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Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106

D. L. Parker
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
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Abstract: This document was prepared to comply with Hanford Federal Facility Agreement and Consent Order (HFFACO) Milestone M-45-05H and Target Date M-45-05M-T01. This document presents the basis for the Washington State Department of Ecology and U.S. Environmental Protection Agency to approve an exception to the waste retrieval criteria established in the HFFACO for single-shell tank 241-C-106 (SST C-106). On the basis of the information presented in this document, the U.S. Department of Energy concludes that there is no technical, risk reduction, or economic justification to support deployment of retrieval technologies to further retrieve waste from SST C-106.

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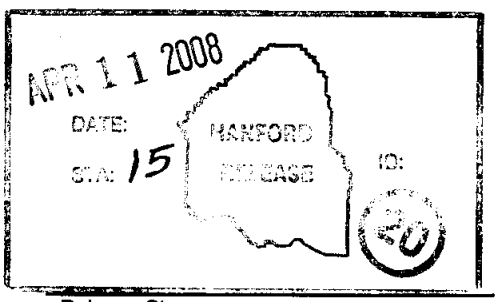

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Revision 3

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EXECUTIVE SUMMARY

This document was prepared to comply with *Hanford Federal Facility Agreement and Consent Order*[1] (HFFACO) Milestones M-45-05H and M-45-05M-T01. This document presents the basis for the Washington State Department of Ecology and the U.S. Environmental Protection Agency to approve an exception to the waste retrieval criteria established in HFFACO for single-shell tank 241-C-106. On the basis of the information presented in this document, the U.S. Department of Energy concludes that there is no technical, risk reduction, or economic justification to support deployment of retrieval technologies to further retrieve waste from single-shell tank 241-C-106. Based on that conclusion, the U.S. Department of Energy requests the Washington State Department of Ecology and U.S. Environmental Protection Agency concur that retrieval of waste from single-shell tank 241-C-106 is complete. The U.S. Department of Energy acknowledges that attaining the HFFACO waste retrieval criteria may not be sufficient for some single-shell tanks; however, for single-shell tank 241-C-106, the analysis supports issuance of an exception to the waste retrieval criteria.

In response to HFFACO, Appendix H, Attachment 2, Criterion 2, a review of the two retrieval technology deployments in single-shell tank 241-C-106 was completed. The review determined that the limits of technology for retrieval of waste from single-shell tank 241-C-106 have been reached for these technologies. Section 2.1 documents that sluicing (the initial retrieval technology deployed in 1998-1999 to resolve high-heat safety issues) and modified sluicing and acid dissolution (the retrieval technology demonstration under the HFFACO for modified sluicing in a sludge tank completed in 2003) were demonstrated to have reached the limit of their technical ability to effectively retrieve waste from single-shell tank 241-C-106.

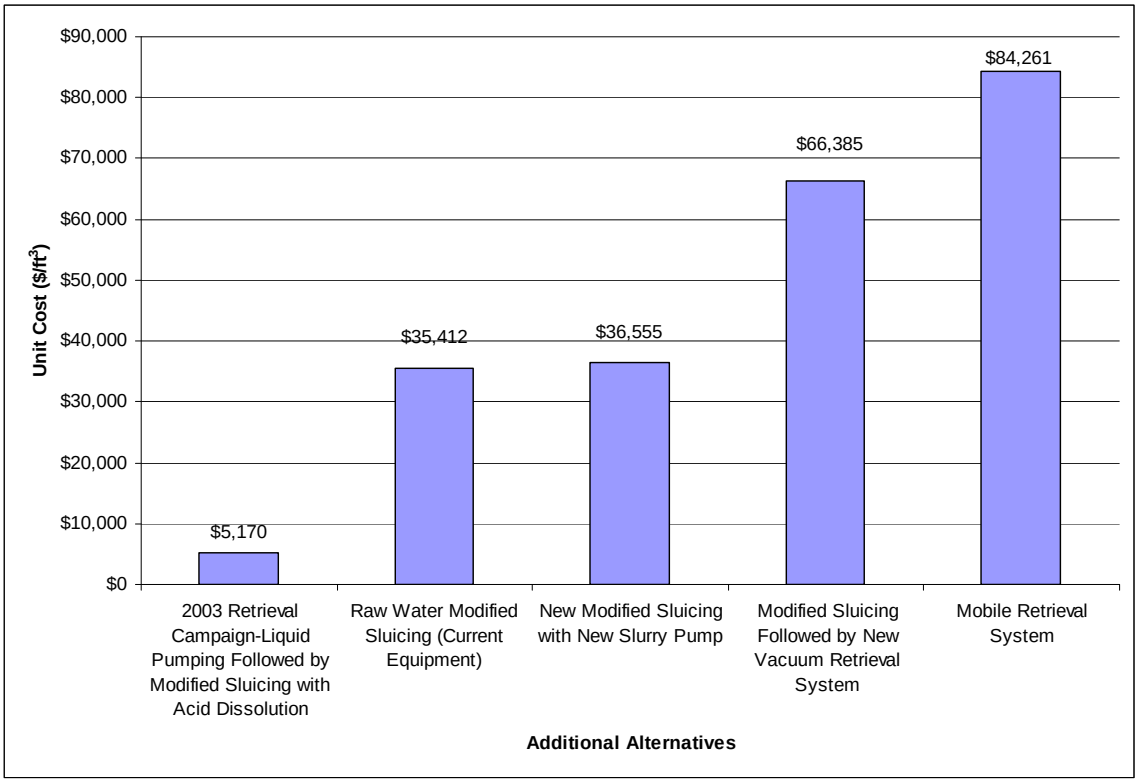
In response to HFFACO, Appendix H, Attachment 2, Criterion 3, an analysis of available additional alternative waste retrieval technologies was completed and is summarized in Section 2.2. This analysis compares four alternatives for deployment of additional available retrieval technologies (i.e., two modified sluicing alternatives under alternative configurations, the mobile retrieval system, and modified sluicing followed by use of the vacuum retrieval system). The alternatives evaluation includes documentation of the cost and schedule for each alternative as well as comparative analysis of the relative performance against waste retrieval functions and six criteria [i.e., cost, schedule, risk to workers, risk to human health and the environment (i.e., impacts to groundwater quality), ease of implementation, and impact on the River Protection Project mission]. The analysis shows there is sufficient uncertainty about whether the deployment of available alternative technologies would reduce the waste volume remaining in single-shell tank 241-C-106 to the HFFACO retrieval criteria and that no further consideration of deployment is warranted.

Additional waste retrieval may require from 12 to 18 months to complete and may cost from $5.7 to $13.5 million. Figure ES-1 illustrates the cost per cubic foot of additional waste removed by alternative and compares those costs to those experienced under the 2003 retrieval campaign.

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

As indicated, the four waste retrieval alternatives would cost from approximately $35,000 to $84,000/ft^3 if it is assumed that approximately 160 ft^3 of waste could be removed. The 160 ft^3 volume was estimated to be the volume of waste that would need to be removed to ensure the remaining residual waste volume was below 360 ft^3 when the uncertainties in waste volume measurements were considered. The actual volume of waste that could be removed is unknown. The 2003 campaign cost was $5,170/ft^3 of waste removed, while retrieving 4,340 ft^3 of waste. Deployment of any waste retrieval technology would result in increased radiological, chemical, and industrial risk to workers and place added constraints on near-term double-shell tank space (90,000 to 1.87 million gal) available for retrieval of waste from other single-shell tanks. Potential future waste retrieval technologies were also identified and described; however, these technologies are not sufficiently mature to support additional assessment of their retrieval effectiveness, cost, or deployment schedules.

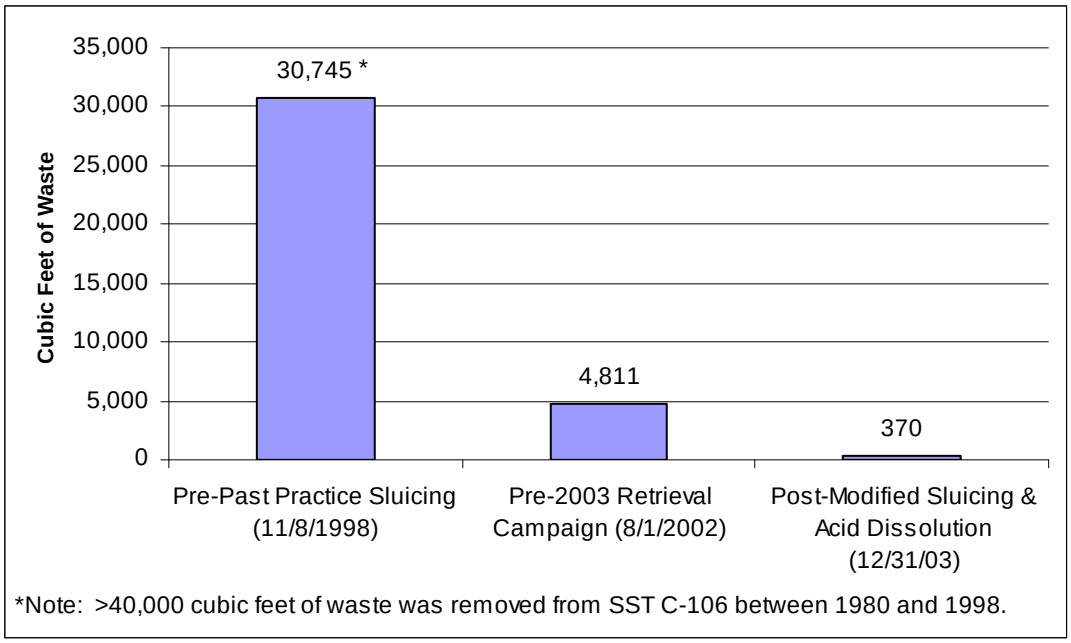
Figure ES-1. Comparison of the Cost per Cubic Foot of Waste Retrieval between the 2003 Retrieval Campaign and the Additional Retrieval Technology Alternatives.



In response to HFFACO, Appendix H, Attachment 2, Criterion 4, Section 2.3 summarizes the volume and characteristics of waste remaining in single-shell tank 241-C-106. At its peak during operation, single-shell tank 241-C-106 contained as much as 530,000 gal of waste. Between 1980 and 1998 approximately 40,000 ft^3 of waste was removed from single-shell tank 241-C-106. Cumulatively, the two retrieval campaigns have removed approximately 30,400 ft^3 of waste from single-shell tank 241-C-106 (Figure ES-2). The 1998-1999 campaign using sluicing removed approximately 25,940 ft^3 of waste and the 2003 campaign using liquid pumping followed by modified slicing and acid dissolution retrieved at least 4,340 ft^3 of waste.

The calculated waste volume remaining in single-shell tank 241-C-106 is between 275 and 467 ft^3 with a 95% confidence level. The nominal waste volume is 370 ft^3. The chemical and radiological characteristics have been analyzed in accordance with the approved data quality objectives.[2] The current inventory of contaminants of potential concern includes approximately 0.165 Ci of ^{99}Tc and 3.78 kg of chromium (the primary drivers of long-term human health risk via the groundwater pathway). The total curies of radionuclides have been reduced from approximately 10.1 million Ci in the tank prior to the 1998-1999 retrieval campaign to the current total of approximately 135,000 Ci (a decrease of approximately 99%).

Figure ES-2. Waste Volume Remaining following Retrieval Campaigns for Single-Shell Tank 241-C-106.



In response to HFFACO, Appendix H, Attachment 2, Criterion 5, an assessment of the expected impacts to human health if the residual waste is left in place was completed. A summary of this analysis is provided in Section 2.4. For the groundwater pathway, ^{99}Tc was identified as the primary driver of radiological incremental lifetime cancer risk and radiological dose for the all-pathways farmer and incremental lifetime cancer risk, while for nonradiological contaminants, hexavalent chromium was identified as the primary driver for human health impacts from chemicals. Incremental lifetime cancer risk from the residual waste in single-shell tank 241-C-106 does not exceed the U. S. Environmental Protection Agency risk threshold values of 1.0×10^{-4} to 10^{-6} for radionuclides. None of the 18 nonradionuclide analytes with an oral cancer potency factor were reported with a concentration above the laboratory's minimum detection limit. Using an inventory based on one-half the detection limit, the model estimated groundwater concentration for these analytes was below 0.001 μg/L, which is effectively zero.

[2] RPP-13889, 2004, *Tank 241-C-106 Component Closure Action Data Quality Objectives*, Rev.1, CH2M HILL Hanford Group, Inc., Richland, Washington.

At this point, these analytes were dropped from the analysis and incremental lifetime cancer risk was not calculated. The Hazard Index for this tank also does not exceed the *Washington Administrative Code* (WAC) 173-340-705, "Model Toxics Control Act--Cleanup, Use of Method B," threshold value of 1.0. Based on the current residual inventory, no groundwater quality standards would be exceeded. Analysis of additional retrieval indicates that further waste removal would result in insignificant reduction in health risks and groundwater quality. The impacts for the residual waste remaining in single-shell tank 241-C-106 related to the groundwater pathway per performance metric are provided in Table ES-1. Table ES-2 provides the results for the inadvertent intruder analyses.

Table ES-1. Cumulative Incremental Lifetime Cancer Risk, Hazard Index, and Radiological Drinking Water Dose from Peak Groundwater Concentration Related to Residual Waste Volume in Single-Shell Tank 241-C-106.

