**	**Post-Retrieval Inventory Change Factor**	**New Fraction of Class C Limit**
^{63}Ni	4.06E-11	3.24E+02	1.31E-08
^{90}Sr	6.45E-09	2.82E+02	1.82E-06
^{137}Cs	2.91E-06	7.44E-01	2.16E-06
Sum of Fractions	**2.92E-06**		**4.00E-06**

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The remainder of the 10 CFR 61.55 Tables 1 and 2 radionuclides are calculated similarly and the results are presented in Table 6-10.

Table 6-10 shows that the maximum sum of ratios for 10 CFR 61.55 Table 1 radionuclides occurs at a 2.52×10^{-2} SOF. Table 6-11 shows that the maximum sum of ratios for 10 CFR 61.55 Table 2 radionuclides occurs at a 4.59×10^{-2} SOF. Using the inventory values assumed for this calculation, the stabilized tanks, ancillary structures and residuals would not exceed Class C concentration limits.

6.5.4 Pipeline Concentration Comparison for Revised Inventories Based on Post-Retrieval Sampling

After the completion of the modeling for WMA C PA, five additional SSTs have been retrieved (C-101, C-102, C-107, C-111 and C-112) and the post-retrieval samples have been obtained. The discussion below provides a comparison of the Class C limits based on the WMA C PA inventory estimates and the Class C limits based on the BBI inventory estimates updated with post-retrieval samples for the five SSTs.

The waste transfer pipeline inventory was based on the average BBI concentration for retrieved tanks. Therefore, the Class C limits for the pipelines would change in relation to the change in the average tank inventories.

The evaluation of the Class C limits was based on the change in the inventory for each 10 CFR 61.55 Tables 1 and 2 radionuclides based on:

$$Inventory\ Factor = \frac{Post\ Retrieval\ Inventory\ (Ci)}{WMA\ C\ PA\ Inventory\ (Ci)}$$

The inventories for both the post-retrieval inventory and the WMA C PA inventory are provided in Table 2-6.

The fraction of the Class C limit for each radionuclide provided in Table 6-10 and Table 6-11 were multiplied by the inventory factor to obtain the new fraction of the Class C limit. A sum of these fractions that was less than 1.0 would show that for the new post-retrieval inventories, the pipelines and their residuals meet the concentration limits for Class C LLW.

The fraction of the Class C limits for the post-retrieval inventory for the pipelines are provided in Table 6-17. The sum of fractions for the post-retrieval inventory Class C limits were 8.03×10^{-3} and 1.54×10^{-2} for the 10 CFR 61.55 Table 1 and Table 2 radionuclides, respectively. Therefore, the post-retrieval inventory for the pipelines meet the Class C concentration limits of 10 CFR 61.55.

6.6 CONCLUSION FOR CONCENTRATION LIMITS

The stabilized WMA C wastes at closure are anticipated to meet concentration limits for Class C LLW as set out in 10 CFR 61.55.

Table 6-17. Pipelines Class C Limit Comparison for the Waste Management Area C Performance Assessment Inventory Versus Post-Retrieval Inventory.

Table 1 Radionuclides	Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit	Post-Retrieval Inventory Change Factor	New Fraction of Class C Limit
^{14}C	6.48E-10	4.44E-01	2.88E-10
^{59}Ni	1.54E-08	4.48E-03	6.90E-11
^{99}Tc	2.06E-08	2.69E-01	5.56E-09
^{129}I	1.34E-08	1.28E-01	1.72E-09
^{237}Np	3.81E-05	1.86E+01	7.07E-04
^{238}Pu	2.53E-04	3.36E-01	8.50E-05
^{239}Pu	1.75E-02	3.41E-01	5.97E-03
^{240}Pu	3.74E-03	2.10E-01	7.86E-04
^{241}Pu	1.43E-06	4.31E-01	6.15E-07
^{242}Pu	1.01E-06	5.74E+00	5.80E-06
^{241}Am	3.66E-03	1.31E-01	4.78E-04
^{243}Am	1.95E-06	6.41E-02	1.25E-07
^{243}Cm	5.03E-07	1.81E-02	9.12E-09
^{244}Cm	8.32E-07	1.80E-02	1.50E-08
Sum of Fractions	**2.52E-02**		**8.03E-03**
Table 2 Radionuclides	**Waste Management Area C Performance Assessment Inventory Fraction of Class C Limit**	**Post-Retrieval Inventory Change Factor**	**New Fraction of Class C Limit**
^{63}Ni	4.53E-07	7.54E+00	3.41E-06
^{90}Sr	1.03E-02	3.70E-01	3.82E-03
^{137}Cs	3.56E-02	3.26E-01	1.16E-02
Sum of Fractions	**4.59E-02**		**1.54E-02**

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7.0 CONCLUSION

Section Purpose

The purpose of this section is to provide a summary of the analyses provided in this Draft WIR Evaluation.

Section Contents

This section summarizes the analyses and conclusions of this document.

Key Points

- This Draft WIR Evaluation demonstrates that the stabilized residuals in the waste tanks and ancillary structures, the waste tanks, and the ancillary structures (including integral equipment) at the time of closure meet the criteria of DOE M 435.1-1.

This Draft WIR Evaluation and its supporting references demonstrate that the stabilized (grouted) tanks, ancillary structures (including integral equipment), and residuals within the WMA C at closure will meet the criteria set forth in DOE M 435.1-1, Section II.B.(2)(a), for determining that waste is incidental to the reprocessing of SNF, is not HLW and may be managed as LLW. Summarized below are the assessments and rationale in this Draft WIR Evaluation, which show that the criteria in DOE M 435.1-1 are met.

As to the first criterion in DOE M 435.1-1 concerning removal of key radionuclides to the maximum extent technically and economically practical, this Draft WIR Evaluation shows that DOE has removed the bulk of the waste (for example, approximately 96 percent of the waste volume and radionuclide activity for 100 series tanks), using a systematic progression of technologies which were deployed to the limit of technology. Based on the prior flushing of the transfer components (diversion boxes and pipelines) and the waste retrieval plans for the C-301 Catch Tank and the 244-CR Process Vault, waste and key radionuclides also have been or will be removed from the ancillary structures to the maximum extent technically practical. The analyses further shows that it would not be economically practical to attempt to remove additional waste and key radionuclides in light of the negligible potential reduction in future doses, a significant increase in worker exposure (an estimated 13.8 person rem), financial costs (an estimated $148,500,000), and other considerations.

Consistent with the second criterion in DOE M 435.1-1, the stabilized tanks, ancillary structures and residuals at closure of WMA C will meet safety requirements comparable to the performance objectives for land disposal of LLW in 10 CFR Part 61, Subpart C.. Those performance objectives are discussed below and address: protection of the general population from radioactivity releases; protection of individuals from inadvertent intrusion on the disposal site; protection of workers and the public during disposal facility operations; and the stability of the disposal site after closure.

WMA C PA results show that there is reasonable expectation that the annual peak doses for a future hypothetical member of the public will remain well below 25 mrem, in compliance with safety requirements comparable to the performance objective at 10 CFR 61.41. The WMA C PA (deterministic base case) projects a peak, all-pathways annual dose to a future member of the public of 2×10^{-3} mrem during the compliance period (1,000 years after WMA C closure) and, for additional information, 0.10 mrem during the sensitivity time period (10,000 years after WMA C closure), both of which are significantly below the dose of 25 mrem per year specified in the performance objective at 10 CFR 61.41 and DOE M 435.1-1. In addition, doses will be maintained ALARA through a number of measures which serve to minimize migration of radionuclides and public exposure, including an engineered surface barrier and grouting (stabilization) of the tanks and applicable ancillary structures.

Regarding compliance with safety requirements comparable to the performance objective at 10 CFR 61.42, this Draft WIR Evaluation shows, based on analyses in the WMA C PA, that the projected dose for an inadvertent intruder is 36 mrem/yr (acute) and 8.2 mrem/yr (chronic) during the 1,000-year, post-closure compliance period, and for additional information, 8.2 mrem/yr (acute) and 0.07/yr (chronic) during the 10,000-year, post closure sensitivity period. Therefore, there is reasonable expectation that the DOE M 435.1-1 performance measures (100 mrem in a year and 500 mrem total effective dose equivalent excluding radon in air, for chronic and acute exposure scenarios respectively), and the 10 CFR 61.42 performance objective (500 mrem/yr) will not be exceeded during both the 1,000-year and 10,000-year periods after WMA C closure.

DOE also has programs in place to ensure compliance with safety requirements comparable to the performance objective at 10 CFR 61.43, for protection of workers and the public during facility operations. As discussed in this Draft WIR Evaluation, DOE requirements include enforceable regulations and Order provisions for occupational radiological protection of workers and for radiological protection of the public and the environment during operations.

This Draft WIR Evaluation further assesses and documents that WMA C will meet safety requirements comparable to the performance objective at 10 CFR 61.44, concerning long-term site stability at closure. Site conditions and characteristics – including demography, geography, meteorology, climatology, ecology, geology, seismology and hydrogeology – do not present hazards that impact WMA C stability. In addition, WMA C closure methods will result in facility closure that minimizes long-term, active maintenance.

Regarding the third criterion in DOE M 435.1-1 concerning incorporation of the waste into a solid form that does not exceed concentration limits for Class C LLW, this Draft WIR Evaluation demonstrates that the stabilized (grouted) tanks, ancillary structures and residuals will have been incorporated into a solid physical form at closure of the WMA C. In keeping with the third criterion in DOE M 435.1-1, this Draft WIR Evaluation also shows that the waste will be well below (by more than an order of magnitude) the concentration limits for Class C LLW set forth in 10 CFR 61.55.

In sum, this Draft WIR Evaluation demonstrates that the stabilized residuals, waste tanks, and ancillary structures (including integral equipment) at the time of WMA C closure will meet DOE M 435.1-1 criteria, are incidental to the reprocessing of SNF, are not HLW, and may be

managed as LLW. DOE is consulting with the NRC and issuing this Draft WIR Evaluation for comments by States, Tribal Nations and the public. Following review by the NRC and consideration of comments from States, Tribal Nations and the public, DOE plans to prepare a final WIR Evaluation. Based on the final WIR Evaluation, DOE may, in the future, determine (in a WIR Determination) that the stabilized tanks, ancillary structures (including integral equipment), and residuals within WMA C at closure meet M 435.1-1 criteria, are not HLW and may be managed (disposed of in place) as LLW.

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8.0 REFERENCES

04-TPD-025, 2004, "Completion of Hanford Federal Facility Agreement and Consent Order (HFFACO) Target Date M-45-05L-T01 and Partial Completion of Target Date M-45-05M-T01," dated 2/27/04, (letter from R. J. Schepens, Office of River Protection, U.S. Department of Energy to M. A. Wilson, Nuclear Waste Program, Washington State Department of Ecology) Office of River Protection, U.S. Department of Energy, Richland, Washington.

04-TPD-059, 2004, "Stage II Retrieval Data Report for Single-Shell Tank 241-C-106" and, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106" dated 6/3/04 (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology) Office of River Protection, U.S. Department of Energy, Richland, Washington.

10 CFR 20, "Standards for Protection Against Radiation," Code of Federal Regulations, as amended.

10 CFR 20, "Standards for Protection Against Radiation," Subpart A—General Provisions, § 20.1003, Definitions, Code of Federal Regulations, as amended.

10 CFR 20, "Standards for Protection Against Radiation," Subpart B—Radiation Protection Programs, § 20.1101, Radiation protection programs, Code of Federal Regulations, as amended.

10 CFR 20, "Standards for Protection Against Radiation," Subpart C—Occupational Dose Limits, § 20.1201, Occupational dose limits for adults, Code of Federal Regulations, as amended.

10 CFR 20, "Standards for Protection Against Radiation," Subpart C—Occupational Dose Limits, § 20.1208, Dose equivalent to an embryo/fetus, Code of Federal Regulations, as amended.

10 CFR 20, "Standards for Protection Against Radiation," Subpart D—Radiation Dose Limits for Individual Members of the Public, § 20.1301, Dose limits for individual members of the public, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives § 61.40, General requirement, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives, § 61.41, Protection of the general population from releases of radioactivity, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives, § 61.42, Protection of individuals from inadvertent intrusion, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives § 61.43, Protection of individuals during operations, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C—Performance Objectives § 61.44, Stability of the disposal site after closure, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.52, Land disposal facility operation and disposal site closure, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, Waste classification, Code of Federal Regulations, as amended.

10 CFR 820, "Procedural Rules for DOE Nuclear Activities," Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart A—General Provisions, § 835.2, Definitions, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart B—Management and Administrative Requirements, § 835.101, Radiation protection programs, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart C—Standards for Internal and External Exposure, § 835.202, Occupational dose limits for general employees, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart C—Standards for Internal and External Exposure, § 835.206, Limits for the embryo/fetus, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart C—Standards for Internal and External Exposure, § 835.208, Limits for members of the public entering a controlled area, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart G—Posting and Labeling, § 835.602, Controlled areas, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart G—Posting and Labeling, § 835.603, Radiological areas and radioactive material areas, Code of Federal Regulations, as amended.

10 CFR 835, Occupational Radiation Protection, U.S. Department of Energy, Washington D.C., May 13, 2011.

10 CFR 835, "Occupational Radiation Protection," Subpart K—Design and Control, Code of Federal Regulations, as amended.

10 CFR 835, "Occupational Radiation Protection," Subpart K—Design and Control, § 835.1002, Facility design and modifications, Code of Federal Regulations, as amended.

12-NWP-178, 2012, "Re: Department of Ecology Response to the United States Department of Energy's Letter 12-TF-0037, dated September 4, 2012, and *Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108*, RPP-52290, Rev. 1," (letter from J. A. Hedges to T. Fletcher, Office of River Protection, U.S. Department of Energy, November 16), Nuclear Waste Program, State of Washington Department of Ecology, Richland, Washington.

13-TF-0025, 2013, "The U.S. Department of Energy, Office of River Protection (ORP) Submits the Retrieval Completion Certification and Report for Tank 241-C-108" (letter from T. W. Fletcher, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, May 1), Office of River Protection, U.S. Department of Energy, Richland, Washington.

13-TF-0037, 2013, "The U.S. Department of Energy (DOE), Office of River Protection (ORP) Submits the Retrieval Completion and Report for Tank 241-C-109" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, June 4), Office of River Protection, U.S. Department of Energy, Richland, Washington.

13-TF-0120, 2013, "Submittal of Retrieval Data Report for Single-Shell Tank 241-C-108" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, November 27) Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-NWP-164, 2014, “Re: Response to U.S. Department of Energy’s Letter 14-TF-0012, dated February 18, 2014, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology for Tank 241-C-101"” (letter from J. A. Hedges to K. W. Smith, Office of River Protection, U.S. Department of Energy, August 20) Nuclear Waste Program, State of Washington Department of Ecology, Richland, Washington.