Metric[a]	Single-Shell Tank 241-C-106 Post-Retrieval Average Inventory		Performance Objective[b]
	Industrial Land Use	Residential Land Use	
Radioactive chemicals ILCR (unitless)	9.11E-09[c,d]	2.21E-07[c,d]	1.0E-06 to 1.0E-04[e]
Nonradioactive chemicals ILCR (unitless) WAC 173-340 Method B	Not evaluated	RNC[f]	1.0E-05[g]
Hazard Index (unitless) WAC 173-340 Method B	Not evaluated	4.57E-04[c,d]	1.0[g]
	Single-Shell Tank 241-C-106 Post-Retrieval Average Inventory		
All-pathways farmer (mrem/yr)	1.18E-03[c,d]		15[e] or 25[h]
EPA MCL beta/photon emitters (mrem/yr Target Organ Dose)	2.94E-03[c,d]		4[i]

Notes:
ILCR = incremental lifetime cancer risk.
MCL = maximum contaminant level
WMA = Waste Management Area
WAC = *Washington Administrative Code*

[a] Metric ILCR-rad was evaluated using industrial and residential land use scenarios described in HNF-SD-WM-TI-707. ILCR-nonrad and Hazard Index were evaluated using WAC 173-340-705 (4) Method B (residential).

[b] Performance objectives apply to entire WMA, not just a single component of the WMA.

[c] Analytes with a fenceline concentration of less than either 0.001 pCi/L (radioactive) or 0.001 µg/L (nonradioactive) are not included in the total.

[d] Total includes nondetects with inventory calculated at one-half the detection limit.

[e] EPA/540/R-99/006, *Radiation Risk Assessment at CERCLA Sites: Q & A, Directive 9200.4-31P.*

[f] RNC = Risk metric was not calculated because no nonradioactive analyte with a cancer slope factor was predicted to have a concentration greater than 0.001 µg/L.

[g] WAC 173-340-705 (4).

[h] DOE O 435.1, *Radioactive Waste Management.*

[i] 65 FR 76708, "National Primary Drinking Water Regulations; Radionuclides; Final Rule."

Table ES-2. Intruder Dose Summary for Single-Shell Tank 241-C-106.

Years after Closure	Inventory	Inadvertent Intruder Scenario	
		Single-Shell Tank Performance Assessment Reference Case	
		Well Driller (Acute) (mrem)	Rural Farmer with Pasture (Chronic) (mrem/yr)
500	Average	3.3	0.84

Notes:
Site closure is assumed to occur on 1/1/2032.
The performance objective for the well driller is 500 mrem. The performance objective for the other scenarios is 100 mrem/y.

Section 2.5 provides additional information regarding compliance with applicable requirements, as identified in HFFACO, Appendix H, in response to HFFACO, Appendix H, Attachment 2, Criterion 6. At the time of the May 2004 meetings between staff from the U.S. Department of Energy and Washington Department of Ecology, no additional information, beyond the information presented in this document, was identified for submission in support of this basis of exemption report. Ecology reserved the right to request additional information at a later date.

In response to HFFACO, Appendix H, Attachment 2, Criterion 1, this document concludes that if one of the four additional available waste retrieval technologies were to be deployed in single-shell tank 241-C-106, the benefit gained in the reduction of impacts to human health or the environment would not justify the cost of additional waste removal. The 2003 waste retrieval campaign resulted in the removal of 4,340 ft^3 of tank waste at a cost of approximately $22.4 million. Removal of the additional 160 ft^3 of waste would cost from $5.7 to $13.5 million. This additional waste removal, assuming a corresponding reduction in the contaminants that drive risk, would reduce the incremental lifetime cancer risk from 9.11E-09 to 5.17E-09 for the average inventory, yielding a net benefit of only 3.94E-09 incremental lifetime cancer risk averted, or 3.9 in 1 billion. In terms of all-pathways farmer dose, the corresponding risk reduction would be from 0.00118 mrem/year to 0.00067 mrem/year, yielding a net benefit of only 0.0005 mrem/year of dose averted.

The conclusion would not change if the nominal waste volume (370 ft^3) was considered instead of the 95% upper confidence level (467 ft^3). The cost for operating the alternative waste retrieval systems to retrieve 10 ft^3 would be lower than retrieving 160 ft^3; however, the operating costs are small in comparison to the construction, startup, and post-retrieval activities.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

1.0 INTRODUCTION 1-1

2.0 SUMMARY OF AVAILABLE DATA AND INFORMATION 2-1

2.1 COMPLETION OF WASTE RETRIEVAL USING EXISTING TECHNOLOGIES TO THE LIMIT OF TECHNOLOGY 2-1
2.1.1 Sluicing System Retrieval Campaign, 1998-1999 2-1
2.1.2 Modified Sluicing and Acid Dissolution Retrieval Campaign – 2003 2-3
2.1.3 Conclusions 2-10
2.2 EVALUATION OF WASTE RETRIEVAL TECHNOLOGIES 2-10
2.2.1 Additional Available Waste Retrieval Technologies 2-11
2.2.2 Potential Future Waste Retrieval Technologies 2-25
2.2.3 Conclusions 2-28
2.3 VOLUME AND CHARACTERISTICS OF RESIDUAL WASTE 2-29
2.3.1 Volume of Residual Waste 2-29
2.3.2 Characteristics of Residual Waste 2-32
2.3.3 Conclusions 2-33
2.4 EXPECTED IMPACTS TO HUMAN HEALTH AND THE ENVIRONMENT 2-36
2.4.1 Inventory and Contaminants of Potential Concern 2-36
2.4.2 Impacts to Human Health and the Environment 2-36
2.4.3 Conclusions 2-46
2.5 ADDITIONAL INFORMATION REGARDING CONFORMANCE WITH RELEVANT REQUIREMENTS 2-47

3.0 CONCLUSIONS 3-1

4.0 REFERENCES 4-1

APPENDIX – RELATIVE COMPARISON OF THE RETRIEVAL ALTERNATIVES AND NO ACTION ..... A-i

LIST OF FIGURES

Figure ES-1. Comparison of the Cost per Cubic Foot of Waste Retrieval between the 2003 Retrieval Campaign and the Additional Retrieval Technology Alternatives. . ii

Figure ES-2. Waste Volume Remaining following Retrieval Campaigns for Single-Shell Tank 241-C-106. iii

Figure 1. Total Volume Waste Remaining in Single-Shell Tank 241-C-106. 2-5

Figure 2. Borehole Location Map. 2-9

Figure 3. Comparison of the Cost per Cubic Foot of Waste Retrieval between the 2003 Retrieval Campaign and the Additional Retrieval Technology Alternatives. .. 2-22

Figure 4. Relative Comparison of Single-Shell Tank 241-C-106 Additional Retrieval Alternatives. 2-24

Figure 5. Sensitivity Case Comparison of Single-Shell Tank 241-C-106 Additional Retrieval Alternatives. 2-24

Figure 6. Single-Shell Tank 241-C-106 Waste Volume Reductions. 2-31

Figure 7. Change in Single-Shell Tank 241-C-106 Technetium-99 Residual Waste Inventory, Pre-Retrieval Compared to Post-Retrieval Sample Data and Total Waste Management Area C Inventory. 2-34

Figure 8. Inventory of Technetium-99 by Single-Shell Tank in Waste Management Area C at Completion of Single-Shell Tank 241-C-106 Retrieval. 2-35

Figure 9. Inventory of Chromium by Single-Shell Tank in Waste Management Area C at Completion of Single-Shell Tank 241-C-106 Retrieval. 2-35

Figure 10. Technetium-99 Radiological Dose for the All-Pathways Farmer at the Waste Management Area C Fenceline. 2-41

Figure 11. Incremental Lifetime Cancer Risk (Radiological Constituents) for the Industrial Worker at the Waste Management Area C Fenceline. 2-41

Figure 12. Hazard Index for the Industrial Worker at the Waste Management Area C Fenceline 2-42

Figure 13. Change in All-Pathways Farmer's Dose, Radiological Incremental Lifetime Cancer Risk for the Industrial Worker, and Hazard Index for Single-Shell Tank 241-C-106 Residual Waste as a Function of Waste Volume Reduction. 2-45

LIST OF TABLES

Table ES-1. Cumulative Incremental Lifetime Cancer Risk, Hazard Index, and Radiological Drinking Water Dose from Peak Groundwater Concentration Related to Residual Waste Volume in Single-Shell Tank 241-C-106. iv

Table ES-2. Intruder Dose Summary for Single-Shell Tank 241-C-106. v

Table 1. Material Balance Estimates for Sluice Water Additions to Single-Shell Tank 241-C-106. 2-6

Table 2. Handheld Moisture Gauge Measurements around Single-Shell Tank 241-C-106. 2-8

Table 3. Borehole Data Evaluations and Depths of Gamma and Moisture Changes around Single-Shell Tank 241-C-106. 2-10

Table 4. Comparison of Technologies and Functions. 2-13

Table 5. Comparison of Retrieval Alternatives versus Basic Retrieval Functions. 2-19

Table 6. Summary Comparison of Single-Shell Tank 241-C-106 Retrieval Alternatives. 2-20

Table 7. Single-Shell Tank 241-C-106 Waste Volumes Following Completion of Sluicing... 2-30

Table 8. Single-Shell Tank 241-C-106 Waste Volumes Following Completion of Modified Sluicing and Acid Dissolution. 2-32

Table 9. Estimate of Single-Shell Tank 241-C-106 Inventory of Total Curies Before and After the 1998-1999 and the 2003 Waste Retrieval Campaigns. 2-32

Table 10. Comparison Between Post-Retrieval Sample Inventory and Pre-Retrieval Inventory for Selected Constituents. 2-34

Table 11. Cumulative Incremental Lifetime Cancer Risk, Hazard Index, and Radiological Drinking Water Dose from Peak Groundwater Concentration Related to Post-Retrieval Residual Waste Volume in Single-Shell Tank 241-C-106. 2-37

Table 12. Comparison of Estimated Groundwater Concentrations from Single-Shell Tank 241-C-106 between Average and 95% Upper Confidence Level Inventory. .. 2-39

Table 13. Human Health Impacts for WMA C using the Post-Retrieval Average Inventory for C-106 and the HTWOS Predicted Final Inventory for Tanks C-103, C-109, C-112, and C-301. 2-40

Table 14. Relative Contribution of Single-Shell Tank 241-C-106 Residual Waste (Includes Nondetected Constituents) to Total WMA C Residual Waste All-Pathways Farmer (Dose), Industrial Receptor (ILCR-Rad), and Hazard Index at the WMA C Fenceline at Selected Retrieval Volumes. 2-43

Table 15. Intruder Dose Summary for Single-Shell Tank 241-C-106. 2-46

LIST OF TERMS

Abbreviations, Acronyms, and Initialisms

AEAT	AEA Technology Engineering Services
ALARA	as low as reasonably achievable
BBI	best-basis inventory
CAD	computer-aided design
CCMS	video camera/CAD modeling system
CH2M HILL	CH2M HILL Hanford Group, Inc.
COPC	contaminant of potential concern
DOE	U.S. Department of Energy
DQO	data quality objectives
DST	double-shell tank
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent.
EPA	U.S. Environmental Protection Agency
FY	fiscal year
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HI	Hazard Index
HIHTL	hose-in-hose transfer line
HQ	Headquarters
ILCR	incremental lifetime cancer risk
ILCR-nonrad	incremental lifetime cancer risk (nonradiological)
ILCR-rad	incremental lifetime cancer risk (radiological)
ITV	in-tank vehicle
k_d	distribution coefficient
MCL	maximum contaminant level
MLDUA	Modified Light-Duty Utility Arm
MRS	mobile retrieval system
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORP	U.S. Department of Energy, Office of River Protection
RPP	River Protection Project
SST	single-shell tank
TWINS	Tank Waste Information Network System
UCL	upper confidence level
VRS	vacuum retrieval system
WTP	Waste Treatment and Immobilization Plant
WMA	Waste Management Area

Units

%	percent
ft	foot
ft^3	cubic feet
ft^3/min	cubic feet per minute

gal	gallon
in.	inch
L	liters
m	meter
mrem/yr	millirem per year
pCi	picocurie
vol%	volume percent

1.0 INTRODUCTION

This document was prepared to comply with Ecology et al. (1989), *Hanford Federal Facility Agreement and Consent Order* (HFFACO), Milestone M-45-05H and target date M-45-05M-T01. The document presents the basis for an exception to the waste retrieval criteria established in the HFFACO for single-shell tank 241-C-106 (SST C-106). This document was revised from its previous revision to incorporate responses to comments from the U.S. Nuclear Regulatory Commission (NRC) and the Washington State Department of Ecology (Ecology), a revised inventory taken from Revision 1 of RPP-20699, *Tank 241-C-106 Residual Waste Inventory Estimates for Component Closure Risk Assessment*, and a revised risk assessment based on DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site.*

The HFFACO states that the waste retrieval criteria in Milestone M-45-00 are to be applied on a tank-by-tank basis. If the U.S. Department of Energy (DOE) does not believe the criteria are achievable for a specific tank, DOE must submit a request for an exception to the U.S. Environmental Protection Agency (EPA) and Ecology for approval in accordance with the procedure outlined in HFFACO, Appendix H. Appendix H, Attachment 2, of the HFFACO lists the specific content requirements for the request for an exception from the waste retrieval volume limit of less than 360 ft^3 of residual waste for 100-series SSTs following completion of waste retrieval identified in Milestone M-45-00. According to Attachment 2, a request for an exception must include, as a minimum, the following information:

1. The reason DOE does not believe the waste retrieval criteria can be met.
2. Schedule, using existing technology, to complete retrieval to the criteria—if possible.
3. Potential for future waste retrieval technology developments that could achieve the waste retrieval criteria, including estimated schedules and costs for development and deployment of technologies.
4. Volume of waste proposed to be left in place, and its chemical and radiological characteristics.
5. Expected impacts to human health and the environment if the residual waste is left in place.
6. Additional information as required by EPA and/or Ecology.

Based on discussions with the EPA and Ecology, DOE has determined that it would be helpful for the NRC to review the waste retrieval actions completed at SST C-106 as described in this document. Therefore, DOE will request NRC to perform a technical review of this document and assess the soundness of DOE's conclusions regarding completion of retrieval.

Section 2.1 responds to Criterion 2 and documents the basis for determining that completing waste retrieval to the HFFACO waste retrieval criteria is not possible "using existing technology." Section 2.2 responds to Criterion 3 and documents the basis for determining that attaining the HFFACO waste retrieval criteria is not practical using additional available retrieval technologies or "future waste retrieval technology developments." Section 2.3 responds to Criterion 4 and documents the residual waste volume and its chemical and radiological

characteristics, and Section 2.4 responds to Criterion 5 and presents the "expected impacts to human health and the environment if the residual waste is left in place." Section 2.5 responds to Criterion 6 and provides additional information regarding conformance with relevant requirements as identified in HFFACO, Appendix H. Section 3.0 responds to Criterion 1, drawing on the information and conclusions presented in Section 2.0 to form the basis of the position that the HFFACO retrieval criteria cannot be met.

Throughout the text of this document, numbers were rounded to two significant figures (e.g., 212 would be rounded to 210 and 0.126 would be rounded to 0.13). Numbers in tables and figures derived from supporting and referenced documents have not been rounded to preserve traceability to the source information. In certain cases, numbers in the text were not rounded to preserve the ability to understand differences between comparable numbers and/or between the number presented and those established in standards and/or requirements.

Where information regarding treatment, management, and disposal of the radioactive source, byproduct material, and/or special nuclear components of mixed waste (as defined by the *Atomic Energy Act of 1954*, as amended) has been incorporated into this document, it is not incorporated for the purpose of regulating the radiation hazards of such components under the authority of Chapter 70.105, "Hazardous waste management," Revised Code of Washington and its implementing regulations, but is provided for information purposes only.

2.0 SUMMARY OF AVAILABLE DATA AND INFORMATION

This section responds to HFFACO, Appendix H, Attachment 2, Criteria 2 through 5. The information and conclusions presented in this section support the response to Criterion 1, which is presented in Section 3.0.

2.1 COMPLETION OF WASTE RETRIEVAL USING EXISTING TECHNOLOGIES TO THE LIMIT OF TECHNOLOGY

This section responds to HFFACO, Appendix H, Attachment 2, Criterion 2: "Schedule, using existing technology, to complete retrieval to the criteria—if possible." The information provided documents that the existing technologies previously deployed to retrieve waste from SST C-106 cannot complete waste retrieval to the HFFACO retrieval criteria.

Two retrieval technologies have been deployed to retrieve waste from SST C-106. The first technology deployed was sluicing. This technology was deployed in November 1998 and reached the limit of its capability in October 1999. In April 2003, a second retrieval campaign was initiated with the pumping of 18,000 gal of liquid from SST C-106. The second retrieval technology deployed in SST C-106 as a retrieval technology demonstration under the HFFACO was modified sluicing with acid dissolution. This technology reached the technical limit of its capability in December 2003.

2.1.1 Sluicing System Retrieval Campaign, 1998-1999

SST C-106 is a 530,000-gal tank that was used to store mixed radioactive waste since the tank was placed in service in 1947. At its peak during operation, SST C-106 contained as much as 530,000 gal of waste. Numerous waste transfers were made into and out of SST C-106 over its 30-plus year operating history. When operations ceased, about 230,000 gal of waste remained. As with other Hanford tanks, SST C-106 received waste from various sources during its operational life from 1947 until 1979. During this time, SST C-106 waste was transferred to other tanks in a number of batches. Prior to declaring the tank inactive in 1979, most of the supernate in the tank was pumped out leaving approximately 230,000 gal of waste remaining in the tank.

To address a high-heat safety issue, a waste retrieval effort using a sluicing system was initiated in SST C-106 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 double-shell tank (DST) 241-AY-102 (DST AY-102) supernate as a sluicing medium.

The sluicing effort successfully resolved the SST C-106 high-heat safety issue. The campaign also met the following waste retrieval requirements:

- Retrieve at least 95% (approximately 187,000 gal.) of the estimated total sludge of 1.8 m (6 ft) from SST C-106.

- Retrieve waste from SST C-106 until the rate of sludge removal is less than 7,500 gal (approximately 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 SST 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-45-03B"].

In July 2000, approximately 44,892 gal of solid and liquid waste remained in SST C-106 (RPP-12547, *Tank 241-C-106 Residual Liquids and Solids Volume Calculation*). In August 2002, a new measurement estimated waste volume in SST C-106 at 35,986 gal. From July 2000 to August 2002, the volume of liquids decreased by approximately 10,000 gal. The reduction in liquid volume was attributed to evaporation. For SST C-106, the evaporation rate was evaluated based on measured moisture content in the air being exhausted from the tank following conclusion of the 1998-1999 waste retrieval campaign. The total difference between the 2000 and the 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 1998-1999 sluicing campaign was completed in October 1999. The ventilation system (which also served SST C-105) operated until June 2001. Prior to 1998, SST C-106 was the high-heat tank and the evaporation rate was about 189 gal/day (in 1994). Following the 1998-1999 retrieval, the average evaporation rate was between 10 and 24 gal/day.

Monthly psychrometric readings were taken for the SST C-106 ventilation system until agreement to cease readings was reached. Ecology agreed with the decision to cease collecting psychrometric readings in 2001 and sent the DOE and CH2M HILL Hanford Group, Inc. (CH2M HILL) a concurrence letter 0101378, "Transmittal of Concurrence with Decision to Cease Collecting Psychrometric Survey Data for Single-Shell Tanks 241-C-105 and 241-C-106" (letter 0101378) The following is a statement from letter 0101378:

> We concur with the U.S. Department of Energy's contention that 241-C-106 no longer requires psychrometric monitoring. Ecology has reviewed available tank data on that tank and has no other related concerns.

In letter 0101378, Ecology did not concur with ceasing SST C-105 data collection.

Retrieval engineers completed review of the monthly psychrometric data and the volume measurements that confirmed the monthly evaporation was from 10 gal/day to a much higher rate. Evaporation of liquid in the tanks is controlled by the surface area of liquid, temperature, and the sweep of air (ventilation flow rate). As long as the tanks are actively ventilated (in 2000 the rate was about 2,600 ft^3/min), evaporation occurs at a fairly high rate due to the large surface area in a 75-ft-diameter tank. For additional information regarding waste volume estimates for SST C-106, see Section 2.3.

Additionally, the U.S. Department of Energy, Office of River Protection (ORP) completed drywell spectral scans prior to, during, and following the 1998-1999 waste retrieval campaign

(RPP-7305, *Spectral Drywell Scans Around C-106 During Retrieval Operations*). Data from these monitoring efforts were provided to Ecology in 2001. Therefore, the data collected prior to, during, and following the 1998-1999 retrieval campaign provide no evidence of a leak loss during waste retrieval operations.

2.1.2 Modified Sluicing and Acid Dissolution Retrieval Campaign – 2003

To remove the remaining waste in SST C-106, a retrieval demonstration campaign, defined in the HFFACO, was initiated in April 2003. From project start through completion of retrieval activities in December 2003, the total cost for this project was approximately $22.4 million. This campaign began in April 2003 by pumping approximately 18,000 gal of liquid from SST C-106 to DST AY-102. The 2003 campaign continued through December 2003 using modified sluicing and acid dissolution removing an additional approximately 14,500 gal of waste.

Modified sluicing uses various performance enhancements over the “past-practice” sluicing techniques used to remove the bulk of SST C-106 waste (see Section 2.1.1). These enhancements included combinations of pump and nozzle designs to break up the solids and move them to the pump intake. Acid dissolution reflects the use of oxalic acid to dissolve solids. Oxalic acid, which has historically been used at the Hanford Site and other DOE sites to decontaminate tanks and equipment, was used to dissolve solids. The combination of the two methods was designed to maximize removal of the residual waste.

Through experience gained operating DOE Savannah River Site facilities, the effectiveness of oxalic acid to remove contamination on waste processing equipment was documented (WSRC-TR-2003-00401, *Waste Tank Heel Chemical Cleaning Summary*). Laboratory-scale testing of acid dissolution (using a sample of the SST C-106 waste) demonstrated that nearly 70% 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 retrieval operation of SST C-106:

- Oxalic acid was added in discrete and accurately measured batches through the mixer-eductor or the pump drop-leg (for volumes of oxalic acid added per batch, see RPP-20110, *Stage I Retrieval Data Report for Single-Shell Tank 241-C-106*, Section 2.7.1).

- Acid was recirculated with the mixer-eductor (for the first four batches of oxalic acid), followed by removal of the acid using the retrieval pump.

- Water was continuously added (between 85 and 350 gal/min) 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.

The oxalic acid dissolution process leached additional waste constituents directly from the sludge and also reacted with carbonates in the waste to increase solid waste porosity. Both 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. At the completion of the acid reaction, the dissolved wastes were transferred via a pump to DST AN-106.

During acid dissolution, operations were performed using oxalic acid with a concentration of 0.9 molar. For the first four batches of oxalic acid, the mixer-eductor was used to recirculate the oxalic acid in SST C-106. The acid dissolution reaction for each acid batch reached steady state (i.e., reaction complete) after an average of 7 days based on in-tank monitoring of waste pH levels. After the acid reaction reached steady state, dissolved wastes were transferred via a pump to DST AN-106.

Recirculation of the oxalic acid batches was no longer possible after removal of the mixer-eductor following the fourth 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.

The modified sluicing technology used a hydraulic process that deployed an articulated high-pressure water head that moved the slurry to the retrieval pump intake. In the 2003 retrieval campaign, sluicing 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, sluicing created piles of solids against the tank walls in the location of the tank circumference farthest from the sluicer. The motive force of the sluicer nozzle at this configuration of waste could not move the remaining waste to the pump intake.

The chronology for the retrieval operations in SST C-106 is shown in the following. Figure 1 summarizes the relationship between the six oxalic acid batch campaigns and four sluicing campaigns and the remaining waste volume in SST C-106 calculated from material balance data.

- About 187,000 gal of waste were removed from SST C-106 during the retrieval operation in 1998 and 1999. At that time, 62,000 gal of residual waste were left in the tank, which included an estimated 5,200 gal of solids.

- About 18,000 gal of residual supernate were pumped from the tank, starting April 1, 2003. Evaporation of water reduced the volume that was left following the end of sluicing in 1999 to about 36,000 gal.

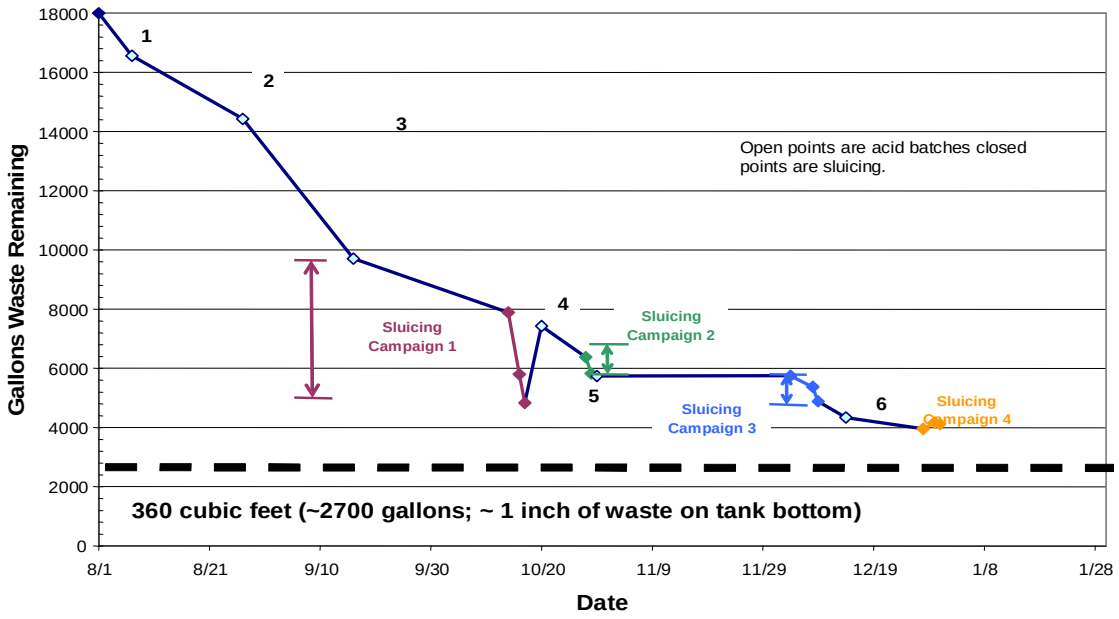
- The sluicer in Riser R-3 was used to level the solids and rinse soluble constituents. Approximately 37,000 gal of sluicing liquid was pumped, starting June 9, 2003. Starting waste volume was determined.

- The first oxalic acid batch was added, starting August 7, 2003.

- The second oxalic acid batch was added, starting August 27, 2003.

- The third oxalic acid batch was added, starting September 16, 2003.

Figure 1. Total Volume Waste Remaining in Single-Shell Tank 241-C-106.



Note: Numbers 1 through 6 indicate oxalic acid batch campaign. Waste remaining based on material balance calculations.

- To prepare for sluicing, the pump was replaced and the new pump tested, starting October 3, 2003.
- The first modified sluicing operation was conducted, starting October 14, 2003.
- The fourth oxalic acid batch was added, starting October 20, 2003.
- The second modified sluicing operation was conducted, starting October 28, 2003.
- The fifth oxalic acid batch was added, starting October 30, 2003.
- To allow for additional spray head coverage, the mixer-eductor was replaced by the second sluicer, starting November 6, 2003.
- The third modified sluicing operation was conducted, starting December 4, 2003.
- The sixth oxalic acid batch was added, starting December 14, 2003.
- The fourth modified sluicing operation was conducted, starting December 28, 2003.
- In January 2004, approximately 15,000 gal of buffer (caustic) was added to SST C-106.