14-NWP-210, 2014, “Re: Response to United States Department of Energy Letter 14-TF-0087, dated August 4, 2014, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-112"” (letter from J. A. Hedges to K. W. Smith , Office of River Protection, U.S. Department of Energy, September 29), Nuclear Waste Program, State of Washington Department of Ecology, Richland, Washington.

14-TF-0007, 2014, “The U.S. Department of Energy, Office of River Protection Submits the Retrieval Completion Certification and Report for Tank 241-C-110” (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, January 29), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0012, 2014, “Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-101” (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, February 18), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0013, 2014, “The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-104” (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, February 18), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0020, 2014“The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-109” (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, March 13), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0086, 2014, “The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-110” (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, August 6), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0087, 2014, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-112" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Ecology Nuclear Waste Program, Washington State Department of Ecology, August 4), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0113, 2014, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Completion Certification and Report for Tank 241-C-101" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Ecology Nuclear Waste Program, Washington State Department of Ecology, September 24), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0114, 2014, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Completion Certification and Report for Tank 241-C-107" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy J. A. Hedges Ecology Nuclear Waste Program, Washington State Department of Ecology, September 30), Office of River Protection, U.S. Department of Energy, Richland, Washington.

14-TF-0115, 2014, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Completion Certification and Report for Tank 241-C-112" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Ecology Nuclear Waste Program, Washington State Department of Ecology, September 30), Office of River Protection, U.S. Department of Energy, Richland, Washington.

15-NWP-177, 2015, "Re: Response to U.S. Department of Energy Letter 15-TF-0073, dated August 10, 2015, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-102"" (letter from J. A. Hedges, Nuclear Waste Program to K. W. Smith, Office of River Protection, U.S. Department of Energy, October 2), State of Washington Department of Ecology, Richland, Washington.

15-TF-0018, 2015, "Transmittal for Approval of the Federal Agreement and Consent Order Change Control Form M-45-15-02 to Modify Milestone M-45-62 Due Date" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Ecology Nuclear Waste Program, Washington State Department of Ecology, March 31), Office of River Protection, U.S. Department of Energy, Richland, Washington.

15-TF-0073, 2015, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-102" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, August 10), Office of River Protection, U.S. Department of Energy, Richland, Washington.

15-TF-0086, 2015, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-107" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, September 14), Office of River Protection, U.S. Department of Energy, Richland, Washington.

15-TF-0098, 2015, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-112" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, September 30), Office of River Protection, U.S. Department of Energy, Richland, Washington.

15-TF-0099, 2015, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-101" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, September 24), Office of River Protection, U.S. Department of Energy, Richland, Washington.

15-TF-0116, 2015, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Completion Certification Report for 241-C-102" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, November 30), Office of River Protection, U.S. Department of Energy, Richland, Washington.

16-TF-0090, 2016, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Completion Certification Report for 241-C-111" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to A. K. Smith, Nuclear Waste Program, Washington State Department of Ecology, August 29), Office of River Protection, U.S. Department of Energy, Richland, Washington.

16-TF-0115, 2016, "The U.S. Department of Energy, Office of River Protection Submits the Retrieval Data Report for Tank 241-C-102" (letter from K. W. Smith, Office of River Protection, U.S. Department of Energy to J. A. Hedges, Nuclear Waste Program, Washington State Department of Ecology, September 24), Office of River Protection, U.S. Department of Energy, Richland, Washington.

40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," Subpart H—National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities, § 61.92 Standard, Code of Federal Regulations, as amended.

48 CFR 970, "DOE Management and Operating Contracts," Code of Federal Regulations, as amended.

64 FR 61615, 1999, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)," Federal Register, Vol. 64, pp. 61615–61625 (November 12).

65 FR 37253, 2000, "Establishment of the Hanford Reach National Monument," Federal Register, Vol. 65, pp. 37253–37257 (June 13).

78 FR 75913, 2013, "Record of Decision: Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington," Federal Register, Vol. 78, pp. 75913–75919 (December 13).

0075083, 2008, "Re: Department of Ecology Letter of Completion for Retrieval Data Reports (RDR) for Single-Shell Tanks (SST) 241-C-103, 241-C-201, 241-C-202, 241-C-203, and 241-C-204" (letter from J. J. Lyon, Nuclear Waste Program to S. J. Olinger, Office of River Protection, U.S. Department of Energy, January 7), State of Washington Department of Ecology, Richland, Washington.

1227037, 2014, "Re: Response to United States Department of Energy Letter 14-TF-0087, dated August 4, 2014, "Request for Washington State Department of Ecology Agreement that the U.S. Department of Energy, Office of River Protection may Forego Implementing a Third Retrieval Technology in Tank 241-C-112"" (letter from J. A. Hedges, Nuclear Waste Program to K. W. Smith, Office of River Protection, U.S. Department of Energy, September 29), State of Washington Department of Ecology, Richland, Washington.

ASTM A283/A283M-03, 2005, "Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates," ASTM International, West Conshohocken, Pennsylvania.

ASME 2004, T.S. LaGuardia, et al., *The Decommissioning Handbook*, The American Society of Mechanical Engineers, New York, NY.

Atomic Energy Act of 1954, 42 USC 2011, et seq., as amended.

BHI-01103, 1999, "Clastic Injection Dikes of the Pasco Basin and Vicinity – Geologic Atlas Series," Rev. 0, Bechtel Hanford Inc., Richland, Washington.

BNWL-1709, 1973, "Collection and Analysis of Pump Test Data for Transmissivity Values," Pacific Northwest Laboratories, Richland, Washington.

BNWL-B-360, 1974, "Selected Water Table Contour Maps and Well Hydrographs for the Hanford Reservation, 1944-1973," Pacific Northwest Laboratory, Richland, Washington.

BPF-73550, 1944, "Specifications For Construction of Composite Storage Tanks Bldg. No. 241 Hanford Engineer Works Project 9536," Rev. 2, Richland, Washington.

Cambridge 2004, *Cambridge Dictionary of American English*, Cambridge University Press, 2004 (http:// dictionary.cambridge.org/define.asp?key=practical*2+0&dict=A).

Consent Decree, "State of Washington v. Department of Energy," Case No. CV-08-5085-RMP, United States District Court, Eastern District of Washington (October 25, 2010), as amended by Amended Consent Decree (March 11, 2016), and the Second Amended Consent Decree (April 12, 2016).

DOE/EIS-0222-F, 1999, "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement," U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/EIS-0310, 2000, "Final Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility," U.S. Department of Energy, Office of Nuclear Energy, Science and Technology, Washington, D.C.

DOE/EIS-0391, 2012, "Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington," U.S. Department of Energy, Washington, D.C.

DOE G 435.1-1, 1999, Implementation Guide for Use with DOE M 435.1-1, *Radioactive Waste Management Manual*, U.S. Department of Energy, Washington, D.C.

DOE/NE-ID-11226, 2006, "Basis for Section 3116 Determination for the Idaho Nuclear Technology and Engineering Center Tank Farm Facility," Rev. 0, Idaho National Laboratory, Idaho.

DOE M 435.1-1, 2007, *Radioactive Waste Management Manual*, U.S. Department of Energy, Washington, D.C.

DOE O 435.1, 2001, *Radioactive Waste Management*, U.S. Department of Energy, Washington, D.C.

DOE O 440.1B, 2013, *Worker Protection Program for DOE (Including the National Nuclear Security Administration) Federal Employees*, U.S. Department of Energy, Washington, D.C.

DOE O 458.1, 2013, *Radiation Protection of the Public and the Environment*, U.S. Department of Energy, Office of Health, Safety and Security, Washington, D.C.

DOE/ORP-2003-02, 2003, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA: Inventory and Source Term Data Package*, Rev. 0, U.S. Department of Energy, Office of River Protection, Richland, Washington.

DOE/ORP-2008-01, 2010, *RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas*, Rev. 1, U.S. Department of Energy, Office of River Protection, Richland, Washington.

DOE/RL-92-04, 1993, *PUREX Source Aggregate Area Management Study Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-93-33, 1996, *Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Area*, Rev 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-11, 1999, *200-BP-1 Prototype Barrier Treatability Test Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-39, 2002, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2009-10, 2013, *Hanford Site Cleanup Completion Framework*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2009-85, 2012, *Remedial Investigation Report for the 200-PO-1 Groundwater Operable Unit*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2011-119, 2012, *Hanford Site Environmental Report for Calendar Year 2011*, Rev. 0, U.S. Department of Energy Richland Operations Office, Richland, Washington.

DOE/RL-2013-18, 2013, *Hanford Site Environmental Report for Calendar Year 2012*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2013-22, 2013, *Hanford Site Groundwater Monitoring Report for 2012*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

DOE/RL-2013-47, 2013, *Hanford Site Environmental Report for Calendar Year 2013*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2014-32, 2014, *Hanford Site Groundwater Monitoring Report for 2013*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RW-0070, 1986, *Nuclear Waste Policy Act (Section 112), Environmental Assessment, Reference Repository Location*, Hanford Site, Washington, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE/RW-0164, 1988, *Consultation Draft Site Characterization Plan Reference Repository Location, Hanford Site*, Washington, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE-STD-1196-2011, 2011, *Derived Concentration Technical Standard*, U.S. Department of Energy, Washington, D.C.

Ecology, EPA, and DOE, 1989, *Hanford Federal Facility Agreement and Consent Order – Tri-Party Agreement*, 2 vols., as amended, State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

EPA-402-R-93-081, 1993, *Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil, Office of Radiation and Indoor Air*, U.S. Environmental Protection Agency, Washington, D.C.

EPA/540/F-95/041, 1996, *Soil Screening Guidance: Fact Sheet*, Publication 9355.4-14FSA, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

ERDA-1538, 1975, "Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington," U.S. Energy Research and Development Administration, Richland, Washington.

Fitzsimmons, T., 1999, "Completion of Hanford Federal Facility Agreement and Consent Order Interim Milestone M-45-03B" (Letter to K. A. Klein, Manager, DOE-RL, and R. T. French, ORP, December 21), Washington State Department of Ecology, Olympia, Washington.

Fowler 1930, *A Dictionary of Modern English Usage*. Fowler, H., 1930.

Gelhar, L. W., 1993, Stochastic Subsurface Hydrology, Prentice Hall, New York, New York.

Gelhar, L. W. and C. L. Axness, 1983, "Three-dimensional stochastic analysis of macrodispersion in aquifers," Water Resources Research, Vol. 19, pp. 161–180.

Gelhar, L. W., C. Welty, and K. R. Rehfeldt, 1992, "A Critical Review of Data on Field-Scale Dispersion in Aquifers," Water Resources Research, Vol. 28, pp. 1955–1974.

HFSUWG, 1992, "The Future for Hanford: Uses and Cleanup, Summary of the Final Report of the Hanford Future Site Uses Working Group," Hanford Future Site Uses Working Group, Westinghouse Hanford Company, Richland, Washington.

HNF-2358, 2002, "Single-Shell Tank Interim Stabilization Project Plan," Rev 5, CH2M HILL Hanford Group Inc., Richland, Washington.

HNF-3273, 1998, "Hanford Defined Waste Model Limitations and Improvements," Rev. 0A, Cogema/Lockheed Martin Hanford Corporation, Richland, Washington.

HNF-4769, 1999, "Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste Performance Assessment," Rev. 1, Fluor Daniel Northwest, Inc., Richland, Washington.

HNF-5183, 2016, "Tank Farm Radiological Control Manual," Rev. 5L, Washington River Protection Solutions, LLC, Richland, Washington.

HNF-5267, 1999, "Waste Retrieval Sluicing System Campaign Number 3 Solids Volume Transferred Calculation," Rev. 2, Lockheed Martin Hanford Corporation, Richland, Washington.

HNF-EP-0182-126, 1998, "Waste Tank Summary Report for Month Ending September 30, 1998," Lockheed Martin Hanford Corporation, Richland, Washington.

HNF-EP-0182, 2014, "Waste Tank Summary Report for Month Ending September 30, 2013," Rev. 306, Washington River Protection Solutions, LLC, Richland, Washington.

HNF-SD-RE-TI-178, 2007, "Single-Shell Tank Interim Stabilization Record," Rev. 9a, CH2M HILL Hanford Group, Inc., Richland, Washington.

HNF-SD-WM-TI-707, 2007, "Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment," Rev. 5, CH2M HILL Hanford Group, Inc., Richland, Washington.

HNF-SD-WM-TI-740, 1999, "Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes," Rev. 0C, Lockheed Martin Hanford Corporation, Richland, Washington.

ICRP, 1996, "ICRP Publication 72: Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients," Annals of the ICRP, International Commission on Radiation Protection, Vol. 26, No. 1.

ICRP, 2006, "ICRP Publication 101a: Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public," Annals of the ICRP, International Commission on Radiation Protection, Vol. 36, No. 3.

ICRP, 2007, "ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection," Annals of the ICRP, International Commission on Radiation Protection, Vol. 37, No. 2-4, pp. 1–332.

ICRP, 2008, "ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations," Annals of the ICRP, International Commission on Radiation Protection, Vol. 38, No. 3, pp. 7–96.

Interagency Steering Committee on Radiation Standards Final Report, 2002, "A Method for Estimating Radiation Risk from Total Effective Dose Equivalent (TEDE)", ISCORS Technical Report 2002-02

Jannik, T., 2014, "Environmental Dosimetry," Savannah River Chapter of Health Physics Society Seminar, Savannah River National Laboratory, Aiken, South Carolina.

Khaleel, R., J. F. Relyea, and J. L. Conca, 1995, "Evaluation of van Genuchten-Mualem Relationships to Estimate Unsaturated Hydraulic Conductivity at Low Water Contents," Water Resources Research, Vol. 31, Issue 11, pp. 2659–2668.

Khaleel, R. and J. F. Relyea, 1997, "Correcting Laboratory-Measured Moisture Retention Data for Gravels," Water Resources Research, Vol. 33, Issue 8, pp. 1875–1878.

Khaleel, R. and P. R. Heller, 2003, "On the Hydraulic Properties of Coarse-Textured Sediments at Intermediate Water Contents," Water Resources Research, Vol. 39, Issue 9, pp. 1233–1237.

Klute, A., 1986, *Methods of Soil Analysis, Part 1—Physical and Mineralogical Methods*, Second Edition, American Society of Agronomy-Soil Science Society of America, Madison, Wisconsin.

LAB-RPT-10-00001, 2010, "Results of Physicochemical Characterization and Caustic Dissolution Tests on Tank 241-C-108 Heel Solids," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

National Council on Radiation Protection NCRP, 2009, "Ionizing Radiation Exposure of the Population of the United States," NCRP Report 160.

Newcomb, R. C., J. R. Strand, and F. J. Frank, 1972, "Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington," Professional Paper 717, U.S. Geological Survey, Washington, D.C.