In response to the diminished performance of the single sluicer head, the mixer-eductor was 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 sluicing following the sixth oxalic acid addition and fourth sluicing operation.

Table 1 contains the material balance of the sluicing operations. The material balance for the sluicing operations was recorded to determine 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 this technology. An observed declining trend of waste removed for each sluicing operation ranged from 8% for the first operation to 0.3% for the final operation.

Table 1. Material Balance Estimates for Sluice Water Additions to Single-Shell Tank 241-C-106.

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

Notes:
DST = double-shell tank.
[a] Estimate of volume of waste removed for each sluicing campaign.

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

1. **Acid Dissolution**—The purpose of the acid dissolution process was to dissolve the sludge and the solid waste prior to sluicing. The result of this reaction included increased solution density and smaller waste particle size, which allowed increased waste removal once sluicing commenced. The smaller particle size allowed more waste to be entrained and then pumped out of the tank. The estimated 18,000 gal of waste left in the tank following the April 2003 pumping of 18,000 gal of liquids from SST C-106 and prior to retrieval, using modified sluicing and acid dissolution, 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 (RPP-13707, *Process Control Plan for Tank 241-C-106 Closure)* and the data were recorded for each batch until steady-state pH readings were attained. Oxalic acid was added in six separate

batches during the retrieval, and the dissolution performance ended in diminished returns for the last two acid batches. In the final batch, the pH of the solution showed a gradual increase during the first 6 days, indicating that the acid was reacting with the waste and then no increase (steady state) during the rest of the contact period. The average pH over the last 4 days was approximately 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 some waste remained unreacted, and that the limits of this technology to further dissolve and entrain waste had been reached (RPP-20110). The result of waste forms not dissolving in the acid are consistent with the laboratory testing, which documented that up to 30% of the solids would not dissolve in oxalic acid (RPP-17158).

2. **Waste Entrainment**—The waste solids remaining were resistant to further breakdown to a smaller size either by acid dissolution or by mechanical breakup by the sluicing stream. This was documented by the diminished mass transfer of solids in the waste slurry pumped from the tank (RPP-20577, *Stage II Retrieval Data Report for Single-Shell Tank 241-C-106*). Therefore, the remaining solids would not likely be entrained in waste slurry at a rate equal to or higher than the efficiencies documented in the last sluicing batches.

3. **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 (RPP-19866, *Calculation for the Post-Retrieval Waste Volume Determination for Tank 241-C-106*). 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 then 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. During the last sluicing, the two nozzles were not able to appreciably move additional waste to the pump inlet as indicated by the diminishing amount of entrained waste recorded.

At the limit of waste retrieval technology performance for modified sluicing and acid dissolution, approximately 467 ft^3 of waste based on the 95% upper confidence level (UCL) remained in SST C-106. The residual waste estimate based on the 95% UCL reflects uncertainty in the residual waste measurement technique. The actual waste volume measurement (also known as the nominal residual waste volume) in SST C-106 at the limit of the retrieval technology was calculated consistent with the methodology identified in HFFACO, Appendix H, Attachment 1, to be approximately 370 ft^3. The residual waste volume at the 95% lower confidence level is 275 ft^3. See Section 2.3 for additional information regarding residual waste volume estimates and the characteristics of the residual waste remaining in SST C-106.

In-tank and ex-tank measurements were performed to monitor potential leak losses from SST C-106 during waste retrieval operations. The in-tank measurements included assessment of the material balance and liquid-level measurements prior to, during, and following the retrieval campaign. The material balance was consistent throughout the retrieval campaign resulting in a

cumulative material balance to within 341 gal. Exceptions to the material balance were attributable to major equipment changes prior to the initial modified sluicing operation and a DST AN-106 level reading that over accounted for recovery on December 4, 2003. Liquid level measurements were taken during extended periods of stable liquid levels in the tank including prior to retrieval from February 26 to March 26, 2003 (readings ranged from 18.09 to 18.08 in.); during retrieval operations from November 14 to December 2, 2003 (readings ranged from 14.72 to 14.73 in.); and post-retrieval in January 2004 when liquid levels were stable in the tank for 5 days, recording measurements ranging from 23.74 to 23.73 in.

The ex-tank measurements included borehole logging data from logging events using hand-held moisture gauges and logging vans from April 2003 through February 2004 (prior to, during, and following the retrieval campaign). Hand-held moisture gauges were used to take measurements in eight boreholes at various depths in accordance with the Process Control Plan nominally on a weekly frequency. Moisture measurements were taken on up to 38 occasions from July 2003 to April 2004. Table 2 identifies the boreholes logged with the handheld moisture gauges and the number of occasions for which data was obtained for each borehole. Figure 2 provides a map view of borehole locations at SST C-106.

Table 2. Handheld Moisture Gauge Measurements around Single-Shell Tank 241-C-106.

Borehole	Number of Occasions Borehole Logged	Total Number of Measurements All Occasions
30-06-02	38	188
30-00-01	29	29
30-06-03	37	186
30-06-04	36	213
30-05-02	36	493
30-06-09	36	465
30-06-10	38	1136
30-06-12	37	215

In December 2003, an increase in moisture content in two boreholes, 30-06-09 and 30-05-02, was identified. In response, CH2M HILL requested S. M. Stoller Corporation to perform spectral gamma logging at boreholes in the vicinity of SST C-106 and to evaluate borehole data to help determine if an increase in moisture content was associated with leakage during retrieval from SST C-106 (DOE-EM/GJ899-2005, *241-C-106 Tank Waste Retrieval Project Final Report of Drywell Monitoring Data*). S. M. Stoller evaluated spectral gamma, total gamma, and neutron moisture logging data collected between January 1997 and May 2004 from 10 boreholes in the vicinity of SST C-106. Table 3 summarizes the logging measurements acquired and evaluated for each borehole, and the depths of changes in gamma signature or moisture content. DOE-EM/GJ899-2005 provides detailed information regarding borehole geophysical logging data collected around SST C-106.

Figure 2. Borehole Location Map.

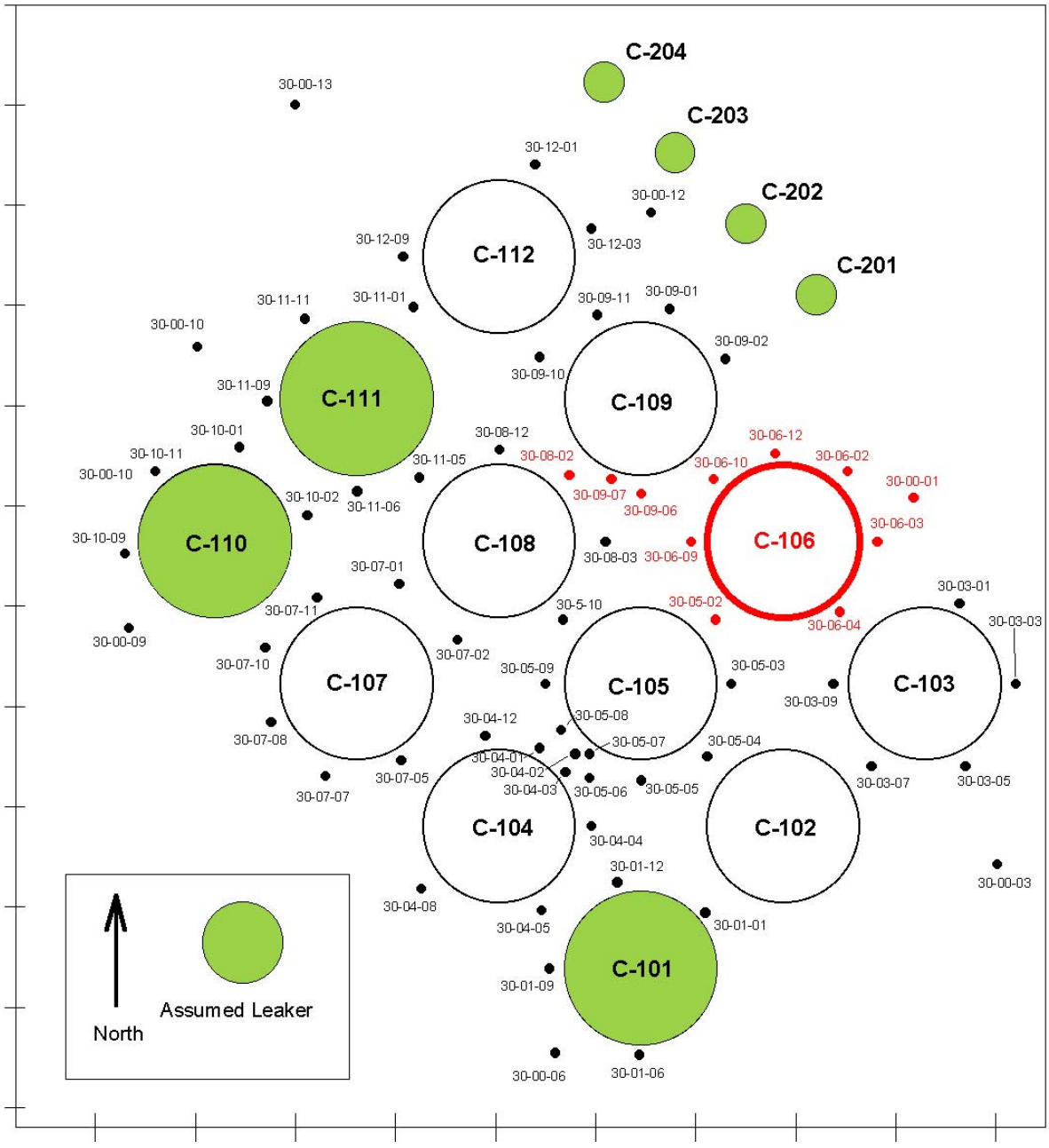


Table 3. Borehole Data Evaluations and Depths of Gamma and Moisture Changes around Single-Shell Tank 241-C-106.

Borehole	SGLS[a]	RAS[b]	NMLS[c]	Gamma Change	Moisture Change
30-06-02	2	8	7	None	56-72 ft
30-06-03	1	8	7	None	55-67 ft
30-06-04	2	9	7	85-91 ft	46-55 ft
30-05-02	2	9	8	None	41-62 ft
30-06-09	2	9	7	None	50-72 ft
30-06-10	3	8	7	116-130 ft	42-54 ft
30-06-12	1	8	7	None	50-60 ft
30-08-02	2	7	2	47-80 ft	None
30-09-07	1	7	2	None	None
30-09-06	1	7	2	78-87 ft	None

[a] Spectral Gamma Logging System (SGLS) provides spectral gamma data.
[b] Radionuclide Assessment System (RAS) was run in the total gamma mode to collect total gamma data.
[c] Neutron Moisture Logging System (NMLS) collects moisture data.

S. M. Stoller Corporation concluded that the observed moisture content increases, with no corresponding increase in gamma activity, were probably associated with seasonal moisture fluctuation rather than a retrieval leak loss. Therefore, both the in-tank and ex-tank measurements supported the conclusion that there was no evidence of a leak loss event during SST C-106 retrieval operations.

2.1.3 Conclusions

The limits of technology for retrieving waste from SST C-106 have been reached for deployment of the following:

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

2.2 EVALUATION OF WASTE RETRIEVAL TECHNOLOGIES

This section responds to HFFACO, Appendix H, Attachment 2, Criterion 3: "Potential for future waste retrieval technology development that could achieve the [waste retrieval] criteria, including estimated schedules and costs for development and deployment [of technologies]." This section describes and compares evaluations of additional waste retrieval technologies that were available at the time SST C-106 retrieval was completed (i.e., do not require further research and development prior to deployment) consistent with the description of additional retrieval technologies provided in HFFACO, Appendix H. It also describes future potential waste retrieval technologies requiring research and development that have potential for future deployment at the Hanford Site tank farms but are not sufficiently mature to evaluate for deployment at this time.

The information provided documents that three additional technologies [modified sluicing, vacuum retrieval system (VRS), and mobile retrieval system (MRS)] configured in four alternatives are sufficiently mature to evaluate for potential deployment to retrieve additional waste from SST C-106.

Cost, schedule, and performance data are presented, as well as an assessment of technical uncertainties potentially limiting the capacity of the technologies to effectively retrieve waste to the HFFACO retrieval criteria. Two additional retrieval technologies are now available that were not available at the time retrieval of SST C-106 was completed. These two technologies are the remote water lance (also known as the Salt Mantis[3]) and the rotary viper. Both technologies are described in Appendix G of RPP-20577. Because neither technology is applicable to the type of waste in SST C-106 and neither offers advantages over the technologies already evaluated for retrieval of additional waste from SST C-106, application of these technologies is not included in Section 2.2.1. The two technologies are discussed in RPP-20577 for the purposes of completeness.

2.2.1 Additional Available Waste Retrieval Technologies

Evaluation of additional waste retrieval technologies was performed using a three-step process that included

- Identifying the retrieval functions the technologies would need to perform.
- Identifying retrieval technologies/alternatives that could be deployed in SST C-106 without further research and development.
- Comparing the relative effectiveness of the additional available technologies/alternatives against performance objectives.

2.2.1.1. Additional Available Waste Retrieval Technologies. Additional waste retrieval technologies available at the Hanford Site at the time SST C-106 retrieval was completed and that could be scheduled for deployment in SST C-106 include the following:

- **Modified Sluicing**—Consists of sluicing system (water supply, nozzles, and controls), a centralized pump, and a transfer system. Modified sluicing has been or is currently being deployed on saltcake tanks (SSTs S-102 and S-112) and sludge tanks (used in SSTs C-106 and C-103).
- **Vacuum Retrieval System**—Consists of an articulated vacuum mast, batch vacuum vessel, control system, and a transfer system. The VRSs were deployed in the C-200-series tanks and are planned to be deployed in the U-200, B-200, and T-200-series tanks.