Northern California Earthquake Data Center, Queried 09/2005, [Advanced National Seismic System (ANSS) Catalog Search], http://www.quake.geo.berkeley.edu/anss/catalog-search.html.

Nuclear Waste Policy Act of 1982, 42 USC 10101, et seq.

NRC 2002, *Decommissioning Criteria for the West Valley Demonstration Project (M-32) at the West Valley Site; Final Policy Statement*. U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Vol. 67, No. 5003, February 1, 2002.

NRC 2007, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations*, NUREG-1854. Draft Final Report, U.S. Nuclear Regulatory Commission, Washington, D.C., August 2007.

NUREG-0945, 1982, Final Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste," U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

NUREG-1854, 2007, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use*, U.S. Nuclear Regulatory Commission, Office of Federal and State Materials and Environmental Management Programs, Washington, D.C.

Open File Report 87-222, 1987, "Subsurface Transport of Radionuclides in Shallow Deposits of the Hanford Nuclear Reservation, Washington – Review of Selected Previous Work and Suggestions for Further Study," U.S. Geological Survey, Tacoma, Washington.

PNL-6328, 1988, "Estimation of Ground-Water Travel Time at the Hanford Site: Description, Past Work, and Future Needs," Pacific Northwest Laboratory, Richland, Washington.

PNL-6464, 1988, "Environmental Monitoring at Hanford for 1987," Pacific Northwest Laboratory, Richland, Washington.

PNL-6956, 1989, "Earthquake Recurrence Rate Estimates for Eastern Washington and the Hanford Site," CONF-8910192--18, in Proceedings, Second DOE Natural Phenomena Hazards Mitigation Conference, Knoxville, Tennessee.

PNL-7297, 1990, "Hanford Waste-Form Release and Sediment Interaction – A Status Report with Rationale and Recommendations for Additional Studies," Pacific Northwest Laboratory, Richland, Washington.

PNL-8337, 1992, "Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System," Pacific Northwest Laboratory, Richland, Washington.

PNL-8478, 1993, "Soil Erosion Rates Caused by Wind and Saltating Sand Stresses in Wind Tunnel," Pacific Northwest Laboratory, Richland, Washington.

PNL-8889, 1993, "Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions, Volume 1: Batch Leach and Adsorption Tests and Sediment Characterization," Pacific Northwest Laboratory, Richland, Washington.

PNL-10835, 1995, "Comparison of Constant-Rate Pumping Test and Slug Interference Test Results at the Hanford Site B Pond Multilevel Test Facility," Pacific Northwest Laboratory, Richland, Washington.

PNNL-6415, 2005, "Hanford Site National Environmental Policy Act (NEPA) Characterization," Rev. 17, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-6415, 2007, "Hanford Site National Environmental Policy Act (NEPA) Characterization," Rev. 18, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11485, 1996, "Radionuclide Adsorption Distribution Coefficients Measured in Hanford Sediments for the Low Level Waste Performance Assessment Project," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11800, 1998, "Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11965, 1998, "Effects of Aging Quartz Sand and Hanford Site Sediment with Sodium Hydroxide on Radionuclide Sorption Coefficients and Sediment Physical and Hydrologic Properties: Final Report for Subtask 2a," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12261, 2000, "Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13037, 2000, "Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW PA)," Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13037, 2005, "Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment," Rev. 2, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13080, 2000, "Hanford Site Groundwater Monitoring: Setting, Sources, and Methods," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13342, 2000, "Analysis of the Hydrologic Response Associated with Shutdown and Restart of the 200-ZP-1 Pump-and-Treat System," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13378, 2001, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 1999," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13514, 2001, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2000," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13641, 2001, "Uncertainty Analysis Framework – Hanford Site-Wide Groundwater Flow and Transport Model," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13672, 2002, "A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site," Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13895, 2003, "Hanford Contaminant Distribution Coefficient Database and Users Guide," Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14058, 2002, "Prototype Database and User's Guide of Saturated Zone Hydraulic Properties for the Hanford Site," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14113, 2002, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2001," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14143, 2002, "The Hanford Site 1000-Year Cap Design Test," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14548, 2004, "Hanford Site Groundwater Monitoring for Fiscal Year 2003," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14656, 2004, "Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14702, 2006, "Vadose Zone Hydrogeology Data Package for Hanford Assessments," Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

PNNL-14744, 2004, "Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-14804, 2004, "Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2003," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15222, 2005, "Hanford Site Environmental Report for Calendar Year 2004," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15892, 2006, "Hanford Site Environmental Report for Calendar Year 2005," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15955, 2007, "Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site," Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-16407, 2007, "Geology of the Waste Treatment Plant Seismic Boreholes," Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-16623, 2007, "Hanford Site Environmental Report for Calendar Year 2006," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-17603, 2008, "Hanford Site Environmental Report for Calendar Year 2007," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-18427, 2009, "Hanford Site Environmental Report for Calendar Year 2008," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-18845, 2011, "200-BP-1 Prototype Hanford Barrier – 15 Years of Performance Monitoring," Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-18934, 2009, "The Effects of Fire on the Function of the 200-BP-1 Engineered Surface Barrier," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-19455, 2010, "Hanford Site Environmental Report for Calendar Year 2009," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-20302, 2011, "First Quarter Hanford Seismic Report for Fiscal Year 2011," Pacific Northwest National Laboratory, Richland, Washington.

PNNL-20548, 2011, "Hanford Site Environmental Report for Calendar Year 2010 (Including Some Early 2011 Information)," Pacific Northwest National Laboratory, Richland, Washington.

Random House 1997, *Random House Unabridged Dictionary,* Random House, Inc. (http://www.infoplease.com/dictionary.html, Web page visited March 15, 2005).

RCW 70.105, "Hazardous Waste Management," Revised Code of Washington, as amended.

Reidel, S. P., N. P. Campbell, K. R. Fecht, and K. A. Lindsey, 1994, "Late Cenozoic Structure and Stratigraphy of South-Central Washington," Regional Geology of Washington State, Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources, Bulletin 80, pp. 159–180.

Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq.

RHO-BWI-C-120/PNL-4219, 1981, "Flood Risk Analysis of Cold Creek near the Hanford Site," prepared by Pacific Northwest Laboratory for Rockwell Hanford Operations, Richland, Washington.

Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Public Law 108-375.

RPP-12547, 2003, "Tank 241-C-106 Residual Liquids and Solids Volume Calculation," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-13033, 2014, "Tank Farms Documented Safety Analysis," Rev. 5-C, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-15408, 2003, "Origin of Wastes in C-200 Series Single-Shell Tanks," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-16525, 2005, "C-200-Series Tanks Retrieval Functions and Requirements," Rev. 6A, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-16945, 2006, "Process Control Plan for the 241-C-200 series Waste Retrieval System," Rev. 8, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-17158, 2003, "Laboratory Testing of Oxalic Acid Dissolution of Tank 241-C-106 Sludge," Rev. 0, Fluor Hanford, Inc., Richland, Washington.

RPP-18744, 2004, "Results of Testing and Error Determination of the CCMS for Tank Volume Measurements," Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-19822, 2005, "Hanford Defined Waste Model – Revision 5.0," Rev. 0-A, CH2M HILL Hanford Group, Inc./Technical Resources International, Inc., Richland, Washington.

RPP-19919, 2004, "Campaign Report for the Retrieval of Water Heel from Tanks 241-C-106," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-20110, 2004, "Stage I Retrieval Data Report for Single-Shell Tank 241-C-106," Rev. 2, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-20577, 2007, "Stage II Retrieval Data Report for Single-Shell Tank 241-C-106," Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-20658, 2008, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106," Rev. 3, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-21895, 2012, "241-C-103 and 241-C-109 Tanks Waste Retrieval Work Plan," Rev. 5, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-22393, 2013, "241-C-102, 241-C-104, 241-C-107, 241-C-108 and 241-C-112 Tanks Waste Retrieval Work Plan," Rev. 7, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-22520, 2014, "241-C-101 and 241-C-105 Tanks Waste Retrieval Work Plan, Rev. 8," Washington River Protection Solutions, LLC, Richland, Washington.

RPP-23403, 2013, "Single-Shell Tank Component Closure Data Quality Objectives," Rev. 6, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-31159, 2006, "Post-Retrieval Waste Volume Determination for Single-Shell Tank 241-C-103," Rev. 0, Freestone Environmental Services, Inc./CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-33116, 2014, "241-C-110 Tank Waste Retrieval Work Plan," Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-37739, 2013, 241-C-111 Tank Waste Retrieval Work Plan, Rev. 2, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-50910, 2011, "Single-Shell Tank Waste Retrieval Limit of Technology Definition for Modified Sluicing," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-52290, 2012, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-53823, 2013, "Retrieval Completion Certification Report for Tank 241-C-104," Rev. 2A, Washington River Protection Solutions, LLC, Richland, Washington

RPP-53824, 2013, "Retrieval Completion Certification Report for Tank 241-C-109," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-53869, 2013, "Retrieval Completion Certificate Report for 241-C-108," Rev 2, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-55849, 2014, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-101," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-56214, 2014, "Retrieval Completion Certification Report for Tank 241-C-110," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-56935, 2014, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-112," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-57570, 2014, "Retrieval Completion Certificate Report for 241-C-101," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-33487, 2007, "Estimate of Waste Volume and Percent Retrieved for Tank 241-C-108," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-CALC-34573, 2007, "Estimate of Waste Volume and Percent Retrieved for Single-Shell Tank 241-C-109," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-CALC-53490, 2012, "Estimated Waste Volume Remaining in Single-Shell Tank 241-C-109 after Hard Heel Retrieval," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-54266, 2013, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-108," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-54284, 2013, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-104," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-54759, 2013, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-109," Rev. 0, Washington River Protection Solutions, LLC/Weirich Consulting Services Inc., Richland, Washington.

RPP-CALC-55938, 2013, "Estimated Waste Volume Remaining in Single-Shell Tank 241-C-110 after Hard Heel Retrieval," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-56399, 2013, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-110," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-56434, 2013, "Post-Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-101," Rev. 0, Washington River Protection Solutions, LLC/ Weirich Consulting Services Inc., Richland, Washington.

RPP-CALC-56856, 2014, "Estimated Waste Volume Remaining in Single Shell Tank 241-C-112 after Hard Heel Retrieval," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-60351, 2015, "Preliminary Estimate of Residual Waste Volume for Single-Shell Tank 241-C-102," Rev. 0, Washington River Protection Solutions, LLC/Weirich Consulting Services Inc., Richland, Washington.

RPP-CALC-60840, 2016, Tank 241-C-111 Waste Retrieval Tracking Volume Calculation, Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-ENV-33418, 2015, "Hanford C-Farm Leak Inventory Assessments Report," Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-ENV-58782, 2016, "Performance Assessment of Waste Management Area C, Hanford Site, Washington," Rev. 0, U.S. Department of Energy, Office of River Protection, Richland, Washington.

RPP-ENV-58813, 2016, "Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-PLAN-40145, 2016, "Single-Shell Tank Waste Retrieval Plan," Rev. 6, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-PLAN-47559, 2012, "Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation," Rev. 1, Washington River Protection Solutions, LLC/Cenibark International, Inc., Richland, Washington.

RPP-PLAN-48868, 2013, "Single-Shell Tank 241-C-110 Hard Heel Retrieval Method Selection," Rev. 2, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-PLAN-51371, 2012, "Process Control Plan for Tank 241-C-109 Waste Heel Retrieval," Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-PLAN-51575, 2012, "Process Control Plan for Tank 241-C-104 Hard Heel Retrieval," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-PLAN-53943, 2013, "Process Control Plan for Tank 241-C-110 Waste Heel Retrieval," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-PLAN-55462, 2013, "Single-Shell Tanks 241-C-111 and 241-C-112 Hard Heel Retrieval Technology Selection," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-26475, 2008, "Retrieval Data Report for Single-Shell Tank 241-C-203," Rev. 1-A, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-29095, 2006, "Retrieval Data Report for Single-Shell Tank 241-C-202," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-30181, 2006, "Retrieval Data Report for Single-Shell Tank 241-C-201," Rev. 0-B, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-33060, 2007, "Retrieval Data Report for Single-Shell Tank 241-C-103," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-34062, 2007, "Retrieval Data Report for Single-Shell Tank 241-C-204," Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-41918, 2010, "Assessment Context for Performance Assessment for Waste in C Tank Farm Facilities after Closure," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-42294, "Hanford Waste Management Area C Soil Contamination Inventory Estimates," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-42323, 2015, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates," Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-44042, 2010, "Recharge and Waste Release within Engineered System in Waste Management Area C," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-44139, 2014, "Nuclear Waste Tank Retrieval Technology Review and Roadmap," Rev. 4, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-45082, 2010, "Implementation Plan for the Single-Shell Tank Integrity Project," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-46088, 2010, "Flow and Transport in the Natural System at Waste Management Area C," Rev. 1, Washington River Protection Solutions, LLC/GSI Water Solutions, Inc., Richland, Washington.

RPP-RPT-46879, 2011, "Corrosion and Structural Degradation within Engineered System in Waste Management Area C," Rev. 2, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-49701, 2011, "Waste Management Area C Closure – Conceptual Design Report," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-49821, 2012, "MARS Vacuum Retrieval System Activity Description," Rev. 2, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-51386, 2012, "Tank 241-C-109 Hard Heel Retrieval Flowsheet," Rev. 1A, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-52449, 2012, "Single-Shell Tank 241-C-108 Hard Heel Retrieval Completion Report," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-52480, 2012, "Retrieval Completion Report for Modified Sluicing of Tank 241-C-112," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-53486, 2012, "Single-Shell Tank 241-C-109 Hard Heel Retrieval Completion Report," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-54072, 2014, "Retrieval Data Report for Single-Shell Tank 241-C-104," Rev. 0, Washington River Protection Solutions, LLC/YAHSGS, LLC, Richland, Washington.

RPP-RPT-55284, 2014, "Retrieval Data Report for Single-Shell Tank 241-C-109," Rev. 0, Washington River Protection Solutions, LLC/YAHSGS, LLC, Richland, Washington.

RPP-RPT-55573, 2013, "Retrieval Completion Report for Modified Sluicing of Tank 241-C-101 Using Extended Reach Sluicing and High-Pressure Water," Rev. 0, Washington River Protection Solutions, LLC/YAHSGS, LLC, Richland, Washington.

RPP-RPT-55896, 2013, "Retrieval Data Report for Single-Shell Tank 241-C-108," Rev. 1, Washington River Protection Solutions, LLC/YAHSGS, LLC, Richland, Washington.

RPP-RPT-56356, 2014, "Development of Alternative Digital Geologic Models of Waste Management Area C," Rev. 0, Freestone Environmental Services Inc./Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-56796, 2014, "Retrieval Data Report for Single-Shell Tank 241-C-110," Rev. 0, Washington River Protection Solutions, LLC, LLC, Richland, Washington.

RPP-RPT-56900, 2014, "Single-Shell Tank 241-C-112 Hard Heel Retrieval Completion Report," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58140, 2014, "Retrieval Completion Certification Report for Tank 241-C-112," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58150, 2014, "Retrieval Completion Certification Report for Tank 241-C-107," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58295, 2015, "Retrieval Data Report for Single-Shell Tank 241-C-107," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58339, 2014, "Phase 2 RCRA Facility Investigation Report for Waste Management Area C," Rev 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58386, 2015, "Retrieval Data Report for Single-Shell Tank 241-C-101," Rev. 2, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58490, 2015, "Retrieval Data Report for Single-Shell Tank 241-C-112," Rev. 2B, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58514, 2015, "Tank 241-C-107 Residual Waste Inventory Estimates for Component Closure Risk Assessment," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58676, 2015, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-102," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58692, 2015, "Tank 241-C-112 Residual Waste Inventory Estimates for Component Closure Risk Assessment," Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-58788, 2015, "Retrieval Completion Certificate Report for 241-C-102" Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-59292, 2016, Single-Shell Tank 241-C-111 Hard Heel Retrieval Completion Report 241-C-111, Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-59363, 2016, "Retrieval Completion Certificate Report for 241-C-111," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-60173, 2017, "Retrieval Data Report for 241-C-111," Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPT-RPP-59631, 2016, "Retrieval Data Report for Single-Shell Tank 241-C-102" Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

SGW-54165, 2014, "Evaluation of the Unconfined Aquifer Hydraulic Gradient Beneath the 200 East Area, Hanford Site," Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-58561, 2015, "WMA C Quarterly October through December 2014 Quarterly Groundwater Monitoring Report," Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SRR-CWDA-2012-00026, 2012, "Cost-Benefit Analysis For Removal of Additional Highly Radioactive Radionuclides From Tank 18 F-Area Tank Farm Savannah River Site" Revision 1, Savannah River

TFC-ENG-CHEM-P-47, "Single-Shell Tank Retrieval Completion Evaluation," Washington River Protection Solutions LLC (WRPS) Tank Farms, Richland, Washington.

TFC-ENG-FACSUP-CD-22, "Post-Retrieval Tank Waste Volume Determination," Washington River Protection Solutions LLC (WRPS) Tank Farms, Richland, Washington.

TFC-ESHQ-RP_ADM-C-26, "Radiological Design Review Process," Washington River Protection Solutions LLC (WRPS) Tank Farms, Richland, Washington.

UCRL-21069, 1988, "Probabilistic Flood Hazard Assessment for the N Reactor, Hanford, Washington," Jack R. Benjamin and Associates, Inc., Mountain View, California.

USACE, 1951, "Artificial Flood Possibilities on the Columbia River," U.S. Army Corps of Engineers, 45 Washington District, Washington, D.C.

USACE, 1989, "Water Control Manual for McNary Lock and Dam, Columbia River, Oregon and Washington," U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

WA7 89000 8967, 2007, "Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion Revision 8C for the Treatment, Storage, and Disposal of Dangerous Waste," State of Washington Department of Ecology, Richland, Washington.

WAC 173-303, "Dangerous Waste Regulations," Washington Administrative Code, as amended.

WCH-520, "Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington," Rev. 1, Washington Closure Hanford, Richland, Washington.

Webster, G. D. and J. W. Crosby, 1982, "Appendix 2R - Stratigraphic Investigation of the Skagit/Hanford Nuclear Project," in Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report, Volume 5, Puget Power, Puget Sound Power and Light Company, Bellevue, Washington.

WHC-EP-0673, 1994, "Permanent Isolation Surface Barrier Development Plan," Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0707, 1994, "216-U-10 Pond and 216-Z-19 Ditch Characterization Studies," Rev. 0 (formerly RHO-ST-45), Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0815, 1995, "Groundwater Impact Assessment Report for the 216-T-4-2 Ditch," Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0883, 1995, "Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site," Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-SA-2448-FP, 1994, "First Generation Long-Reach Manipulator for Retrieval of Waste from Hanford Single-Shell Tanks," Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-012, 1992, "Geologic Setting of the 200 East Area: An Update," Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-014, 1992, "Hydrogeologic Model for the 200 West Groundwater Aggregate Area," Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-019, 1992, "Hydrogeologic Model for the 200 East Groundwater Aggregate Area," Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-ER-TI-003, 1991, "Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports," Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-GN-ER-30009, 1992, "Bibliography and Summary of Geotechnical Studies at the Hanford Site," Rev. 2, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-GN-ER-30038, 2012, "Volcano Ashfall Loads for the Hanford Site," Rev. 2, Washington River Protection Solutions LLC, Richland, Washington.

WHC-SD-W236A-TI-002, 1993, "Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington," Rev. 1A, prepared for Westinghouse Hanford Company by Geomatrix Consultants, Richland, Washington.

Wing, N. R. and G. W. Gee, 1994, "Quest for the Perfect Cap," Civil Engineering, Vol. 64, No. 10, pp. 38–41.

WMP-17524, 2003, "Vadose Zone Hydraulic Property Letter Reports," Rev. 0, Fluor Hanford, Richland, Washington.

WRPS-1603585, "Third Quarter Fiscal Year 2016 Radiological Control Performance Report," Washington River Protection Solutions LLC, Richland, Washington.

WSRC-TR-2003-00401, 2003, "Waste Tank Heel Chemical Cleaning Summary," Westinghouse Savannah River Company, Aiken, South Carolina.

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Appendix A

Consideration of the Criteria in Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005

Appendix Purpose

The purpose of this appendix is to discuss the criteria in Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 with respect to this Draft WIR Evaluation.

Appendix Content

This appendix describes the subject criteria in relation to DOE's plans for closure of Waste Management Area (WMA) C.

Key Points

- Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 does not apply to WMA C.
- However, closure of WMA C would be consistent with the criteria of Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005.

A.1 Introduction

Sections 4 through 6 of this Draft WIR Evaluation demonstrate that the WMA C residuals, waste tanks and ancillary structures at closure meet the criteria of U.S. Department of Energy (DOE) M 435.1-1, *Radioactive Waste Management Manual* for determining that the waste is incidental to reprocessing, is not high-level waste, and may be managed and disposed of as low-level waste (LLW) under DOE's regulatory authority pursuant to the Atomic Energy Act of 1954, as amended. Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 contains similar criteria, and provides that the Secretary of Energy, in consultation with the U.S. Nuclear Regulatory Commission (NRC), may determine that waste resulting from reprocessing of spent nuclear fuel at DOE facilities in South Carolina and Idaho, that is to be disposed of within those States, is not high-level waste where the criteria in Section 3116(a)(1)-(3) are met.[66]

[66] The criteria appear in Subsection (a) of Section 3116. Section 3116(a) provides:

"(a) IN GENERAL.—Notwithstanding the provisions of the Nuclear Waste Policy Act of 1982, the requirements of section 202 of the Energy Reorganization Act of 1974, and other laws that define classes of radioactive waste, with

Although Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 does not apply to the WMA C waste residuals, tanks or ancillary structures,[67] the following discussion addresses the relevant criteria in 3116(a)(1)-(3) for perspective and information, and, because it may be of interest to stakeholders, shows that closure of WMA C at Hanford would be consistent with relevant criteria in Section 3116(a)(1)-(3) of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005.

A.2 Consideration of Whether the Waste Management Area C Residual Wastes Require Permanent Isolation in a Deep Geologic Repository

The first criterion or clause in Section 3116(a), as set forth in Section 3116(a)(1), provides that the waste "does not require permanent isolation in a deep geologic repository for spent fuel or

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respect to material stored at a Department of Energy site at which activities are regulated by a covered State pursuant to approved closure plans or permits issued by the State, the term 'high-level radioactive waste' does not include radioactive waste resulting from the reprocessing of spent nuclear fuel that the Secretary of Energy (in this section referred to as the 'Secretary'), in consultation with the Nuclear Regulatory Commission (in this section referred to as the 'Commission'), determines—

(1) does not require permanent isolation in a deep geologic repository for spent fuel or high-level radioactive waste;

(2) has had highly radioactive radionuclides removed to the maximum extent practical; and

(3)(A) does not exceed concentration limits for Class C low-level waste as set out in Section 61.55 of title 10, Code of Federal Regulations, and will be disposed of—

(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations; and

(ii) pursuant to a State-approved closure plan or State-issued permit, authority for the approval or issuance of which is conferred on the State outside of this section; or

(B) exceeds concentration limits for Class C low-level waste as set out in section 61.55 of title 10, Code of Federal Regulations, but will be disposed of—

(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations;

(ii) pursuant to a State-approved closure plan or State-issued permit, authority for the approval or issuance of which is conferred on the State outside of this section; and

(iii) pursuant to plans developed by the Secretary in consultation with the Commission."

Subsection (b) of Section 3116 addresses monitoring by NRC. Subsection (c) addresses inapplicability to certain materials (i.e., materials transported from the covered State). Subsection (d) identifies the covered States (South Carolina and Idaho.) Subsection (e) addresses certain matters concerning construction of Section 3116, and provides that the section does not establish any precedent in any State other than South Carolina and Idaho. Subsection (f) provides for judicial review of determinations made pursuant to Section 3116 and of any failure by NRC to carry out its monitoring responsibilities.

[67] That Section 3116(a) applies only to waste from reprocessing at DOE facilities in South Carolina and Idaho, which is to be disposed of in those states, is made clear by the language used, which includes the following:

"(c) INAPPLICABILITY TO CERTAIN MATERIALS.—Subsection (a) shall not apply to any material otherwise covered by that subsection that is transported from the covered State.

(d) COVERED STATES.—For purposes of this section, the following States are covered States:

(1) the State of South Carolina.

(2) the State of Idaho."

(e) CONSTRUCTION.—

…

(2) Nothing in this section establishes any precedent or is binding on the State of Washington, the State of Oregon, or any other State not covered by subsection (d) for the management, storage, treatment, and disposition of radioactive and hazardous materials.

high-level radioactive waste." DOE M 435.1-1 does not contain an identical consideration, but similarly provides in relevant part in Chapter II.B.(2)(a) that the waste "will be managed as low-level waste" and meet the criteria in Section II.B.(2)(a).

With respect to the first criterion or clause, as provided in Section 3116(a)(1), the DOE, in consultation with the NRC, has explained:

> "Clause (1), noted above, is a broader criterion for the Secretary, in consultation with the NRC, to consider whether, notwithstanding that waste from reprocessing meets the other two criteria, there are other considerations that, in the Secretary's judgment, require its disposal in a deep geologic repository. Generally, such considerations would be an unusual case because waste that meets the third criterion would be waste that will be disposed of in a manner that meets the 10 CFR 61, Subpart C performance objectives and either falls within one of the classes set out in 10 CFR 61.55 that the NRC has specified are considered "generally acceptable for near-surface disposal" or for which the Secretary has consulted with NRC concerning DOE's disposal plans. As the NRC explained in *In the Matter of Louisiana Energy Services, L.P. (National Enrichment Services)* (CLI-05-05, 2005), the 10 CFR Part 61, Subpart C performance objectives in turn "set forth the ultimate standards and radiation limits for (1) protection of the general population from releases of radioactivity; (2) protection of individuals from inadvertent intrusion; (3) protection of individuals during operations; and (4) stability of the disposal site after closure." It follows that if disposal of a waste stream in a facility that is not a deep geologic repository will meet these objectives, in the ordinary case that waste stream does not "require disposal in a deep geologic repository" because non-repository disposal will be protective of public health and safety.
>
> It is possible that in rare circumstances a waste stream that meets the third criterion might have some other unique radiological characteristic or may raise unique policy considerations that warrant its disposal in a deep geologic repository. Clause (1) is an acknowledgement by Congress of that possibility. For example, the waste stream could contain material that, while not presenting a health and safety danger if disposed of at near- or intermediate-surface, nevertheless presents non-proliferation risks that the Secretary concludes cannot be adequately guarded against absent deep geologic disposal. Clause (1) gives the Secretary, in consultation with NRC, the authority to consider such factors in determining whether waste that meets the other two criteria needs disposal in a deep geologic repository in light of such considerations." [68]

That is not the case here. As demonstrated in Section 4 of this Draft WIR Evaluation, key radionuclides will have been removed from the subject tanks and applicable ancillary structures to the maximum extent technically and economically practical. Moreover, the WMA C waste residuals will be in a solid physical form and will not exceed the concentration limits for Class C LLW in Title 10, Code of Federal Regulations (CFR), Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D—Technical Requirements for Land Disposal

[68] DOE/NE-ID-11226, "Basis for Section 3116 Determination for the Idaho Nuclear Technology and Engineering Center Tank Farm Facility."

Facilities, § 61.55, Waste classification (10 CFR 61.55), as described in Section 6. As explained in Section 5, management and closure of WMA C as LLW at Hanford also would meet safety requirements comparable to the NRC performance objectives in 10 CFR 61, Subpart C—Performance Objectives, so as to provide for the protection of human health and safety and the environment. As such, the management and closure of WMA C as LLW does not present a danger to human health and safety, such that disposal in a deep geologic repository would be warranted. Furthermore, the management and closure of WMA C does not present unique radiological characteristics, or raise non-proliferation risks or other unique policy considerations, which, while not manifesting a danger to human health, nevertheless would command deep geologic disposal. Accordingly, the management and closure of WMA C as LLW at Hanford meets DOE criteria and would be consistent with the first criterion of Section 3116(a).

A.3 Consideration of Removal of Highly Radioactive Radionuclides

The second criterion of Section 3116(a) specifies that the waste "has had highly radioactive radionuclides removed to the maximum extent practical." DOE M 435.1-1, Chapter II.B.(2)(a)1, contains a similar provision, which specifies that such wastes "[h]ave been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical." [69]

Section 4 of this Draft WIR Evaluation identifies key radionuclides for the WMA C waste residuals. As can be seen in this section, all radionuclides in Tables 1 and 2 of 10 CFR 61.55 were considered. Furthermore, Section 4 of this Draft WIR Evaluation describes how key radionuclides have been removed to the maximum extent technically and economically practical, thus satisfying the DOE criterion and evincing consistency with the second criterion of Section 3116(a).

A.4 Consideration of Radionuclide Concentration Limits, Waste Disposal Performance Objectives, and State-approved Closure Plan or State-issued Permit

The third criterion in Section 3116(a)(3) concerns whether the waste meets the concentration limits for Class C LLW in 10 CFR 61.55 and whether the waste will be disposed of in accordance with the performance objectives at 10 CFR 61, Subpart C and the State approved Closure Plan. The criteria in DOE M 435.1-1, Chapter II.B.(2)(a)2 and (a)3 similarly provide that waste "[w]ill be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR Part 61, Subpart C" and "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 61.55", respectively. Section 6 of this Draft WIR Evaluation demonstrates that the WMA C waste residuals, stabilized tanks, and ancillary structures do not exceed the Class C concentration limits in 10 CFR 61.55.