[3] TMR Salt Mantis is a Mantis technology of TMR Associates, Lakewood, Colorado.

- **Mobile Retrieval System**—The MRS is a combination of the VRS and an in-tank vehicle (ITV). The system is currently slated for deployment on SSTs T-110, T-111, C-101, C-110, and C-111. The MRS is typically identified as the waste retrieval technology for leaking 100-series tanks.

- **Chemical Addition**—The chemical addition system consists of adding chemicals to dissolve and loosen up waste. The chemical addition system was recently deployed on SST C-106.

Table 4 shows the retrieval technologies available at the time SST C-106 retrieval was completed and describes how well the technologies perform various waste retrieval functions including the following:

- Dissolving waste.
- Breaking up agglomerated waste.
- Mobilizing/moving waste in the tank.
- Transferring waste out of tank.
- Minimizing waste volume.

Many of the waste retrieval technologies that could be deployed in the near term could satisfy multiple retrieval functions.

2.2.1.2. Development of Retrieval Alternatives using Additional Available Technologies. A range of alternatives was identified to compare the ability of the technologies to meet performance criteria (e.g., dissolve and break up waste and mobilize and transfer waste). Alternatives were identified by combining waste retrieval technologies, as necessary, to satisfy all the functions of waste retrieval. In this section, alternatives are discussed and costs, schedules, and deployment requirements are identified. The basis for water usage and detailed cost estimates for each alternative are documented in RPP-20577, Section 4.1.3.

While it is the overall goal to define systems that will remove as much of the residuals as possible, the alternatives described in the following are discussed in the context of a common "minimum volume goal" of 200 ft^3 (i.e., removal of 160 ft^3). At the 95% UCL of residual waste remaining in a tank, 467 ft^3 are present in the tank and the alternative retrieval technology selected must retrieve at least an additional 107 ft^3 of waste from the tank to reach the 360 ft^3 residual waste volume requirement. At the nominal residual waste volume of 370 ft^3 an additional 10 ft^3 would need to be retrieved to reach the 360 ft^3 residual waste volume requirements. To ensure the residual waste volume in the tank is less than or equal to the 360 ft^3 requirement, the removal volume goal was conservatively set at 160 ft^3 based on the estimation error associated with the residual waste volume determination and the additional uncertainties associated with the waste retrieval technology performance.

Each of the alternatives potentially could attain the minimum volume goal; however, there are differences in costs, schedule, and water usage impacts to the DSTs and the evaporator, as well as ease of implementation and technical risk.

Table 4. Comparison of Technologies and Functions.

Retrieval Technology Systems	Functions					
	Dissolve Waste	**Break Up Waste**	**Mobilize/Move Waste In Tank**	**Transport Waste Out of Tank**	**Transport to Receiver Tank**	**Minimize Waste**
Modified sluicing – saltcake tank	Via water addition through spray nozzles or pump drop-leg. Waste dissolution also occurs during soak periods.	Via water nozzles. Not all waste will break up via water agitation.	Via directed water spray from nozzles. Not all waste can be directed to the pump intake via water spray.	Via in-tank pump. Waste particles must be small enough to pass through pump intake screen.	Via in-tank pump. No booster pump is required.	Waste minimized by using as little water as possible and optimizing conditions such as raw water temperature.
Modified sluicing – sludge tank	N/A	Via water nozzles. Not all waste will break up via water agitation.	Via water nozzles. Not all waste can be directed to the pump intake via water spray.	Via in-tank pump. Waste particles must be small enough to pass through pump intake screen.	Via in-tank pump. No booster pump is required.	Waste minimized by using as little water as possible. Could be accomplished through recirculation of supernate.
Vacuum retrieval	N/A	Waste within vacuum wand operating radius broken up via vacuum wand and scarifying nozzles.	Waste within vacuum wand operating radius is moved/mobilized via the vacuum mast suction and physical manipulation with the vacuum wand.	Waste is removed from the tank via the vacuum wand suction.	Ex-tank vacuum vessel and booster pump.	Waste minimized by using as little water as possible. Could be accomplished through recirculation of supernate.
Mobile retrieval	N/A	Waste within vacuum wand operating radius broken up via vacuum wand and scarifying nozzles. Waste located on the floor of the tank can be broken up via the ITV blade or tracks or water cannon.	Vacuum wand and scarifying nozzles in radius of influence, ITV in all floor areas.	Waste is removed from the tank via the vacuum wand suction.	Ex-tank vacuum vessel and booster pump.	Waste minimized by using as little water as possible. Could be accomplished through recirculation of supernate.
Chemical addition	Via chemical addition and soaking.	Dissolves waste and potentially softens solids.	N/A. Must be combined with other waste transport technology.	N/A. Must be combined with other waste transport technology.	N/A. Must be combined with other waste transport technology.	Waste minimized by using as little chemical addition as possible.

Notes:
ITV = in-tank vehicle.
N/A = not applicable.

Each of the four alternatives for deployment of additional retrieval technologies discussed in this section pose technical challenges and risks that may inhibit their capability to attain the HFFACO retrieval criteria. Among the areas of technical uncertainty are the following:

- The MRS and VRS have yet to be demonstrated in Hanford Site 100-series SSTs. The VRS was used to retrieve waste from C-200-series tanks. The results of these retrieval activities for SSTs C-201, C-202, and C-203 are 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*; and RPP-RPT-26475, *Retrieval Data Report for Single-Shell Tank 241-C-203*, respectively. The results of retrieval activities at C-204 are documented in RPP-RPT-34062, *Retrieval Data Report for Single-Shell Tank 241-C-204*. Demonstration of the MRS has not been completed. Until the demonstrations are complete on comparable tanks (i.e., 100-series tanks) and tank waste (i.e., residual sludge), assurance that either technology could retrieve waste to the HFFACO retrieval criteria remains uncertain.

- Three of the technologies involve deployment of modified sluicing using existing or new equipment (e.g., pumps) under new configurations of risers. The 2003 retrieval campaign involved several mid-campaign optimizations (e.g., reconfiguration of nozzles) of equipment and/or operations that enhanced retrieval effectiveness but failed to complete retrieval of waste to the HFFACO retrieval goal. Further optimizations incorporated into the evaluated alternatives may result in additional waste retrieval; however, the quantity of waste that will be retrieved under the alternatives is uncertain.

The cost estimates used in the evaluation were based on the following:

- SSTs C-103/C-105 Tank Retrieval Systems Fair Cost Estimate (Requisition 108596) was used for the basis of this estimate.
- CH2M HILL operations-related information was provided by a CH2M HILL subject matter expert, Operations Engineer for Project C-106 Retrieval.
- All construction work was assumed to be performed by Plant Forces.
- Project management was applied at 15% of total project cost.
- Title III engineering cost was based on 30% of construction cost.
- Health physics technician costs were developed based on a 4 to 1 ratio of construction personnel.
- Industrial hygiene technician costs were developed based on an 8 to 1 ratio of construction personnel.
- Estimates for characterization and reassessment of closure status were provided by the CH2M HILL Retrieval/Closure Special Projects Manager.
- It was assumed that additional procedures will be required for this activity.

2.2.1.2.1. Alternative A – Raw Water Modified Sluicing (Current Equipment).
For Alternative A, the current SST C-106 modified sluicing system would be restarted and operated to remove tank waste until the minimum goal is satisfied. It is anticipated that retrieval of 160 ft^3 of waste would require approximately 1,870,000 gal of raw water (RPP-20577, Appendix C). Restarting the SST C-106 modified sluicing system includes the following steps:

- Reconnect the hose-in-hose transfer line (HIHTL) from SST C-200-series tanks to the SST C-106 system.
- Reinstall and/or reconnect any SST C-106 equipment that has been decommissioned.
- Operate sluicers and pump until minimum volume goal or lower has been achieved.
- Evaluate volume remaining.
- Collect samples and characterize.
- Decommission equipment.

The use of oxalic acid or a substitute chemical such as nitric acid or a chemical solution such as oxalic acid and nitric acid combined is not expected to be more effective than sluicing. Oxalic acid was added in six separate batches during the retrieval in 2003. Diminishing returns were achieved with the last two acid batches. In the last batch, the pH after 8 days was about 0.79, and the reading did not increase over the last 4 days. Fully depleted oxalic acid is expected to reach a pH of 1.5. The lower pH indicates that all of the reactive solids had reacted. These results confirm laboratory testing showing that about 30% of the solids would not dissolve in oxalic acid. Because the solids in the tank have been exposed to multiple batches of oxalic acid, additional dissolution of the solids would be minimal.

Use of an alternative acid or mixture of acids is not expected to be effective based on the laboratory work (RPP-17158). The laboratory tests at the Savannah River Site and Hanford Site showed the oxalic acid was generally as effective as any other acid for dissolving the sludges in the storage tanks. The use of nitric acid was only slightly more effective than oxalic acid for these sludges. Nitric acid was rejected for use because of the marginal dissolution improvement and the measurable oxidation of tank surfaces. At this time, nitric acid is not considered suitable for tank waste retrieval. For these reasons, chemical addition/modified sluicing is not evaluated further.

The estimated implementation cost for Alternative A is approximately $1.9 million and there would be $3.7 million in evaporator costs resulting in a total retrieval and storage cost of $5.7 million. Due to the high volume of water required for this alternative, the anticipated duration of retrieval from start to finish is approximately 12 months.

If nominal waste volumes were considered, retrieval of 10 ft^3 of waste would require approximately 170,000 gal of raw water and implementation costs would be approximately $1.6 million (estimated by scaling the operating costs). Additionally, there would be $340,000 in evaporator costs resulting in a total retrieval and storage cost of $1.9 million. Given the level of detail in the alternative, the anticipated schedule duration would remain at approximately 12 months.

2.2.1.2.2. Alternative B – New Modified Sluicing with New Slurry Pump. Alternative B consists of the design, procurement, construction, startup, and operation of an entirely new modified sluicing system specifically designed for the sludge residuals in SST C-106. This alternative would support the use of recycled DST supernate as the sluicing medium minimizing total liquid volumes. However, use of DST supernate would introduce new waste to the tank and may require flushing with raw water in later stages of the retrieval campaign. The system would include new pumps and sluice nozzles installed in new risers designed to take the residual volume from current levels to below the minimum volume goal. The new slurry pump may be a progressive cavity or other type capable of pumping solids. The existing transfer route to the AN tank farm would be used. It is anticipated that the volume of additional raw water required to attain the minimum volume goal is 90,000 gal. Implementing the Alternative B system includes the following steps:

- Reconnect the HIHTL from C-200-series tanks to SST C-106 system.
- Replace existing pump with new pump (assume progressive cavity with “fluidizer head”).
- Construct two new risers and install two new sluicer nozzles.
- Reinstall and/or reconnect any SST C-106 equipment that has been decommissioned.
- Operate system until minimum volume goal or lower has been achieved.
- Evaluate volume remaining.
- Collect samples and characterize.
- Decommission equipment.

The estimated implementation cost for Alternative B is approximately $5.7 million and there would be $180,000 in evaporator costs resulting in a total retrieval and storage cost of $5.9 million. The anticipated schedule duration from start to finish is 12 months.

If nominal waste volumes were considered, removal of 10 ft^3 of waste would require approximately 60,000 gal of raw water and implementation costs would be approximately $5.6 million. Additionally, there would be $120,000 in evaporator costs resulting in a total retrieval and storage cost of $5.7 million. Given the level of detail in the alternative, the anticipated schedule duration would remain at approximately 12 months.

2.2.1.2.3. Alternative C – Modified Sluicing (Current Equipment) Followed by New Vacuum Retrieval System. Alternative C is based on the use of modified sluicing to clean up the tank bottom and remove as much as is possible in a short period of time (with minimal water). Two new risers would then be installed near or above the areas where waste solids and fines are located. Vacuum system masts would be installed in the new risers to retrieve as much of the waste solids and fines that would fall within the approximately 20-ft vacuum mast radius. This would be a batch process where waste would be vacuumed into the batch vessel followed by water addition and slurry of the waste to the AN tank farm via the existing SST C-106 HIHTL.

The work consists of the design, procurement, construction, startup, and operation of the existing modified sluicing system and an entirely new VRS specifically designed for the sludge residuals in SST C-106. The current VRS design for B-200-series tanks would be used as a starting point. The Alternative C system would be operated to remove tank waste until the minimum volume goal is attained. It is anticipated that the volume of additional raw water required to attain the minimum volume goal is 225,000 gal. Implementing the Alternative C system includes the following steps:

- Reconnect the HIHTL from the C-200-series tanks to the SST C-106 system.
- Reinstall and/or reconnect any SST C-106 equipment that has been decommissioned.
- Operate the modified sluicing system to clean up the tank bottom.
- Install two new risers above or near the waste solids and fines (accounting for the vacuum mast 20-ft radius).
- Install two vacuum masts.
- Operate the VRS until minimum volume goal or lower has been achieved.
- Evaluate volume remaining.
- Collect samples and characterize.
- Decommission equipment.

The estimated implementation cost for Alternative C is $10.2 million and there would be $450,000 in evaporator costs resulting in a total retrieval and storage cost of $10.6 million. The anticipated duration for retrieval from start to finish is 16 months.

If nominal waste volumes were considered, removal of 10 ft^3 of waste would require approximately 60,000 gal of raw water and implementation costs would be approximately $10.1 million. Additionally, there would be $120,000 in evaporator costs resulting in a total retrieval and storage cost of $10.2 million. Given the level of detail in the alternative, the anticipated schedule duration would remain at approximately 16 months.