[69] In this regard, NRC staff considers key radionuclides and highly-radioactive radionuclides – which are those radionuclides that contribute most significantly to risk to the public, workers, and the environment – to be equivalent for the purpose of evaluating waste determinations (NUREG-1854, NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use).

The HFFACO recognizes the applicability of RCRA and its amendments to the Hanford Site. It incorporates a regulatory strategy that specifically places SST activities, including waste retrieval, facility cleanup, remediation, waste disposal, and closure under the Hazardous Waste Management Act.

Appendix I of the HFFACO Action Plan also establishes a process for closing individual components and the WMAs as contributory actions toward closing the SST system. That process involves a three-tiered structure of documentation to integrate the various closure actions within a WMA into the Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion for the Treatment, Storage, and Disposal of Dangerous Waste (WA 7890008967, Site-Wide Hanford Facility RCRA Permit). The documents include the following:

- RCRA Tier 1 – Framework (SST system-wide) closure plan
- RCRA Tier 2 – WMA closure action plans
- RCRA Tier 3 – Component closure activity plans.

Based on these closure plans, DOE anticipates that the state will issue a revised permit, which would meet the NDAA Section 3116 criteria, if those criteria were applicable here.

A.5 Consultation with U.S. Nuclear Regulatory Commission

Section 3116(a) also provides for consultation with the NRC. As explained previously, DOE is consulting with NRC concerning this Draft WIR Evaluation, as well as making this draft evaluation available for State, Tribal Nation and public comment. DOE will consider NRC comments, as well as comments from the public and other stakeholders, before finalizing the evaluation and before making any final determination as to whether the WMA C waste residuals, tanks and ancillary structures are or are not high-level waste. Accordingly, such consultation is consistent with the provision for NRC consultation in Section 3116 (a) of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005.

A.6 References

Federal Statutes

Atomic Energy Act of 1954, 42 USC 2011, et seq., as amended.

Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Public Law 108-375.

Code of Federal Regulations

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart C – Performance Objectives, Code of Federal Regulations, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Subpart D – Technical Requirements for Land Disposal Facilities, § 61.55, "Waste Classification," Code of Federal Regulations, as amended.

DOE Manuals

DOE M 435.1-1, 2007, *Radioactive Waste Management Manual*, Change 1, U.S. Department of Energy, Washington, D.C.

Other References

CLI-05-05, 2005, In the Matter of Louisiana Energy Services, L.P. (National Enrichment Services), Docket No. 70-3103-ML, U.S. Nuclear Regulatory Commission, Washington, D.C. (January 18, 2005).

DOE/NE-ID-11226, 2006, "Basis for Section 3116 Determination for the Idaho Nuclear Technology and Engineering Center Tank Farm Facility," Rev. 0, Idaho National Laboratory, Idaho.

NUREG-1854, 2007, NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use, U.S. Nuclear Regulatory Commission, Washington, D.C.

Appendix B

Comparability of DOE and NRC Requirements for LLW Disposal

Appendix Purpose

The purpose of this appendix is to show that Department of Energy and Nuclear Regulatory Commission requirements for disposal of low-level waste are comparable.

Appendix Content

This appendix identifies applicable DOE performance objectives and the similar NRC performance objectives and discusses their comparability.

Key Points

- Requirements for low-level waste disposal are embodied in sets of performance objectives for the waste disposal facility.
- The DOE performance objectives are described in DOE Manual 435.1-1, *Radioactive Waste Management Manual*.
- The NRC performance objectives are described in Subpart C, *Performance Objectives*, of 10 CFR Part 61, *Licensing Requirements for Land Disposal of Radioactive Waste*.
- DOE and NRC performance objectives for low-level waste disposal are comparable.

B.1 Introduction

This appendix identifies performance objectives for disposal of LLW by the DOE and the NRC. It then compares these performance objectives. Information in this appendix is based in part on previous detailed comparison studies of DOE and NRC performance objectives for LLW disposal (Cole, et al. 1995 and Wilhite 2001).

B.2 Applicable Performance Objectives

DOE Manual 435.1-1, *Radioactive Waste Management Manual*, describes DOE requirements for disposal of LLW. The comparable NRC requirements appear in Subpart C of 10 CFR Part 61, which lists one general requirement and four performance objectives, which are reproduced below.

B.2.1 Section 61.40, General Requirement

"Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in Sections 61.41 through 61.44."

B.2.2 Section 61.41, Protection of the General Population from Releases of Radioactivity

"Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirem to the whole body, 75 millirem to the thyroid, and 25 millirem to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

B.2.3 Section 61.42, Protection of Individuals from Inadvertent Intrusion

"Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

B.2.4 Section 61.43, Protection of Individuals During Operations

"Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Section 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

B.2.5 Section 61.44, Stability of the Disposal Site After Closure

"The disposal facility must be sited, designed, used, operated, and closed to achieve long- term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active

maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

B.3 Comparability of the General Requirements

B.3.1 DOE

The general requirement in DOE Manual 435.1-1, Section IV.P(1), is expressed as follows:

> "Low-level waste disposal facilities shall be sited, designed, operated, maintained, and closed so that a reasonable expectation exists that the following performance objectives will be met for waste disposed of after September 26, 1988."

B.3.2 NRC

The NRC regulations in 10 CFR 61.40 provide in relevant part:

> "Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in Sections 61.41 through 61.44."

B.3.3 Discussion

The statement of NRC requirements in 10 CFR 61.40 is nearly identical to that of the DOE general requirement. The DOE requirement adds the concept of maintenance, which is implicit in the NRC requirement. The DOE requirement does not mention control after closure, but this concept is embodied in the DOE requirements for closure, specifically DOE Manual 435.1, Section IV.Q (2)(c), which requires DOE control until it can be shown that release of the disposal site for unrestricted use will not compromise DOE requirements for radiological protection of the public.

The DOE general requirement for LLW disposal and the NRC general requirement of 10 CFR 61.40 are therefore comparable.

B.4 Comparability Regarding Protection of the General Population from Releases of Radioactivity

B.4.1 DOE

DOE requirements of DOE Manual 435.1-1, Section IV.P(1), read as follows:

> "(a) Dose to representative members of the public shall not exceed 25 millirem in a year total effective dose equivalent from all exposure pathways, excluding the dose from radon and its progeny in air.
>
> (d) Dose to representative members of the public via the air pathway shall not exceed 10 millirem in a year total effective dose equivalent, excluding the dose from radon and its progeny.

(e) Release of radon shall be less than an average flux of 20 pCi/m^2/s at the surface of the disposal facility. Alternatively, a limit of 0.5 pCi/L of air may be applied at the boundary of the facility."

B.4.2 NRC

NRC regulations in 10 CFR 61.41 are expressed as follows:

> "Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirem to the whole body, 75 millirem to the thyroid, and 25 millirem to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

B.4.3 Discussion

DOE uses more current radiation protection methodology, consistent with that used in NRC's radiation protection standards in NRC's 10 CFR Part 20, *Standards for Protection Against Radiation*. Because NRC has not revised 10 CFR 61.41 to reflect the more current methodology in 10 CFR Part 20, DOE's requirements and those in 10 CFR Part 20 differ slightly from those in 10 CFR 61.41. However, the resulting allowable doses are comparable, as NRC has acknowledged (NRC 2005). Both NRC and DOE use a performance assessment to assess whether the dose limit will be met.

The DOE requirements go beyond this NRC performance objective by specifying an assessment of the impacts of LLW disposal on water resources [i.e., DOE Manual 435.1, Section IV.P (2)(g)]. The NRC requirement includes maintaining releases to the environment ALARA. Although this requirement is not included in the DOE performance objective, it is included in the performance assessment requirements [i.e., DOE Manual 435.1-1, Section IV.P (2)(f)].

B.5 Comparability Regarding Protection of Individuals from Inadvertent Intrusion

B.5.1 DOE

DOE requirements of DOE Manual 435.1-1, Section IV.P(2)(h), for protection of individuals from inadvertent intrusion read as follows:

> "For purposes of establishing limits on the concentration of radionuclides that may be disposed of near-surface, the performance assessment shall include an assessment of impacts calculated for a hypothetical person assumed to inadvertently intrude for a temporary period into the low- level waste disposal facility. For intruder analyses, institutional controls shall be assumed to be effective in deterring intrusion for at least 100 years following closure. The intruder analyses shall use performance measures for

chronic and acute exposure scenarios, respectively, of 100 millirem (1 mSv) in a year and 500 millirem (5 mSv) total effective dose equivalent excluding radon in air."

B.5.2 NRC

NRC requirements of 10 CFR 61.42 are expressed as follows:

> "Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

B.5.3 Discussion

The DOE LLW disposal requirement that the performance assessment include an assessment of the impacts on a person inadvertently intruding into the disposal facility is more stringent than the NRC requirement. The NRC waste classification system is based on intruder calculations using a 500 millirem per year dose limit (NRC 1982). The DOE requirement uses a 100 millirem per year limit for chronic exposures and a 500 millirem limit for acute exposures.

The comparability of DOE and NRC provisions for imposing additional requirements is discussed in Section B.9 below.

B.6 Comparability Regarding Protection of Individuals During Operations

B.6.1 DOE

The DOE requirements in DOE Manual 435.1-1, Section I.E(13), for protection of individual during operations read as follows:

> "Radioactive waste management facilities, operations, and activities shall meet the requirements of 10 CFR Part 835, *Occupational Radiation Protection,* and DOE 5400.5, *Radiation Protection of the Public and the Environment* [now DOE Order 458.1]."

B.6.2 NRC

The NRC requirements of 10 CFR 61.43 are expressed as follows:

> "Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Section 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

B.6.3 Discussion

The ALARA concept is an integral part of DOE radiation and environmental protection programs. DOE requirements for occupational radiological protection are addressed in 10 CFR

Part 835, and similar requirements for radiological protection of the public and the environment are addressed in DOE Order 458.1. The NRC 10 CFR 61.43 requirement references 10 CFR Part 20, *Standards for Protection Against Radiation*, which contains similar radiological protection standards for workers and the public.

B.7 Comparability Regarding Stability of the Disposal Site After Closure

B.7.1 DOE

The DOE requirements of DOE Manual 435.1-1, Sections IV.Q(1)(a) and (b) and IV.Q(2)(c), for stability of the disposal site after closure are expressed as follows:

> "Disposal Facility Closure Plans (DOE Manual 435.1, Section IV.Q(1)(a) and (b)). A preliminary closure plan shall be developed and submitted to Headquarters for review with the performance assessment and composite analysis. The closure plan shall be updated following issuance of the disposal authorization statement to incorporate conditions specified in the disposal authorization statement. Closure plans shall:
>
> (a) Be updated as required during the operational life of the facility.
>
> (b) Include a description of how the disposal facility will be closed to achieve long-term stability and minimize the need for active maintenance following closure and to ensure compliance with the requirements of DOE 5400.5, *Radiation Protection of the Public and the Environment* [now DOE Order 458.1]."
>
> "Disposal Facility Closure (DOE Manual 435.1, Section IV.Q(2)(c)). Institutional control measures shall be integrated into land use and stewardship plans and programs, and shall continue until the facility can be released pursuant to DOE Order 5400.5, *Radiation Protection of the Public and the Environment* [now DOE Order 458.1]."

B.7.2 NRC

The NRC requirements of 10 CFR 61.44 state that:

> "The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

B.7.3 Discussion

The DOE LLW disposal requirements address long-term stability of the site by requiring a description of how closure will achieve stability in the closure plan, and by a description of how closure will minimize the need for active maintenance following closure [DOE Manual 435.1, Section IV.Q (1)(b)]. Additionally, one of the performance assessment requirements (DOE Manual 435.1, Section IV.P (2)(c)) states: "Performance assessments shall address reasonably foreseeable natural processes that might disrupt barriers against release and transport of

radioactive materials." Thus, the performance assessment will include a projection of the long-term stability of the site, considering reasonably foreseeable natural processes such as erosion, degradation of waste packages, etc.

B.8 Comparability Regarding Provisions for Imposing Additional Requirements

B.8.1 DOE

Section 4.d of DOE Order 435.1, *Radioactive Waste Management*, states that:

> "DOE, within its authority, may impose such requirements, in addition to those established in this Order, as it deems appropriate and necessary to protect the public, workers, and the environment, or to minimize threats to property."

B.8.2 NRC

NRC provisions for imposing additional requirements on the license for a LLW disposal facility are contained in 10 CFR 61.24(h), which states:

> "(h) The Commission may incorporate in any license at the time of issuance, or thereafter, by appropriate rule, regulation or order, additional requirements and conditions with respect to the licensee's receipt, possession, and disposal of source, special nuclear or byproduct material as it deems appropriate or necessary in order to:
>
> (1) Promote the common defense and security;
>
> (2) Protect health or to minimize danger to life or property;
>
> (3) Require reports and the keeping of records, and to provide for inspections of activities under the license that may be necessary or appropriate to effectuate the purposes of the Act and regulations thereunder."

B.8.3 Discussion

The DOE requirement is broader in scope than the NRC requirements because the DOE requirement applies to all aspects of radioactive waste management while the NRC requirements apply to licenses for LLW disposal facilities. Otherwise, the requirements are comparable.

B.9 References

Code of Federal Regulations

10 CFR Part 20, *Standards for Protection Against Radiation*.

10 CFR Part 61, Subpart C, *Licensing Requirements for Land Disposal of Radioactive Waste, Performance Objectives*.

10 CFR Part 835, *Occupational Radiation Protection*.

DOE Orders, Policies, and Manuals

DOE Order 435.1, *Radioactive Waste Management*

DOE Order 458.1, *Radiation Protection of the Public and the Environment*, Change 2. U.S. Department of Energy, Washington, D.C., June 6, 2011.

DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, Change 2. U.S. Department of Energy, Washington, D.C., January 7, 1993.

DOE Manual 435.1-1, *Radioactive Waste Management Manual*, Change 1. U. S. Department of Energy, Washington, D.C., June 19, 2001.

Other References

Cole, et al. 1995, *Comparison of Selected DOE and Non-DOE Requirements, Standards, and Practices for Low-Level Radioactive Waste Disposal*, DOE/LLW-225, Revision 0. Cole, L., D. Kudera, and W. Newberry, Idaho National Engineering Laboratory, Lockheed Idaho Technologies Company, Idaho Fall, Idaho, December 1995.

NRC 1982, Final Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste," Summary and Main Report, NUREG-0945, Volume 1.

U.S. Nuclear Regulatory Commission, Washington, D.C., November 1982.

NRC 2005, U.S. Nuclear Regulatory Commission Technical Evaluation Report for the U.S. Department of Energy Savannah River Site Draft Section 3116 Waste Determination for Salt Waste Disposal. U.S. Nuclear Regulatory Commission, Washington, D.C., December 2005.

Wilhite 2001, *Comparison of LLW Disposal Performance Objectives, 10 CFR 61 and DOE 435.1*, WSRC-RP-2001-00341. Wilhite, E.L., Westinghouse Savannah River Company, Aiken, South Carolina, 2001.

Appendix C

Economic Evaluation Information for Tanks C-101, C-102, C-103 and C-108

Appendix Purpose

The purpose of this appendix is to provide representative examples of the factors included in the cost/benefit analysis presented in Section 4.4 of this Draft WIR Evaluation.

Appendix Content

This appendix presents excerpts/summary information from the various retrieval completion documents associated with several WMA C 100-series tanks, which were used in determining the end-point of retrieval operations.

Key Points

- Estimated financial costs of deploying additional retrieval technologies are provided.
- Estimated schedule impacts for additional retrieval activities are provided.
- Estimated worker dose values expected from additional retrieval activities are provided.
- The scenarios analyzed in these documents generally assumed that retrieval equipment and infrastructure would remain in place and functional in support of additional technology deployment.

C.1 Tank C-101 Evaluation

The C-101 tank specific documents reviewed include RPP-22520, *241-C-101 and 241-C-105 Tanks Waste Retrieval Work Plan*; RPP-RPT-58386, *Retrieval Data Report for Single-Shell Tank 241-C-101*; and RPP-55849, *Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-101*.

RPP-55849 describes the waste volume after retrieval, additional technologies or enhancements to retrieval technologies that were evaluated to determine if additional retrieval with these technologies would be successful in retrieval of significant amounts of waste, and the estimated costs for deploying additional retrieval attempts. Economic factors estimated in RPP-55849 include: schedule impact, occupational exposure and impact on mission and costs.

C.1.1 Pre-Retrieval Conditions and Retrieval Methods and Results

The tank was estimated to contain approximately 88,000 gal (11,760 ft^3) of residual sludge waste determined after interim stabilization in 1983. The estimate was later revised to 77,500 gal (10,360 ft^3). The waste consisted of PUREX cladding waste and tributyl phosphate process waste. Tank C-101 was retrieved using modified sluicing with DST supernate and high-pressure water technologies deployed by two ERSS platforms. The residual volume after retrieval was approximately 667 ft^3.

C.1.2 Technologies Considered for Additional Retrieval of Tank C-101

The waste remaining in Tank C-101 after completion of the sluicing and high-pressure water processes had high concentrations of aluminum. The aluminum content in the waste prior to retrieval was higher than 12 percent by weight. Experience in retrieval of other tanks had shown that caustic cleaning had the potential to be an effective retrieval method for removal of waste residuals with high concentrations of aluminum.

The candidate retrieval technologies were evaluated for their ability to retrieve additional tank C-101 residual waste. This evaluation considered the continued use of the existing ERSS system in combination with a third technology. Based on the location and configuration of the remaining waste, or on the tank configuration and availability of risers, candidate technologies were selected for further consideration. The technologies considered are described in RPP-55849 and summarized below.

C.1.2.1 Chemical Dissolution (water)

Previous campaigns where water dissolution was successful involved a multi-step process where caustic was used to react with the aluminum-containing mineral, followed by water addition to dissolve the reaction products. There was not a good basis for expecting water dissolution alone to succeed in retrieving the residual waste in tank C-101. Three water rinses were performed on the residual waste in tank C-101 following the final volume displacement measurements. Each rinse used approximately 6,000 to 7,000 gal of water, including some hot water for the first rinse. These rinses did not appear to reduce the remaining waste volume. The use of additional hot water may enhance waste solubility. However, hot water alone was not considered to be as promising as caustic cleaning.

C.1.2.2 Caustic Cleaning

Caustic cleaning was the most likely candidate technology for breaking up and removing much of the hard-to-remove waste heel on the bottom of the tank. Caustic cleaning had been effective in other tanks with high aluminum content waste. Caustic cleaning using the existing ERSS system would involve some amount of wall washing, which may lead to reduction of the volume of material remaining on tank walls and stiffener rings. Continued contact of the caustic with the material on the walls and stiffener rings was not possible, so reduction of that material would be limited. Caustic cleaning in other tanks had resulted in variable reduction of the volume of waste on the walls and stiffener rings. The high pH atmosphere in the tank vapor space during caustic dissolution in some tanks had removed extensive wall and stiffener ring residual waste.

C.1.2.3 Enhanced Modified Sluicing

Mechanical waste reduction with an in-tank vehicle was considered. Mechanical reduction of hard waste chunks using high-pressure water had met with limited success in the past. Additional mechanical reduction with an in-tank vehicle may provide greater success. However, breakup of the larger chunks of waste with the high-pressure water had not led to mobilization of much additional waste for the tank C-101 waste type (estimated to be less than 5 percent of the initial waste volume). Additional mechanical size reduction was determined to be unlikely to achieve additional waste removal.

C.1.2.4 Mobile Arm Retrieval System

Mobile arm retrieval system (MARS) would provide much more retrieval capability than the ERSS and high-pressure water that were already deployed in tank C-101. The MARS would reach more areas of the wall and stiffener rings. However, the ERSS and high-pressure water had little success removing waste from those areas, even when the nozzle was close to the waste surface. Deployment of a MARS requires a central 47-in. riser. Installation of a central 47-in. riser requires cutting a hole in the concrete dome of the tank. This activity requires appromimately12 months of design and field work, and by its nature results in significant worker radiation dose. It would extend the duration of the retrieval process by a much greater duration than would caustic cleaning, without any anticipated increase in retrieval yield over the caustic cleaning process. Consequently it was determined more effective to consider caustic cleaning as an additional retrieval technology.

C.1.2.5 Process Description Overview For Caustic Dissolution

If an additional technology were deployed, it would be most effective to ensure that solid materials remained suspended as they were moved toward the transfer pump. Further reduction of the liquid in the pool might be achieved through evaporation (e.g., active ventilation of the tank). However, it was assumed that the total volume of the liquid pool could not be removed.

Deployment of caustic cleaning could be performed with the existing equipment and the addition of a caustic drop leg for the initial caustic addition. Two risers could be made available to accommodate the caustic drop leg, with the removal of existing equipment. It should be noted that the slurry transfer pump had already operated for a lengthy period, and may require replacement before the end of a third retrieval campaign.

Given the constraints described previously, chemical retrieval using caustic cleaning was the most viable choice for a third retrieval technology. Chemical retrieval methods generally involve the batch additions of a chemical solution into the tank. The residual waste in tank C-101 likely contains a high concentration of insoluble aluminum, primarily as aluminum hydroxides. Caustic dissolution (or cleaning) systems add concentrated caustic solutions to the tank to convert the aluminum hydroxides to sodium aluminate. The reactions occur slowly and may take several weeks to reach equilibrium. The resultant sodium aluminate will dissolve in water and in dilute caustic solutions. Retrieval through caustic dissolution uses the following process:

- Wash hard heel waste with water to remove phosphates and oxalate that will otherwise precipitate when reacting with the caustic (this step had already been accomplished in tank C-101 through the water rinses at the end of the second technology deployment)
- Add caustic solution (19 molar solution had been used in the past) to the tank

- Recirculate the caustic solution to contact the waste surfaces using one or more modified sluicing systems – the ERRS sluicers and slurry transfer pump may be used for this purpose
- Periodically obtain a sample of the solution to evaluate the progress of the reaction
- When the reaction with caustic had proceeded to equilibrium, add water to dissolve the sodium aluminate
- Retrieve the resulting liquid and any suspended solids using the slurry pump.

Testing shows that approximately 8 gal of water and caustic would be required to retrieve 1 gal of residual waste. Infrastructure requirements for the caustic addition system are in place with the exception of a caustic drop leg (in a riser) for initial addition of caustic into the tank.

The caustic cleaning technology was the preferred alternative because it had the potential to break up the remaining waste piles and reduce large chunks to finer material that could be mobilized or dissolved and retrieved. Caustic cleaning of tanks C-108, C-104 and C-109 was successful in breaking up waste piles and chunks, and led to retrieval of between 50 and 90 percent of the remaining solids. Experience with caustic cleaning had shown variable amounts of success with reduction of the material left on the tank walls and stiffener rings. Caustic cleaning in tank C-108 did not lead to any appreciable reduction in the volume of waste on the walls and stiffener rings. In tanks C-104 and C-109, caustic cleaning led to a reduction of approximately 40 to 50 percent of the waste on the walls and stiffener rings (RPP-55849).

Deployment of caustic cleaning in combination with the existing ERSS may not remove any of the residual waste. In the best case, it had the potential to remove up to approximately 1,693 gal or approximately 1,003 $ft^3$of waste from the tank, leaving as little as approximately 609 gal or 360 ft^3 of waste behind based on the waste location (i.e. tank walls and stiffener rings). A more accurate estimate of caustic cleaning cannot be made because of the limited data available. In addition to the large percentage of aluminum, the waste prior to retrieval was estimated to contain a relatively large quantity of iron and phosphate. Caustic dissolution was expected to be less effective for these components than for the aluminum compounds. Caustic cleaning was the best option available. However, the caustic cleaning was estimated to remove between 0 and 50 percent of the remaining waste on the tank walls and stiffener rings. Also, reduction of the final liquid pool near the central pump pit is a function of the pump intake configuration, therefore additional reduction of the pool was considered unlikely.

C.1.3 Evaluation Of Impacts To Worker Safety From Additional Retrieval

This criterion assesses the actual and potential impact to worker safety during deployment of an additional retrieval technology. All work is performed with safety as the first priority. However, due to the nature of the work, radiological exposure cannot reasonably be avoided.

The exposure that would be received during caustic cleaning at tank C-101 was estimated using the actual exposure during caustic cleaning at tank C-108. Caustic cleaning of tank C-108 was performed in 2011 and 2012. Estimated exposures were developed using the total person-dose associated with work specific to tank C-108. Exposure was incurred during equipment set up/reconfiguration and during retrieval operations. Tank C-108 set-up activities were estimated at approximately 140 person-mrem.

Retrieval operations for tank C-108 incurred an exposure of 111 person-mrem in calendar year 2011 through January 11, 2012. An additional 334 person-mrem were accumulated through the end of tank C-108 retrieval operations. Additional exposure occurred during maintenance activities such as exhauster maintenance and high-efficiency particulate air filter change out. The total exposure estimated for the set-up and operation period for the tank C-108 caustic dissolution technology was on approximately 600 person-mrem. A similar exposure would be expected if caustic cleaning were deployed at tank C-101.

Another potential source of exposure during a caustic cleaning campaign at tank C-101 would have been realized if any of the existing retrieval equipment had to be replaced. The slurry pump in tank C-101 had operated for a longer period than most other slurry pumps deployed during WMA C retrievals. Although the pump had not failed at the time, it was anticipated the slurry pump would require replacement before operation of an additional retrieval technology could be completed. The exposure expected from removal and installation of failed equipment in tank C-101 was estimated using the removal, disposal and installation of similar equipment in tank C-104 as a basis. The tank C-104 equipment removal, disposal and installation incurred 117 person-mrem for each piece of equipment. Therefore, the cumulative for C-101 was estimated dose at 700 person mrem.

C.1.4 Retrieval Schedule Impacts

The best-case schedule estimate for deploying caustic dissolution was 5 months. This best-case estimate assumed that trained field construction and operations personnel are available to perform the work. Because of the limited numbers of available, trained personnel, tank C-101 retrieval could not be performed simultaneously with other ongoing retrieval activities. Physical constraints limited the number of WMA C tanks that could be retrieved simultaneously (e.g., the number of DSTs available to receive waste, the available control trailer space, and the configuration of transfer lines and equipment). The best-case schedule for deploying caustic cleaning at tank C-101 assumed that both the existing ERSS and the slurry pump continue to operate for the duration of the caustic cleaning process. If any of these assumptions are incorrect, the schedule impact would be to delay retrieval by a minimum of 3 to 6 months.

C.1.5 Cost Estimate For Deploying Additional Retrieval Technology

A cost estimate for deployment of a third technology in tank C-101 was developed in RPP-55849. The initial estimate did not including the cost for replacement of a pump or ERSS should that be necessary. The estimate assumed that no additional waste sampling and analysis was required to design, construct, and operate the additional technology. Waste sampling at the end of retrieval, development of a retrieval data report, and any activities associated with closure are excluded from the estimate of $7,695,802.

Installation of a flow meter and containment box will cost approximately $1,000,000 for all materials, fabrication, and labor, including reconfiguration of HIHTL. Combined with the initial estimate of in $7,695,802, led to an estimate of nearly $9,000,000, assuming that no pump or ERSS replacement was required. The cost estimate for an SST slurry pump replacement was estimated at $3,938,741. The estimate (based on actual costs for the tank C-112 ERSS replacement) was $2,000,000. The total cost estimate to deploy caustic cleaning in tank C-101,

including anticipated replacement of the waste slurry pump, was between $12,000,000 and $13,000,000.

C.1.6 Impacts to Waste Treatment

Caustic cleaning will require the addition of approximately 12,000 to 20,000 gal of caustic (19 M sodium hydroxide), which will add to the sodium inventory for the treatment plant. The additional waste that could potentially be retrieved consists of insoluble sludge fines and chunks. These solids my require particle size reduction before they can be treated. However, other solids that will require particle size reduction are expected from existing retrieval activities. Solids are expected to contain aluminum, which will increase final waste volume.

Because of the additional sodium added to the system and the additional waste volume that could be retrieved the deployment of an additional retrieval technology in tank C-101 would result in a negligible increase in duration of treatment plant feed preparation or processing steps, and a negligible increase in the final volume of waste forms produced by the treatment plant.

C.1.7 C-101 Evaluation Summary

Modified sluicing and high-pressure water removed the waste in tank C-101 to a residual volume of approximately 667 ft^3. Chemical dissolution (caustic cleaning) could be used to remove a portion of the remaining waste by altering its chemical form to a soluble form. Caustic dissolution may be marginally effective in removing residual waste from the tank floor. It may be less successful in removing waste from the walls and stiffener rings.

- Deployment of caustic cleaning would likely remove some of the residual waste, but would not remove a significant amount of existing residual.
- The incremental reduction in inventory and risk would be relatively small, even if the operation is successful.
- The deployment of caustic cleaning would lead to an additional ~600 to 700 person-mrem of worker exposure.
- The duration of additional field activities would be between 5 and 12 months, leading to potential delay in subsequent retrieval activities.
- The cost to deploy caustic cleaning was estimated between $12,000,000 and $13,000,000.