2.2.1.2.4. Alternative D – Mobile Retrieval System. The MRS consists of a VRS in combination with an ITV. Alternative D consists of the design, procurement, construction, startup, and operation of a new MRS specifically designed for the sludge residuals in SST C-106. The existing transfer route to the AN tank farm would be used. The MRS would be operated to remove tank waste until the minimum goal is satisfied. The MRS generates water from the vacuum system and requires significant water to transfer wastes to the AN tank farm. It is anticipated that the volume of additional raw water required to attain the minimum volume goal is 175,000 gal. Retrieving SST C-106 with the MRS includes the following steps:

- Reconnect the HIHTL from C-200 series tanks to the SST C-106 system.
- Install new ITV riser.
- Install the new ITV.

- Remove the Gorman-Rupp pump[4] from Riser 13.
- Install vacuum system.
- Operate MRS until minimum volume goal or lower has been achieved.
- Evaluate volume remaining.
- Collect samples and characterize.
- Decommission equipment.

The estimated implementation cost for Alternative D is approximately $13.1 million and there would be $350,000 in evaporator costs resulting in a total retrieval and storage cost of $13.5 million. The anticipated duration of retrieval from start to finish is 18 months.

If nominal waste volumes were considered, removal of 10 ft^3 of waste would require approximately 60,000 gal of raw water and implementation costs would be approximately $13.1 million. Additionally, there would be $120,000 in evaporator costs resulting in a total retrieval and storage cost of $13.2 million. Given the level of detail in the alternative, the anticipated schedule duration would remain at approximately 18 months.

2.2.1.3. Comparative Evaluation of Available Waste Retrieval Alternatives. The four alternatives identified in Section 2.2.1.2 were comparatively evaluated using three methods. The first method compared how well the waste retrieval alternatives satisfied the retrieval functions identified in Section 2.2.1.1. The functions compared included dissolving, breaking up, mobilizing, transferring, and minimizing waste. Table 5 presents the results of this comparison.

The second method was a comparison of the costs (retrieval implementation as well as evaporator costs for supporting efficient DST storage of the retrieved waste), schedules (start to finish for the retrieval function only), impacts on near-term DST storage (storage required to support retrieval and prior to evaporation), and the estimated total cost per cubic foot of waste retrieved to meet a minimum target level of waste retrieval that would ensure attaining the HFFACO retrieval criteria, given measurement and retrieval technology performance uncertainties. For this evaluation, comparable information was presented for the 2003 retrieval campaign. Table 6 summarizes the results of this comparison.

[4] Product of Gorman-Rupp Company, Mansfield, Ohio.

Table 5. Comparison of Retrieval Alternatives versus Basic Retrieval Functions.

Retrieval Alternatives	Functions					
	Dissolve Waste	**Break Up Waste**	**Mobilize/Move Waste In Tank**	**Transport Waste Out of Tank**	**Transport Waste to Receiver Tank**	**Minimize Waste**
A - Raw Water Modified Sluicing (Current Equipment)	N/A	Not very efficient at breaking up remaining agglomerated wastes in SST C-106.	Not very efficient at moving waste in SST C-106 due to location of sluice nozzle with respect to solids residuals. Also, “320” sluicer flow rate makes solids movement difficult due to rapid rise of liquid level in tank (high flow rate).	Satisfactory as long as waste can be moved to the intake of the pump.	Satisfactory.	Not very effective due to the high volume of required raw water to meet objectives. (1,870,000 gal)
B - New Modified Sluicing with New Slurry Pump	N/A	More effective at breaking up waste due to the proximity of the new risers and sluicers to the remaining waste areas.	More effective at moving waste due to the proximity of the new risers and sluicers to the remaining waste areas.	Satisfactory as long as waste can be moved to the intake of the pump.	Satisfactory.	Best of all alternatives at minimizing waste. Minimal raw water usage due to use of recirculated supernate. May required addition of raw water to remove supernate. (90,000 gal)
C - Modified Sluicing Followed by New Vacuum Retrieval System	N/A	More effective at breaking up waste due to the location of the new risers and vacuum masts directly over the waste areas.	Very effective at moving waste within the working area of vacuum mast. Not effective at moving waste outside this radius.	Satisfactory.	Satisfactory; however, water must be added in the batch vessel to adjust the slurry for pumping to the DST system.	Moderately effective; however, high volumes of water are needed to slurry the waste to the DST system. (225,000 gal)
D - Mobile Retrieval System	N/A	Most effective at breaking up waste due to the combination of the tracked vehicle with a blade and the vacuum mast and scarifying nozzles.	Very effective at moving waste in all parts of the tank.	Satisfactory.	Satisfactory; however, water must be added in the batch vessel to adjust the slurry for pumping to the DST system.	Moderately effective; however, high volumes of water are needed to slurry the waste to the DST system. (175,000 gal)

Notes:
DST = double-shell tank.
N/A = not applicable.
SST = single-shell tank.

Table 6. Summary Comparison of Single-Shell Tank 241-C-106 Retrieval Alternatives.

Retrieval Alternatives	Retrieval System Cost	Increase in Evaporator Costs [a]	RPP Retrieval and Storage Life-Cycle Costs	Actual or Estimated Volume of Waste Removed (ft^3) [b]	Cost per Unit Volume Removed (retrieval and storage) ($/$ft^3$)	Near-Term DST Storage Impact (gal.) [c]	Duration Start to Finish (months)
2003 Liquid Pumping/ Modified Sluicing and Acid Dissolution	$21,419,600	$1,000,000	$22,419,600	4,340	$5,170	500,000	9
A - Raw Water Modified Sluicing (Current Equipment)	$1,925,950	$3,740,000	$5,665,950	160	$35,412	1,870,000	12
B - New Modified Sluicing with New Slurry Pump	$5,668,735	$180,000	$5,848,735	160	$36,555	90,000	12
C - Modified Sluicing Followed by New Vacuum Retrieval System	$10,171,593	$450,000	$10,621,593	160	$66,385	225,000	16
D - Mobile Retrieval System	$13,131,774	$350,000	$13,481,774	160	$84,261	175,000	18

Notes:

DST = double-shell tank.

RPP = River Protection Project.

[a] Based on DOE/ORP-11242, $2/gal cost to evaporate.

[b] For the additional retrieval alternatives waste removal was assumed at 160 ft^3.

[c] DST storage required during and following retrieval and prior to evaporation.

DOE/ORP-11242, 2003, *River Protection Project System Plan.*

- **River Protection Project (RPP) Total Retrieval and Storage Cost**—Costs include the up-front design, procurement, construction, and operation costs as well as the costs resulting from sending additional volume to the evaporator. The costs are summarized in Table 6. The costs ranged from $5.7 million for Alternative A to $13.5 million for Alternative D. The cost is an estimate of the potential costs associated with each alternative. Costs not included in the estimate include costs associated with decontamination and decommissioning and/or disposal of equipment used under each alternative, and the cost of treatment and disposal of the retrieved waste. Costs not included in the retrieval alternative estimates are not included in retrieval project estimates under the RPP cost estimate process.

- **Schedule**—Alternatives A and B could be completed in the shortest amount of time, 12 months, while Alternative D would require approximately 18 months to complete.

- **Cost per Cubic Foot of Waste Volume Removed during Retrieval by Alternative**—Table 6 presents the RPP retrieval and storage total costs by alternative as well as the targeted volume of waste removal estimated for the additional retrieval technology alternatives. Table 6 also presents comparable data for the 2003 retrieval campaign, including the costs and volume of waste removed associated with liquid pumping and deployment of modified sluicing and acid dissolution. Based on the data in Table 6, Figure 3 illustrates the comparison of the cost per cubic foot of waste removed for the alternatives evaluated in this document as well as the 2003 retrieval campaign. The 2003 retrieval campaign costs approximately $5,170/ft^3 of waste retrieved from SST C-106. The cost per cubic foot of waste retrieved for the four additional evaluated alternatives would range from $35,000/ft^3 to $84,000/ft^3. These costs per unit of waste removed are a factor of 7 to 16 times greater than experienced for the 2003 retrieval campaign.

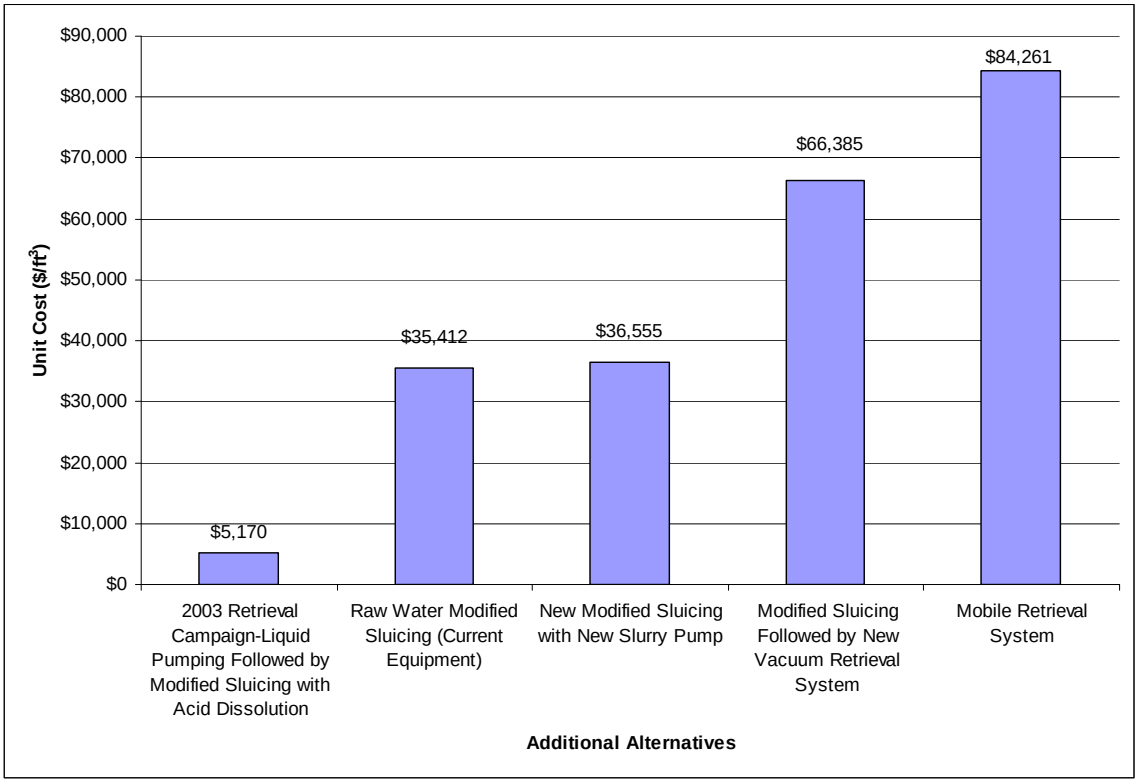
It is assumed that the appropriate assessments [e.g., criticality; waste compatibility; infrastructure impacts (e.g., transfer lines and evaporator availability); and sequence impacts] would be performed for each alternative before design and implementation of a given alternative. These assessments are not part of this discussion.

The final method used to compare the alternatives was a value engineering process, which is summarized in the following with supporting information presented in the Appendix to this document. For the purpose of the analysis, the four alternatives identified in Section 2.2.1.2 and a no further action case were considered. The no action alternative assumed no further waste retrieval activities were initiated for SST C-106.

Paired comparison analysis is particularly beneficial in establishing priorities when there are conflicting demands (e.g., cost versus schedule) on limited resources. The paired comparison analysis aided in establishing the relative importance of the following evaluation criteria:

a. **Cost of the Alternative**—This criterion includes all facets of the alternative. A higher value means the total cost for installing, operating, and demobilizing the particular technology is less than other technologies that are being considered. A higher value also means that the total estimated cost contains a higher level of confidence for completing within the indicated estimate.

Figure 3. Comparison of the Cost per Cubic Foot of Waste Retrieval between the 2003 Retrieval Campaign and the Additional Retrieval Technology Alternatives.



b. **Schedule for the Alternative**—This criterion includes all facets of the alternative. A higher value means the total duration for installing, operating, and demobilizing of the particular technology is shorter than other technologies that are being considered and that the schedule contains a higher level of confidence for achieving the scheduled end date.

c. **Risk to Workers for the Alternative**—This criterion includes as low as reasonably achievable (ALARA) considerations for both industrial (e.g., structural, chemical, electrical) and radiological safety and health. A higher value means lower risk to the worker for implementing that particular technology.

d. **Ease of Implementation for the Alternative**—This criterion refers to the level of difficulty that each alternative may include when installing, operating, and demobilizing equipment, instruments, etc. It also includes the level of project and technical risk associated with implementation. A higher value means comparatively less difficulty for implementing and less risk for that particular alternative.

e. **Risks to the Public or Nonoccupational Personnel for the Alternative**—Usually this criterion includes near-term or long-term releases to the air or surrounding soils that account for the potential risk to the environment. A higher value means comparatively lower risk to the public for that particular alternative.

f. **Impacts of each Alternative to the RPP Mission**—This criterion assesses the potential for each alternative to divert or delay other activities or programs that would otherwise be

completed. A higher value means comparatively lower impacts for that particular alternative.

Risk evaluations were based on the knowledge and expertise of the subject matter experts participating in the exercise. Risk to the public and nonoccupational personnel considered the potential probability and consequences of an environmental release during retrieval operations (i.e., short-term risk). Risk to the environment considered intrusion into or release from the residual waste in the time following loss of institutional control (i.e., long-term risk).