C.2 Tank C-102 Evaluation

Tank C-102 tank specific documents include RPP-RPT-58788, *Retrieval Completion Certification Report for Tank 241-C-102;* RPP-RPT-59631, *Retrieval Data Report for Single-Shell Tank 241-C-102;* and RPP-RPT-58676, *Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-102.*

Section 4.3.2 in this Draft WIR Evaluation describes the retrieval actions “limits of technology” and includes information taken from RPP-RPT-59631 and RPP-RPT-58788. RPP-RPT-58676 describes the waste volume after retrieval, additional technologies or enhancements to retrieval technologies that were evaluated to determine if additional retrieval with these technologies

would be successful in retrieval of significant amounts of waste, and the estimated costs for deploying additional retrieval attempts. Economic factors estimated in RPP-RPT-58676 include: facilitating WMA C tank closures, worker safety, and overall impact on mission and costs.

C.2.1 Pre-Retrieval Conditions and Retrieval Methods and Results

Tank C-102 had been retrieved to a residual volume of approximately 2,700 ft^3 using modified sluicing with double-shell tank supernate and high-pressure water technologies of ERSS by assemblies. Tank C-102 was sampled in 1986 which showed a significantly lower gibbsite (aluminum) concentration than expected. The caustic dissolution process is effective in removing wastes with high aluminum content. Caustic dissolution retrieval technology had not been successfully deployed for this type of waste in the WMA C tanks. Because of the waste residual remaining in tank C-102 following the deployment of modified sluicing and high pressure water nozzle technologies, DOE developed a Practicability Request which described the review of additional technologies (RPP-RPT-58676). In the Practicability Request, DOE evaluated a set of candidate technologies for hard heel waste retrieval that were reviewed and documented in RPP-RPT-44139. From this evaluation, it was concluded that none of the existing retrieval technologies was a viable candidate as an immediately available technology in tank C-102. None of the existing retrieval technologies were determined to have a reasonable expectation of successful retrieval of a significant quantity of waste. The use of a new chemical retrieval using a different chemical agent was determined to be the most viable choice for a retrieval technology. However, the practicality, cost of implementation, and the actual effectiveness of such a chemical process were uncertain.

The presence of large aggregate and a low aluminum concentration, along with a high calcium content in the waste samples, led to the postulation that much of the remaining waste was concrete. A core sampling attempt in riser 2 reportedly encountered a concrete block. On July 31, 2012, during equipment removal work in tank C-102, water from a spray wand was directed onto the mounded waste surface under riser 2. The surface under riser 2 was hard and did not yield to the water. Visual examination supports the earlier assertion that the material under riser 2 was concrete; portions of the material exposed are slab-like and other portions appear to be aggregate.

Waste piles comprised of larger pieces of waste material and a shallow pool of liquid remains in the center region of the tank, at about the pump intake level. There was waste on the stiffener rings and walls. The waste remaining in the tank includes the liquid in the center of the tank. Waste solids cover almost all of the tank bottom. The most noticeable piles are in the south side of the tank. Large chunks of “cobble” material are located along the knuckle of the tank around the entire perimeter. Based on observations during retrieval, much of the waste remaining on the tank floor had been broken into particles too large or too dense to be suspended in liquid in order to pump them out of the tank.

C.2.2 Evaluation of Technologies for Consideration in Tank C-102

Additional retrieval technologies were evaluated for their ability to retrieve the tank C-102 residual waste using a process similar to that used in the selection of the second retrieval technology for deployment in tank C-102, and taking into account the observed effectiveness of the technologies deployed to date. The evaluation also considered the continued use of the

existing ERSSs in combination with an additional technology. The candidate technologies were evaluated to determine their potential for success. The candidate technologies included:

C.2.2.1 Chemical Retrieval – Caustic Dissolution

Caustic dissolution would use a multi-step process comprised of a caustic soak and a hot water dissolution, followed by another caustic strike. In addition, hot water was required during waste retrieval operations. The post-retrieval rinses would require more than 50,000 gal of water. The caustic dissolution was estimated to require the use of several thousand gal of caustic and associated water rinses to get the most out of the waste retrieval effort. The addition of those volumes of caustic and water to the DST system would have a major impact on available tank space. Caustic dissolution was a plausible candidate technology; however, prior waste sample results indicate that caustic dissolution may not be as effective as needed to provide a significant reduction in residual waste volume.

C.2.2.2 New Chemical Retrieval Technology

A new chemical retrieval technology using alternate dissolution media (such as acid) would have required development based on the chemical and physical characteristics of the residual waste. Additional activities include sampling and analysis of the residual waste (9 to 12 months), waste compatibility studies and a new chemical retrieval flowsheet. The estimated time for development and deployment was estimated at three years or more based on projections to develop and implement similar technologies in the past.

C.2.2.3 Mechanical Waste Reduction

Mechanical waste reduction using Enhanced Modified Sluicing combined with an in-tank vehicle, such as the FoldTrack®, was considered. Mechanical forces associated with this combination of technologies have the potential to break up some of the remaining waste chunks. Based on observation of the FoldTrack® performance in tank C-110, this would not lead to significant waste recovery for tank C-102. Also, deployment of an in-tank vehicle will not have any impact on waste remaining on tank walls and stiffener rings.

C.2.2.4 Mobile Arm Retrieval System

It was not clear that a MARS would provide much more retrieval capability than the ERSSs and high-pressure water retrieval that were already deployed in tank C-102. Deployment of a MARS requires a central 47-in. riser. Installation of a central 47-in. riser requires cutting a hole in the concrete dome of the tank. This activity requires approximately 12 months of design and field work, and by its nature results in significant worker dose. Thus, it was not considered viable.

C.2.2.5 Chemical Dissolution

Caustic dissolution was planned, but because of the waste composition the technology would likely be unsuccessful in significantly reducing the amount of residual waste. The use of a new chemical retrieval using another chemical agent was a viable choice for a third retrieval technology. However, the time frame of such a development and the actual effectiveness of such a chemical process was uncertain.

Deployment of caustic dissolution or a new chemical dissolution retrieval process in combination with the existing ERSSs may not remove any or a negligible amount of the residual waste.

Two core sampling attempts were made in tank C-102 from April 1986 through July 1986. The data indicates poor dissolution of the sludge composite using sequential acid dissolution steps. The first core from riser 2 was not completed because the rotary sampler struck an obstruction on the sludge surface. Additionally, the aluminum concentration was extremely low. Additional analyses performed on an archive sample from tank C-102 indicated only 4 percent moisture. Therefore, it was determined that in the best case, chemical dissolution may remove half of the waste from the tank. This best case estimate does not include the remaining liquid pool that was below the slurry pump intake.

C.2.3 Evaluation of Exposure That Could Be Incurred During Chemical Dissolution

The exposure that would be received during a new chemical retrieval process at tank C-102 was estimated using the actual exposure during caustic dissolution at tank C-112 and equipment replacement at tank C-112. Tank C-112 recorded exposure for caustic dissolution was 1,243 person-mrem. Additional exposure during a chemical retrieval campaign at tank C-102 would have been realized if any of the existing retrieval equipment had to be replaced. Equipment replacement was considered likely based on operating experience. The exposure expected from removal and installation of failed equipment in tank C-102 was estimated using the previous equipment replacement in in tank C-112, and replacement of the slurry pump in tank C-107. Replacement and disposal of equipment and additional operational time deploying chemical retrieval in tank C-102 would range from 1,200 to 2,100 person-mrem depending on the need to replace failed equipment.

C.2.4 Financial Cost Evaluation

The likely total cost estimate to deploy a new chemical dissolution in tank C-102 was estimated at a minimum of $12,000,000. Should equipment replacement be required, the cost will increase to greater than $19,000,000. The estimate was developed using the caustic dissolution cost basis, plus assumed development costs for the new technology. An alternate chemical dissolution technology would require additional waste analysis necessary to develop and test the third technology. Additional waste sampling and analysis would be required during the operation of the technology. Waste sampling at the end of retrieval, development of a retrieval data report, and any activities associated with closure are excluded from this estimate.

C.2.5 Retrieval Schedule Impacts

The best-case schedule for deploying a chemical dissolution process (to be defined through laboratory testing) at tank C-102 assumes that the existing ERSSs as well as the slurry pump continue to operate for the duration of the chemical dissolution process. Deployment of a chemical dissolution process will require sampling and analysis (4 to 5 months if caustic was used); and for a new chemical dissolution process it will take 9 to 12 months to analyze and review sample results, 9 to 15 months to develop a process and do testing, and 12 months to develop procedures, conduct training, do a safety analysis and potentially update the safety basis. Once the process was well defined, some equipment design and construction (as required) would take place in parallel with the final procedure and training activities. The best-case schedule assumes that existing equipment will not require replacement. That assumption was assumed not to be valid, and all existing equipment would have had to be evaluated to determine if

replacement was warranted. Once all processes and equipment are in place, a period of two to six months was assumed to perform the chemical retrieval process cycle. However, the overall process development, preparation and deployment was anticipated to take six months for caustic dissolution and three to four years for a new chemical dissolution technology.

C.2.6 Impacts to Waste Treatment

The most promising third technology, chemical dissolution, will add to the chemical load to be processed by the Waste Treatment Plant. Chemical dissolution will require the addition of an unspecified amount of chemicals, including both the chemicals needed for the retrieval process and any additional chemicals required to keep the DST receiver tank chemistry within specification. Any added chemicals would increase the inventory requiring treatment, and some chemicals have the potential to require new treatment processes. The overall outcome of deployment of a third retrieval technology in tank C-102 could not be determined until a chemical retrieval process could be defined.

C.2.7 C-102 Evaluation Summary

Caustic dissolution would likely be unsuccessful in significantly reducing the amount of residual waste. None of the other existing retrieval technologies had a reasonable expectation of being of value to successfully retrieve additional waste to reduce the overall hazardous constituents within the waste; likely only the "inert" chemical components would be retrieved. The use of a new chemical retrieval using another chemical agent was a viable choice for a retrieval technology. However, the time frame of such a development and the actual effectiveness of such a chemical process was uncertain.

Modified sluicing and high-pressure water processes removed the waste in tank C-102 to a residual volume of ~2,700 ft^3. Based on the waste characteristics observed during the retrieval activities to date, and prior sampling events, chemical retrieval processes are the only practical candidate operations for an additional technology deployment.

Chemical retrieval could enable most of the residual waste piles to be broken up into smaller pieces for subsequent retrieval by an additional sluicing step, but sampling of the waste must be done first to provide waste characterization data to indicate the viability of such a process through laboratory and process testing. Such a new chemical dissolution process would take time to develop and would be costly. Furthermore, any process will likely not be successful in removing waste from the walls and stiffener rings.

- Development and deployment of a new chemical retrieval process would likely remove some of the residual waste, but the likelihood of success could not be predicted. Based on residual waste composition estimates, the reduction in inventory and the incremental reduction in risk would likely be relatively small.
- The deployment of chemical retrieval would lead to an additional 1,200 to 2,100 person-mrem of worker exposure, without considering work/laboratory technician exposure during process testing activities.
- The minimum duration of additional process development for a new chemical dissolution process and field activities would be between three and four years, because of the need to develop an alternate process/retrieval technology resulting in significant delay in subsequent retrieval activities of at least that amount of time.

- The cost to develop and deploy a new chemical dissolution retrieval technology was estimated between $12,000,000 and $19,000,000.

C.3 Tank C-103 Evaluation

RPP-RPT-33060, *Retrieval Data Report for Single-Shell Tank 241-C-103,* was used as the primary document for C-103 information. Other document reviewed included RPP-18811, *Tanks C-103 and C-105 Waste Retrieval Functions and Requirements,* and RPP-21895, *241-C-103 and 241-C-109 Tanks Waste Retrieval Work Plan*. The retrieval of tank C-103 met all expectations. Tank C-103 had been retrieved to a residual volume of 338 ft^3 using modified sluicing with double-shell tank supernate.

C.3.1 Waste Description Prior to Retrieval

The volume of waste in SST C-103 at the start of retrieval consisted of approximately 77,800 gal of waste. During its service life, the tank was used to store waste from many sources including metal waste from the bismuth phosphate process, cladding waste from the plutonium-uranium extraction plant, solids from tank C-106, and liquid wastes from other tanks of WMA C.

C.3.2 Additional Retrieval Technologies

This section provides an analysis of the use or development of other technologies to retrieve additional waste from tank C-103. The feasibility/viability of other available retrieval technologies for the retrieval of additional waste from C-103 have been evaluated. Available retrieval technologies are those that have been proven in the operational environment and can be readily deployed. These available retrieval technologies are the vacuum retrieval system, remote water lance (salt mantis), saltcake dissolution, rotary viper, and chemical addition. A retrieval technology was considered feasible/viable if it could possibly remove a significant amount of additional waste from the tank. Of these available retrieval technologies, chemical addition of caustic was the only technology deemed feasible/viable, and taken forward for the completion of a cost estimate.

C.3.2.1 Vacuum Retrieval System

The vacuum retrieval system (VRS) consists of an articulating mast system with a vacuum head, a vacuum pump, a slurry vessel, and a number of slurry transfer pumps. A VRS system was deployed into the 200-series tanks in WMA C and successfully removed waste. The VRS would not have the capacity to retrieve significant C-103 waste volume because much of the waste was dispersed beyond the reach of the mast and there was significant debris and large particle sizes in the tank. Therefore, this technology was not considered feasible for retrieving the residual waste in C-103.

C.3.2.2 Remote Water Lance

The Remote Water Lance assists sluicing retrieval of hard saltcake waste. It uses a low-volume, high-pressure water lance to break up hard layers and push waste to the pump. The Remote Water Lance is lowered through a riser to the bottom of the tank, where it can be maneuvered across the waste surface. The high-pressure water is delivered in close proximity to the waste. The high-pressure system cuts into the hard waste material, increases effective surface area for

dissolution, and breaks the waste into smaller pieces. It is most effective in a submerged environment to break up large stationary forms of waste. The technology would not be effective in breaking up hard mobile debris since the waste would be pushed out of the way with nothing holding it in place. It was not likely that the Remote Water Lance technology, operated in concert with the existing retrieval system in C-103, would significantly reduce the volume of residual waste. The Remote Water Lance was not considered feasible/viable for retrieving the residual waste in C-103.

C.3.2.3 Saltcake Dissolution

Saltcake dissolution is a process by which water is added to a tank and allowed to dissolve the soluble components of the waste, and the resulting brine is then pumped out of the tank. Saltcake dissolution can be an effective technology for retrieving porous saltcake material where water addition is practical. Saltcake dissolution was demonstrated at tank S-112, and described in RPP-RPT-27406, *Demonstration Retrieval Data Report for Single-Shell Tank 241-C-112*. Because the residual waste in C-103 was not saltcake, this technology was not considered feasible/viable for retrieving the residual waste in C-103.

C.3.2.4 Rotary Viper

The Rotary Viper is a rotating spray system mounted on a long shaft that can be inserted directly into tank waste. The Rotary Viper sprays water from nozzles at approximately 32,000 psi at a flow rate of approximately 6 to 12 gpm. The water dissolves the waste and washes it to a central pump for removal. The Rotary Viper can also be positioned to clean pump screens which can become clogged with waste as retrieval progresses. Because the Rotary Viper uses low volumes of water, it helps minimize the amount of waste to be transferred to the double-shell tanks. The Rotary Viper had been tested at Hanford and been deployed at S-102. Because the residual waste in C-103 was not in a hard waste layer to be broken up and does not present a solid surface to spray against, this technology was not considered feasible/viable for retrieving the residual waste in C-103.

C.3.2.5 Chemical Addition

Chemical addition would consist of adding chemicals to the tank residuals to dissolve and loosen waste. Chemical addition technology was used in C-106. The process relies on the reaction of a chemical with the residual waste to either decrease the particle size or to convert insoluble material to soluble or vapor form to decrease the residual waste material. Decreasing the particle size enables the smaller waste pieces to be more easily suspended in the liquid and pumped out of the tank.

In C-106 retrieval, oxalic acid was added to the tank to dissolve residual wastes and reduce particle size. Oxalic acid can be used effectively on iron oxides but is not as effective on other materials. During the retrieval process, after chemical addition, pH or density was monitored to determine when the chemical reaction had achieved diminishing returns. One disadvantage to oxalic acid chemical addition is that following use of this technology, the waste must be neutralized, which generates significant volumes of oxalate solids in the tank. Based on sample analysis results, iron makes up less than 10 percent of the remaining solids in C-103. It was unlikely that an oxalic acid digest of the remaining solids would have a significant effect to improve the retrieval of C-103.

Similarly, caustic addition can be effective on alumina or silica waste forms. In S-112, a caustic solution had been added to dissolve waste and assist in reducing particle size. The caustic solution addition to S-112 appears to have significantly aided the retrieval efforts. Sample analysis results show that aluminum was the single largest constituent of the remaining solid waste in C-103. Some mineral forms of aluminum are very soluble in strong caustic solutions. Other mineral forms of aluminum are very difficult to dissolve. In all cases the dissolution is a very slow process. At typical tank temperatures it would take at least 6 months for the reaction to complete. If a strong caustic solution were placed in the tank and allowed to digest for 6 months to a year, it may be possible to either dissolve or break up a significant fraction of the remaining waste. However, laboratory testing would be required to establish the effectiveness of the treatment.

C.3.3 Evaluation Of Impacts To Worker Safety From Additional Retrieval

Estimates of radiation dose to workers to deploy the additional technology were not available in any available documentation.

C.3.4 Cost Estimate

The total estimated cost for use of caustic dissolution technology was $6,500,000. This was a total of all of the project management, design, procurement, installation, startup and readiness, chemical, and operational costs. These activities would include but are not limited to preparing work packages, design and procurement of a system to add and measure the chemical, periodic sampling to assess effectiveness of the caustic, final transfer of waste to a DST, and documentation of the process in an RDR. It should be noted that this $6.5 million estimate was based on a number of assumptions (e.g., operating time), which cannot be validated without additional analysis, including waste testing. Without additional analysis, it was not possible to predict how successful caustic addition followed by additional modified sluicing may be and how much additional waste may be removed through application of this technology.

C.3.5 C-103 Evaluation Summary

The C-103 modified sluicing deployment successfully removed waste to the limit of the technology and satisfied requirements set out in HFFACO Milestone M-45-00. However, it appears that additional waste removal may be possible using caustic addition followed by redeployment of a modified sluicing system. A preliminary cost estimate for using caustic addition followed by additional modified sluicing of $6.5 million was prepared. Without additional analysis, it was not possible to predict how successful caustic addition followed by additional modified sluicing may be and how much additional waste may be removed through application of this technology.

C.4 Tank C-108 Evaluation

The C-108 tank specific documents reviewed for this analysis include RPP-52290, *Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-108*; RPP-53869, *Retrieval Completion Certification and Report for Tank 241-C-108*; RPP-RPT-55896, *Retrieval*

Data Report for Single-Shell Tank 241-C-108; and RPP-22393, *C-102, C-104, C-107, C-108, and C-112 Tanks Waste Retrieval Work Plan*.

Section 4.3.2 in this Draft WIR Evaluation describes the retrieval actions including information taken from RPP-22393 and RPP-RPT-55896. RPP-52290 describes the waste volume after retrieval, additional technologies or enhancements to retrieval technologies that were evaluated to determine if additional retrieval with these technologies would be successful in retrieval of significant amounts of waste, and the estimated costs for deploying additional retrieval attempts. Economic factors estimated in RPP-52290 include risk reduction, facilitating WMA C tank closures, worker safety and overall impact on mission and costs.

C.4.1 Pre-Retrieval Conditions and Retrieval Methods and Results

Tank C-108 was retrieved using modified sluicing and chemical dissolution (caustic cleaning) technologies as described in RPP-22393 to a final waste volume of ~460 ft^3. The first waste retrieval technology deployed was modified sluicing, which removed 90 percent of the initial waste inventory; a second waste removal technology comprised of chemical dissolution (caustic cleaning) with a subsequent heel water wash, which removed approximately 1,900 gal more waste.

C.4.2 Technologies Considered for Additional Retrieval of Tank C-108

Several technologies were considered to remove additional radionuclides. They include a wide range of technologies. The technologies and a summary of the evaluation are described below.

C.4.2.1 Chemical Cleaning

Caustic cleaning was effective in breaking up and removing much of the hard to-remove waste heel on the tank bottom. Limited reduction of the volume of material remaining on tank walls and stiffener rings was achieved by the second retrieval technology. An additional step of chemical cleaning would not be expected to achieve further waste reduction.

Additional modified sluicing may add some further waste reduction. Enhanced modified sluicing was likely to be more effective, and thus the preferred approach. Articulating sluicers that could be directed at the waste on the tank walls and stiffener rings may achieve some additional reduction in these areas. Either articulating sluicers or modified sluicing combined with an in-tank vehicle could move remaining loose material to the central pump location, and may achieve additional reduction of the remaining waste pile.

C.4.2.2 Additional Modified Sluicing

Additional modified sluicing using the existing equipment was unlikely to recover any additional material than was already recovered in the opportunistic sluicing step performed at the end of chemical cleaning. Installation of an additional sluicer may provide some additional reduction of the size of the remaining waste pile, and move the waste material and chunks to the central pump location. Little or no success removing waste from the walls and stiffener rings was achieved during the initial modified sluicing campaign. It was possible that some reduction would occur during additional modified sluicing, but there was not a basis for a quantitative estimate.

Based on previous experience with similar equipment, installing a new sluicer in tank C-108 would require 6 weeks of field work. Standard sluicers are kept available as spare equipment, so no additional time to obtain the new equipment would be required. An additional 2 to 3 months would be required to prepare work packages and perform other field equipment changes to support deployment of the third retrieval technology (e.g., reconfiguring transfer equipment and ventilation equipment then-currently being used for tank C-109 retrieval, installing control and support systems), and to operate the technology, for a total duration of 4 to 5 months.

C.4.2.3 Enhanced Sluicing with Telescoping and/or Articulating Sluicers

The ERSS is an articulating, rotating, and telescoping tool that increases the area of influence of the sluice cannon. It is designed to fit in a 12-in. riser. An ERSS had been deployed in tank C-112. RPP-RPT-44139 provides more information on the design and capabilities of the ERSS unit. The ERSS unit would be expected to reduce the size of the remaining waste piles, and move fine waste material and chunks to the central pump location. The ERSS unit would have the ability to direct a sluice cannon at waste remaining on tank walls and stiffener rings. The effectiveness of waste removal from these areas will depend on many factors, including the waste type, the proximity of the sluice cannon to the waste, and the flow of the sluice stream. Controls would be required to prevent directing a sluice stream upwards during ERSS cleaning of walls, due to the potential for an environmental release.

Little or no success in removing waste from the walls and stiffener rings was achieved in deploying the first two retrieval technologies. There was no clear evidence of any reduction in the waste volume on the walls and stiffener rings during deployment of caustic cleaning. The experience in tank C-112 with a combination of standard sluicing equipment and an ERSS indicates that the ERSS had somewhat greater success in penetrating hard layers of material than does a standard sluicer, although it was also determined an ERSS will not achieve any reduction of the waste on the walls and stiffener rings. It was considered likely that some reduction could occur, but not complete removal. There was no current basis for a quantitative estimate.

An ERSS would have needed to be constructed to operate in tank C-108. This was not an off-the-shelf piece of equipment. Based on experience with obtaining other ERSS units, 6 to 8 months would have been required to have the equipment ready to install in tank C-108. It was estimated 2 to 3 months was required to prepare tank C-108 for the new equipment installation. Approximately 3 to 4 additional months would be required to install the equipment and operate the equipment, for a total duration of 9 to 12 months.

C.4.2.4 Enhanced Modified Sluicing Used with In-Tank Vehicle (FoldTrack®)

The FoldTrack® unit was designed to fit in a 12-in. riser. A FoldTrack had been deployed in tank C-109. A FoldTrack® unit would need to be constructed to operate in tank C-108. This was not an off-the-shelf piece of equipment. Based on experience with obtaining the previous FoldTrack® unit, 6 to 8 months would be required to have the equipment ready to install in tank C-108. It would take on the order of 2 to 3 months to prepare tank C-108 for the new equipment installation (perform engineering changes, clear a riser, dispose of old equipment); this preparation work could be completed in parallel with obtaining the new equipment. Approximately 3 to 4 additional months would be required to install the equipment and operate the equipment, for a total duration of 9 to 12 months.

The FoldTrack® unit would be expected to reduce the size of the remaining waste piles, and move fine waste material and chunks to the central pump location. The FoldTrack® unit would not have significant impact on waste remaining on tank walls and stiffener rings.

The candidate retrieval technologies were selected because they have the potential to break up the consolidated waste piles and reduce these piles to finer material that could be mobilized and retrieved. They have the capability to move the existing loose material closer to the central pump location. It was considered unlikely the technologies would achieve extensive reduction of the material on the tank walls and stiffener rings. Reduction of the final liquid pool near the central pump pit is a function of the pump intake configuration, so additional reduction of this pool was considered unlikely.

C.4.3 Evaluation of Exposure Incurred During Caustic Cleaning

This section assesses the actual and potential impact to worker safety during deployment of an additional retrieval technology. All work is performed with safety as the first priority. However, due to the nature of the work, radiological exposure cannot reasonably be avoided.

For purposes of comparison, the estimate of exposure received during caustic cleaning of tank C-108 was examined. Caustic cleaning of tank C-108 was performed in 2011 and 2012. Exposure estimates associated with the deployment of an additional technology are developed from two categories of work – exposure associated with setup, including clearing one or more risers, disposing of contaminated equipment, and installing the new retrieval equipment; and exposure associated with retrieval operations.

Tank C-108 setup activities included disconnection of HIHTLs at 67 person-mrem, chemical addition riser installation at 1 person-mrem and connection of the HIHTL to an exhaust manifold, at 70 person-mrem. Retrieval operations for tank C-108 incurred an exposure of 111 person-mrem in calendar year 2011 through January 11, 2012. An additional 334 person-mrem were accumulated through the end of tank C-108 retrieval operations. Additional exposure occurred during replacement of cameras and lights, and other maintenance activities such as exhauster maintenance and high-efficiency particulate air filter change out. Thus, the total exposure estimated for the set-up and operation periods for the tank C-108 caustic cleaning technology was estimate at approximately 600 person-mrem.

C.4.4 Schedule Impacts

Based on experience with installation and operation of similar technologies in other tanks, an estimated 6 months duration will be required to install and operate an additional technology in tank C-108. This estimate assumes approximately 5 months to prepare the necessary field changes, engineering work, clear the riser, and install the new equipment. It assumes approximately 4 weeks of operation of the new equipment. If enhanced sluicing using either the ERSS or the FoldTrack® was selected as a third retrieval technology, an additional 6 to 8 months was anticipated to procure this specialized equipment.

Tank C-108 shares common waste retrieval equipment with tank C-109. Operating the additional technology in tank C-108 would necessarily occur after tank C-109 retrieval was completed. Additional time in the field was required to reconfigure this equipment for continued

tank C-108 operation. Retrieval of the two tanks cannot occur at the same time because of the shared equipment.

C.4.5 Impacts to Waste Treatment

The additional technologies do not add to the chemical load to be processed by the treatment plant (e.g., by adding additional sodium to the system). The additional waste that could potentially be retrieved consists of insoluble sludge fines and chunks that are small enough to be mobilized. Solids may need to undergo particle size reduction before they can be treated. Other solids that could require particle size reduction are expected from existing retrieval activities. The technology deployment would not add an additional processing step, but may increase its duration. Solids are expected to contain aluminum, which has the potential to increase final waste volume. Other materials containing aluminum are expected from existing retrieval activities, therefore, additional technology deployment would not add a processing step, but may increase its duration. The overall outcome of deployment of a third retrieval technology in tank C-108 may be a small increase in duration of some feed preparation or processing steps. Because the additional volume that could be retrieved was small, the treatment plant impacts will be small.

C.4.6 Cost Estimate For Deploying Retrieval Technology

The cost for design, construction, installation, operation, and associated activities for an additional retrieval technology was expected to be similar to the cost associated with the second retrieval technology. The cost estimate developed for the second retrieval technology in tank C-112 was used as a template for estimating cost of a third retrieval technology in tank C-108. The operational cost estimates were based on operational experience with previous WMA C tank retrievals. In addition to the costs associated with the additional technology itself, the waste slurry pump will need to be replaced in order to complete operation of the retrieval technology. The cost for waste slurry pump replacement was based on the cost estimates for the replacement of similar tanks. The estimate assumes that no additional waste sampling and analysis was required to design, construct, and operate the third technology. Waste sampling at the end of retrieval, development of a retrieval data report, and any activities associated with closure are excluded from this estimate. Prior to development and dep1oyment of a retrieva1 technology a detailed cost estimate would have been developed. Based on retrieval experience the cost was estimated to be in the range of $10,000,000 to $11,000,000.

C.4.7 C-108 Evaluation Summary

Modified sluicing mobilized approximately 90 percent (by volume) of the waste in tank C-108 so that it could be retrieved. Chemical dissolution (caustic cleaning) was used to remove a portion of the remaining waste heel by altering its chemical form to a soluble form. Caustic cleaning also allowed most of the residual waste piles to be broken up into smaller pieces, some of which were subsequently retrieved by an opportunistic additional water sluicing step. Some portion of this remaining waste may be retrieved by a third technology. However, the remaining residuals on the tank walls and stiffener rings will be difficult to mobilize through use of any available technology.

There was not a high degree of confidence that a significant amount of residual waste can be mobilized and retrieved by the installation of any additional technology that was currently available. The incremental reduction in inventory and risk was considered relatively small, even if the operation was successful. The incremental increase in worker exposure, duration of field activities, potential delay in subsequent retrieval activities, and cost, are similar to those expected from other hard heel removal operations and outweigh whatever level of success may result from installation and operation of an additional retrieval technology.