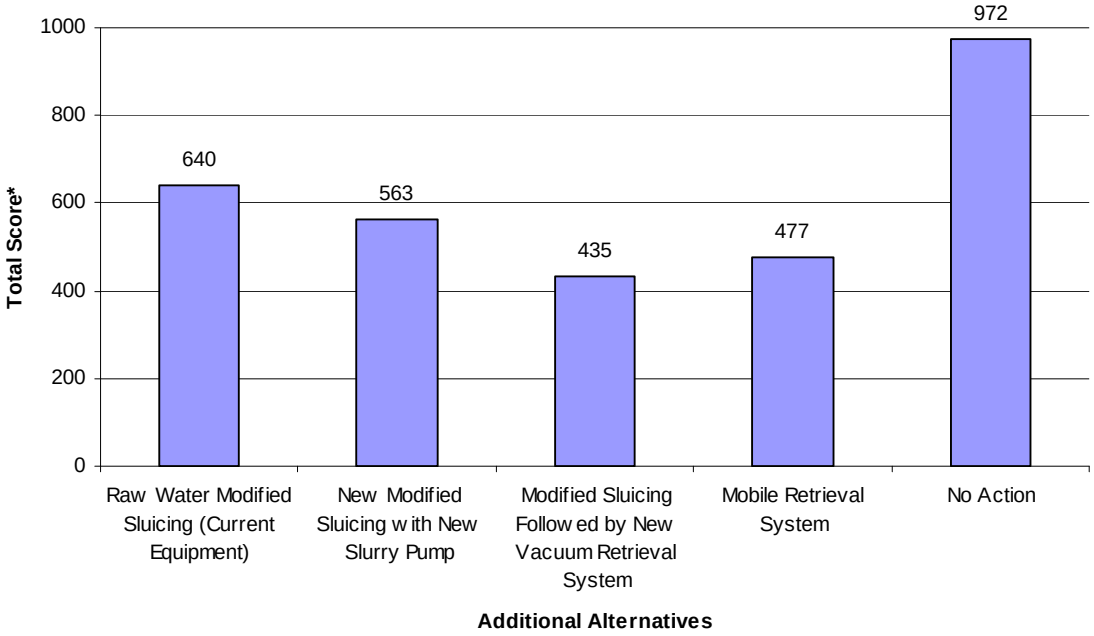
The Appendix to this document contains the results of the paired comparison analysis. The analysis was supported by subject matter experts from the DOE Office of River Protection and CH2M HILL Hanford Group, Inc. (CH2M HILL) and included representatives of retrieval engineering, strategic planning, process engineering, tank closure, and regulatory compliance.

The paired comparison process is a decision-making tool that facilitates selection among management choices based on available information and the informed knowledge of subject matter experts. The tool is limited by the maturity and availability of information and the breadth and depth of directly relevant experience of the involved subject matter experts [Kepner and Tregoe (1997) *The New Rational Manager*].

The analysis was based on available knowledge and engineering judgment relevant to SST C-106. The comparison established that of the above listed six criteria (items a-f), minimizing risk to workers and risk to human health and the environment were the dominant criteria (53 and 28, respectively, out of a total potential base score of 100). The remaining four criteria were scored between two and seven out of a total potential base score of 100. Using the weighed evaluation criteria, the subject matter experts then used an independent scoring process to complete a rated criteria analysis [based on the method described in Kepner and Tregoe (1997)] of the four retrieval alternatives and a no-action case. Each alternative was ranked on a scale of one to 10 for each of the six criteria (10 representing the highest score and one the lowest). The basis for the assignment of the ranked score for each alternative by each criterion is provided in the Appendix to this document. After each alternative was ranked against each of the criteria, the rank score was then multiplied by the weighting assigned to the criteria under the paired comparison, and the scores were tallied to derive a relative ranking of the alternatives. The ranking and weighting is only directly pertinent to decisions on SST C-106 waste retrieval.

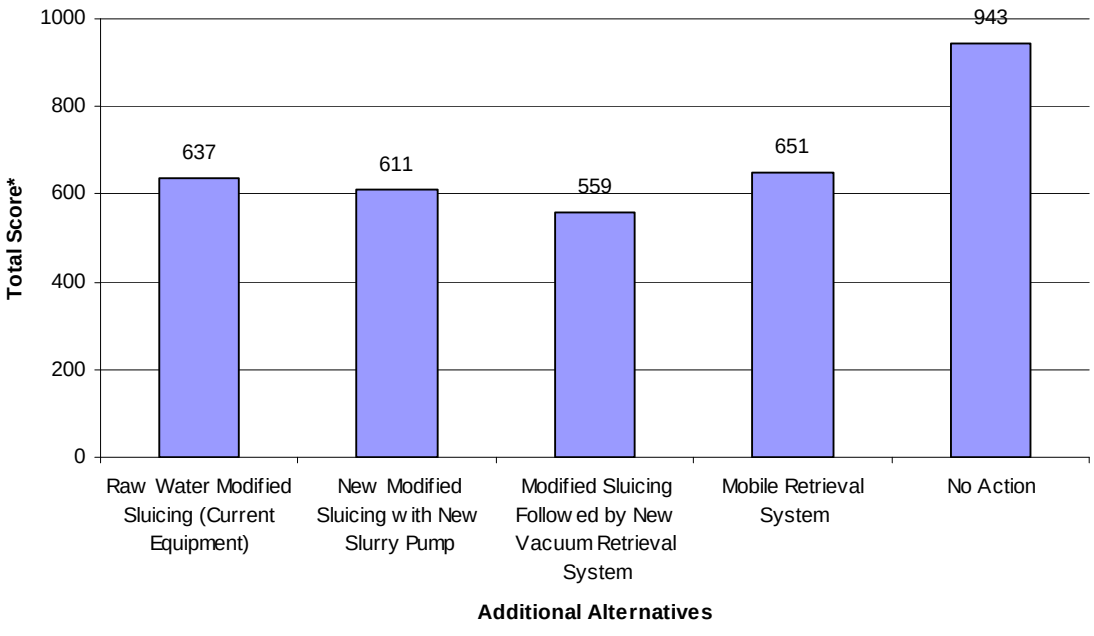
Figure 4 represents the results of the two-step analysis. The analysis determined that the highest ranked alternative based on the six evaluation criteria was to take no further action for SST C-106 waste retrieval. This result was largely driven by the relatively higher risk to workers of all of the other alternatives compared to no action and the relatively minimal amount of risk reduction to the public for Alternatives A through D compared to no action. To test the sensitivity of the analysis to a change in the relative weighting of the dominant criteria (worker risk and human health and environmental risk), the weighting of these criteria was reversed (53 for human health and environment and 28 for worker risk). Figure 5 illustrates that the overall relative ranking of the alternatives remained unchanged. Taking no further action remained the highest ranked alternative. However, Alternative D replaced Alternative A as the second ranked alternative. Other than changing the comparative ranking of the four retrieval alternatives, the other major difference between the results documented in Figures 4 and 5 was that the differences in total scores between the four retrieval alternatives were diminished.

Figure 4. Relative Comparison of Single-Shell Tank 241-C-106 Additional Retrieval Alternatives.



*The total score for each alternative reflects a composite of the comparative ranking and weighted scoring of the six criteria. A higher score reflects a comparatively better ranking against the criteria and provides a relative understanding of the alternatives compared to each other.

Figure 5. Sensitivity Case Comparison of Single-Shell Tank 241-C-106 Additional Retrieval Alternatives.



*The total score for each alternative reflects a composite of the comparative ranking and weighted scoring of the six criteria. A higher score reflects a comparatively better ranking against the criteria and provides a relative understanding of the alternatives compared to each other.

2.2.2 Potential Future Waste Retrieval Technologies

This section describes waste retrieval technologies that were not available for deployment in the Hanford Site tank farms. The technologies discussed in this section were identified, in part, based on their assumed potential to remove some or all of the residual waste in SST C-106. Removal of all waste or a significant portion of the waste may require deployment of multiple technologies.

Past evaluations of government and industry retrieval projects have supported the identification and development of the technologies discussed in Section 2.2.1 and this section (RPP-7807, *Single-Shell Tank C-104 Full Scale Sludge/Hard Heel, Confined Sluicing and Robotics Technology Waste Retrieval Technology Functions and Requirements*, and RPP-10901, *Hanford Federal Facility Agreement and Consent Order Milestone M-45-05-T17: S-102 Initial Waste Retrieval Functions and Requirements*). The technologies discussed in Sections 2.2.2.1 through 2.2.2.6 are at varying stages of development with some requiring substantial investment in research and development while others have been deployed elsewhere and would need to be adapted for deployment at the Hanford Site. None of the technologies discussed in this section are currently planned for deployment in support of tank waste retrieval. If one of the technologies were identified for potential use in support of waste retrieval at SST C-106 or any other tank, the schedule for the initial deployment would range from 3 to 5 years depending on the maturity of the technology (HNF-4454, *Alternatives Generation and Analysis C-104 Single-Shell Tanks Waste Feed Delivery*). Activities that would need to be completed would include engineering, procurement, testing, and construction. Detailed evaluation of the cost and schedule to develop and deploy the potential technologies was not performed because of lack of technology maturity and technical uncertainty regarding the effectiveness in removing residuals to the HFFACO retrieval criteria. In the absence of further development of the potential technologies, it is not possible to estimate the cost for research and development of the potential waste retrieval technologies or to determine if a single technology or combination of technologies would be required to attain the retrieval criteria.

In addition to the technologies presented here, a new technology, the mobile retrieval tool, is under development. The mobile retrieval tool could possibly enhance retrieval performance for future tanks but is not currently available for SST C-106. A brief description of this technology is provided in RPP-20577, Appendix G, Section G3.0.

2.2.2.1. AEA Technology Power Fluidics.[5] CH2M HILL has been working with AEA Technology Engineering Services (AEAT) over the last several years to evaluate the power fluidic concept for sampling, mixing, and pumping tank waste at the Hanford Site. AEAT also provided fluidic pulse jet mixers for use in the five 50,000-gal Bethel Valley Evaporator service tanks. They also provided a unit for use in a 55,000-gal horizontal tank at Oak Ridge National Laboratory (ORNL) with a capital cost reported at $550,000 (DOE/EM-0622, *Innovative Technology Summary Report Russian Pulsating Mixer Pump*).

[5] Power Fluidics is a trademark of AEA Technology Engineering Services, Pittsburgh, Pennsylvania.

A technology search and evaluation of potential technologies applicable for retrieval of saltcake waste from Hanford Site SSTs (RPP-6821, *Technology Evaluation Report for S-103 Saltcake Dissolution Retrieval Demonstration*) recommended the fluidic mixing and pumping systems such as developed by AEAT be considered to demonstrate dissolution retrieval of saltcake waste. It was noted in this evaluation that the fluidic mixing/pumping technology is not only capable of supporting recovery of soluble salt waste, but is also suited for mobilization and retrieval of insoluble solids (e.g., sludge waste). Subsequently, an evaluation was carried out on the fluidic mixing and pumping systems for application in the Hanford Site SST retrieval program (RPP-7819, *An Evaluation of Power Fluidics™ Mixing and Pumping for Application in the Single Shell Tank Retrieval Program*). The AEAT test report 2135-4-015, *Single Shell Tanks Hanford Cold Test Facility Prototype Fluidic System Test Report*, provides an overview of the fluidic equipment, test simulants, test program, test results, and conclusions and recommendations.

2.2.2.2. Russian Pulsatile Mixer Pumps/Fluidic Retrieval Systems. CH2M HILL has worked with the Russian Integrated Mining and Chemical Combine organization at Zheleznogorsk in conjunction with American Russian Environmental Services Inc. over the last several years to evaluate their fluidic concept for mixing and pumping tank waste at the Hanford Site. The system is generally similar to the AEAT system but has design details different for the pump mechanism and nozzles. While the AEAT system has no moving parts in the pump, the Russian unit employs a simple check valve mechanism. Both systems use two distinct cycles, fill and discharge, to perform mixing action. More detailed technical descriptions of the Russian pulsatile mixer pump, the testing program which also involved Battelle Pacific Northwest Division as well as Russia, and initial results of the deployment in one of the gunite and associated tanks at ORNL to mobilize settled solids are provided in Hatchell et al. (2001), *Russian Pulsating Mixer Pump Deployment in the Gunite and Associated Tanks at ORNL*. The design and fabrication of the pulsatile mixer pump occurred in a Russian facility that does not work to U.S. standards, so full compliance with U.S. standards was not achieved. The alliance with American Russian Environmental Services Inc. is intended to allow fabrication in the U.S. to U.S. standards in the future. The pump is capable of being deployed through a 22.5-in.-diameter opening.

A third-generation pulsating mixer/sluicer with a dual nozzle design was developed and has been tested with nonradioactive simulants in 2001 and 2002. A fourth generation dual nozzle pulsating mixer/sluicer underwent cold testing and has been developed for use at the Mining and Chemical Combine nuclear facility in Zheleznogorsk, Russia, to retrieve radioactive sludge from the bottom of their 12-m-diameter by 30-m-high nuclear waste tanks. The large-scale simulant tests of the concept for retrieving tank waste at the Hanford Site were observed in Russia by Hanford Site staff in 2002. This unit can be deployed through a 12-in.-diameter riser and is designed to operate with a minimum amount of liquid (15 cm is expected to be feasible) [Gibbons et al. (2002), *Russian Technology Advancements for Waste Mixing and Retrieval*]. In 2004, the Russians were in the process of retrieving one of their large waste tanks using this technology. CH2M HILL has requested that DOE HQ EM-21 fund this technology to provide a lessons-learned report following completion of waste retrieval. That request is under consideration.

2.2.2.3. Small Mobile Retrieval Vehicles.

a. **Remotely Operated Vehicle Systems at ORNL**—In the 1996-1998 timeframe, the team at ORNL deployed a series of hydraulically powered, remotely operated vehicles. The first two were known as Houdini[6] vehicles and were supplied by RedZone Robotics, Inc. The system was used in other tanks in conjunction with a wall-washing tool (the linear scarifying end-effector), the confined sluicing end-effector, and the Modified Light Duty Utility Arm[7] (MLDUA). Many lessons learned are documented (ORNL/TM-2001/142/V1, *The Gunite and Associated Tanks Remediation Project Tank Waste Retrieval Performance and Lessons Learned*; Vesco et al. 2001, *Lessons Learned and Final Report for Houdini® Vehicle Remote Operations at Oak Ridge National Laboratory*). Many features of these vehicles can be found in the unit currently developed at the Hanford Site for use in SSTs [DOE/EM-0587, *Innovative Technology Summary Report Remotely Operated Vehicle (ROV) System for Horizontal Tanks*].

b. **TMR Associates VAC TRAX**[8]—The VAC TRAX is a remote-operated rotating high-pressure water jetting tool that directs ultra-high-pressure water to remove material coverings from a variety of surfaces (e.g., contaminated paint from concrete walls and floors). At higher pressures, the VAC TRAX is capable of light scabbling or deep scarification of concrete surfaces. The VAC TRAX is fully encapsulated with the water and debris vacuumed from the manifold of the VAC TRAX through a flexible vacuum hose (http://tmrassociates.org/vac_trax.htm). This unit was used at Rocky Flats for cleaning floors, walls, and ceilings of a heavily plutonium-contaminated hot cell. With a different end-effector it was used for taking a core of the concrete floor of the hot cell to determine the depth of plutonium contamination. Numatec Hanford, working with Fluor Hanford in FY 2003, employed TMR Associates to bring their equipment and crew to decontaminate the 233-S Plutonium Facility at the Hanford Site as preparation for dismantling the building.

2.2.2.4. Tank Wall Washing at West Valley Demonstration Project. During the early stage of waste retrieval at the West Valley Demonstration Project, the waste retrieval process was very efficient. As the removal of the contents moved from bulk removal to heel and residue retrieval, the number of transfers and associated time per transfer climbed steadily [Hamel and Damerow (2001), *Completing HLW Vitrification at the WVDP; The Approach to Final Retrieval, Flushing, and Characterization*]. Tethered robotics were evaluated, but not used for retrieval of the waste or characterization because of the many obstructions in the tank. Riser-mounted arms and positioning systems were developed to provide the capability to wash residues from the tanks' internal surfaces. Oxalic acid or mixed organic acids were not used because of concerns with carbon steel tank integrity.

[6] Houdini is a trademark of RedZone Robotics, Inc., Pittsburgh, Pennsylvania.
[7] Modified Light Duty Utility Arm is a trademark of SPAR Aerospace, Ltd., Quebec, Canada.
[8] VAC TRAX is a registered trademark of TMR Associates, Rutherford, New Jersey.

2.2.2.5. Dry Ice Blasting. Decontamination of surfaces using dry ice blasting is a relatively new cleaning process using solid CO_2 pellets. The pellets sublimate (convert directly from a solid blast pellet to a vapor) leaving no residue. This is envisioned as a sand-less sandblasting approach to dislodge hard to remove residue from the tank surfaces. The dry ice is accelerated by compressed air and requires between 80 and 100 psi and 120 to 150 ft^3/min [Lapointe (2004), *Sand-less Sandblasting]*. The EPA identified dry ice blasting with solid pellets as a desirable alternative for cleaning metal surfaces in their fact sheet for alternatives to trichloroethane [EPA (2000), *Technical Fact Sheet for 1,1,1-Trichloroethane (TCA) Hazards and Alternatives*].

2.2.2.6. Modified Light-Duty Utility Arm (MLDUA) at Oak Ridge. Concise reviews are available describing the MLDUA, a custom long-reach manipulator system developed, designed, and built by SPAR Aerospace, Ltd., the same organization that provided the long-reach manipulator system used on the NASA Space Shuttle program [Glassell et al. (2001), *System Review of the Modified Light Duty Utility Arm after the Completion of the Nuclear Waste Removal from Seven Underground Storage Tanks at Oak Ridge National Laboratory*; and DOE/EM-0406, *Innovative Technology Summary Report Light Duty Utility Arm*].

The Light-Duty Utility Arm has been used at Idaho National Engineering and Environmental Laboratory for gathering samples of waste heel materials in their smaller tanks. The MLDUA was used at ORNL for the cleanup of seven underground tanks, either 25 or 50 ft in diameter. The MLDUA performed various types of operations in support of the underground tank waste cleanup operations (e.g., grasping the sluicer to allow deployment of the hose management arm into the tanks, holding and maneuvering the sluicer to remove tank waste and waste material, and tank wall cleaning operations with high-pressure water jets). However, the MLDUA had some problems. Many lessons were learned in both manipulator operations within the tank and manipulator design. These lessons have not been incorporated into any subsequent versions to date.

2.2.3 Conclusions

The comparative evaluations of waste retrieval technologies, which were available for deployment in support of additional waste retrieval from SST C-106 at the time retrieval was completed, establish that

a. All the additional available alternatives are potentially capable of retrieving residual waste from SST C-106. However, the amount of waste that could be retrieved is uncertain and therefore, even following deployment of an additional retrieval technology, the HFFACO retrieval criteria may not be met.

b. The schedule for deployment and completion of waste retrieval for the alternatives for additional technologies range from 12 (Alternatives A and B) to 18 (Alternative D) months (Table 6).

c. The cost of the alternatives ranges from $5.7 to $13.5 million. The estimated costs do not include the costs associated with decontamination and decommissioning and/or disposal of equipment used under each alternative or the costs of treatment and disposal of the retrieved waste (Table 6).

d. The 2003 retrieval campaign cost approximately \$5,170/ft^3 of waste retrieved from SST C-106. The cost per cubic foot of waste retrieved for the four additional evaluated alternatives would range from \$35,000/ft^3 to \$84,000/ft^3 or a factor of seven to 16 times greater than experienced for the 2003 retrieval campaign (Table 6).

e. Additional waste removal is not justified because the cost would be seven to 16 times greater for an equivalent amount of risk reduction, assuming an additional 160 ft^3 of waste is removed and a corresponding reduction in the contaminants that drive risk. Additionally, a value engineering process using paired comparison analysis determined that the highest ranked alternative was to take no further action on SST C-106. This result was largely driven by the relatively higher risk to workers for all of the other retrieval alternatives compared to no action and the relatively minimal amount of risk reduction to the public gained from additional waste removal compared to no action.

f. Consideration of the nominal waste volume of 370 ft^3 instead of the 95% UCL volume of 467 ft^3 does not affect the comparative evaluations of waste retrieval technologies. The cost and schedule for implementation of the waste retrieval technologies are largely dependent on purchasing and installing the equipment on the tank. The time required to retrieve 10 ft^3 would be expected to be less than the time required to retrieve 160 ft^3; however, these differences are minor in comparison to the uncertainties in waste retrieval rates along with time required to install the equipment.

2.3 VOLUME AND CHARACTERISTICS OF RESIDUAL WASTE

This section responds to HFFACO, Appendix H, Attachment 2, Criterion 4: "The volume of waste proposed to be left in place and its chemical and radiological characteristics." The volume of residual waste in SST C-106 was determined following completion of the 1998-1999 sluicing campaign and the 2003 modified sluicing with acid dissolution campaign. The inventory (i.e., chemical and radiological characteristics) of residual waste was calculated from grab samples taken before the introduction of the first acid dissolution batch (identified as pre-retrieval samples) and on completion of the modified sluicing campaign (identified as post-retrieval samples).

2.3.1 Volume of Residual Waste

2.3.1.1. Volume at Completion of the 1998-1999 Sluicing Campaign. The waste volume in SST C-106 before the start of sluicing in 1998 was approximately 230,000 gal and consisted almost entirely of sludge. During the sluicing campaigns conducted in 1998 and 1999, a sludge height equivalent to 67.8 tank in. was transferred to DST AY-102. This height is equivalent to approximately 185,000 gal (HNF-5267).

Estimates of the tank waste volume at the completion of sluicing were initially calculated using a mass flowmeter (HNF-5267) and verified using additional methods (e.g., mass transfer based on

Enraf[9] densitometer density profiles). Computer-aided design (CAD) waste surface topography, as described in RPP-13889, *Tank 241-C-106 Component Closure Action Data Quality Objectives*, and known as the video camera/CAD modeling system (CCMS), was not applied to the tank waste volume until 2002 in preparation for the modified sluicing and acid dissolution campaign. Using video recordings of the inside of the tank and the CCMS, the volume of sludge (solids) and supernate (liquids) remaining in SST C-106 was determined by two separate observations (RPP-12547).

The volume determination from the July 13, 2000, observation presented in Table 7 represents the waste volume following settling after completion of sluicing. The volume of waste remaining in SST C-106 was estimated at approximately 45,000 gal with a 4:1 liquid to solid volume ratio. Subsequent measurements reduced the liquid to solid volume ratio to 3:1 and the volume of waste to approximately 36,000 gal as calculated from the August 1, 2002, video recordings. This value represents the tank waste volume before initiation of modified sluicing and acid dissolution.

Table 7. Single-Shell Tank 241-C-106 Waste Volumes Following Completion of Sluicing.

Video Recording Date: 07/13/2000	**ft^3**	**gal**
Volume of solids	1,210.61	9,056
Volume of liquids	4,790.59	35,836
Total volume in SST C-106	6,001.20	44,892
Video Recording Date: 08/01/2002	**ft^3**	**gal**
Volume of solids	1,210.61	9,056
Volume of liquids	3,600.00	26,930
Total volume in SST C-106	4,810.61	35,986

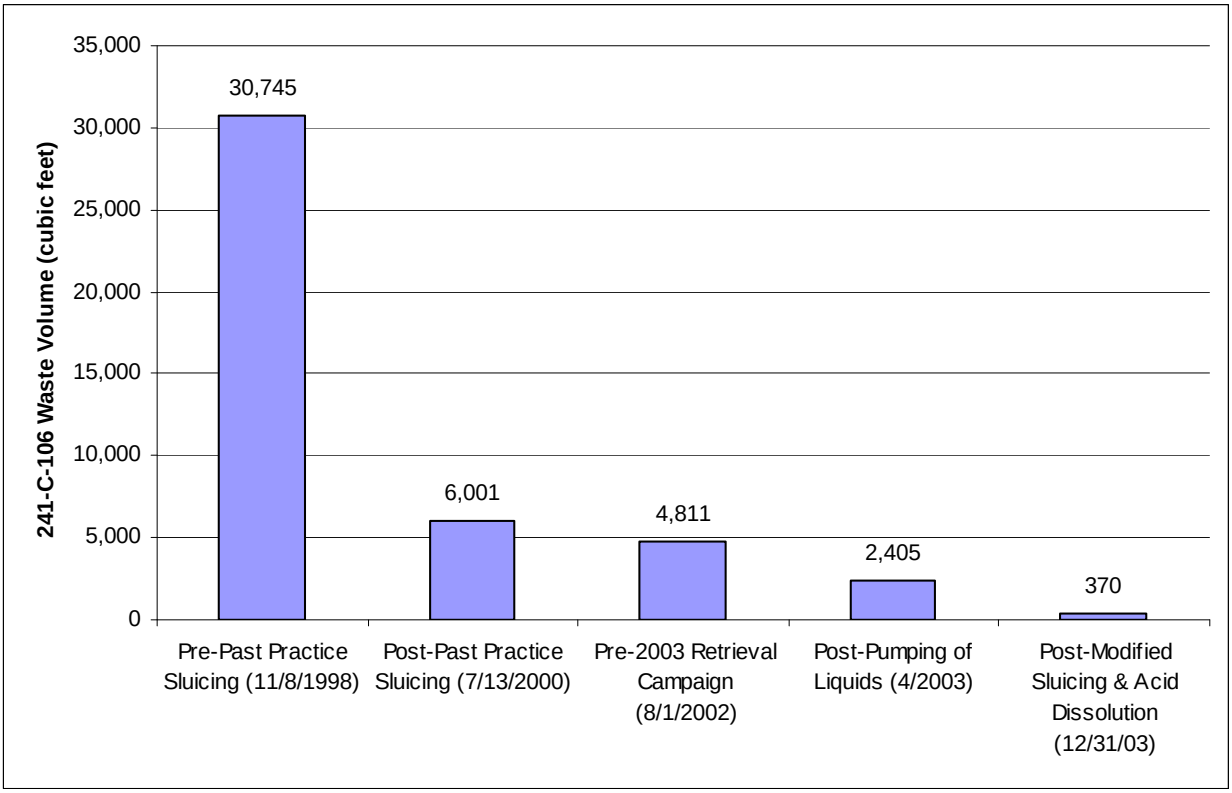
2.3.1.2. Completion of Modified Sluicing and Acid Dissolution. As presented in Table 7, approximately 36,000 gal of solid and liquid waste remained in SST C-106 after completion of the sluicing campaign. In April 2003, approximately 18,000 gal of liquid waste was pumped from SST C-106 to DST AY-102. Following removal of the liquids, modified sluicing and acid dissolution were deployed to dissolve, mobilize, and remove the remaining waste to less than 360 ft^3 or to the limits of the selected technology, whichever is less (RPP-20110).

Post-retrieval waste volume determinations were conducted following completion of the final waste retrieval campaign. Using the validated CCMS methodology (RPP-18744, *Results of the Video Camera/CAD Modeling System Test*), the volume of waste remaining in SST C-106 was determined to be 370 ft^3 ±18% at the 80% confidence interval and ±26% at the 95% confidence

[9] Enraf - Nonius Series 854 is a trademark of Enraf-Nonius, N.V. Verenigde Instrumentenfabrieken, Enraf-Nonius Corporation Netherlands, Rontegenweg 1, Delft, Netherlands.

interval (RPP-19866). The progress of SST C-106 waste retrieval campaigns over time, culminating in the 370 ft^3 end state volume, is presented in Figure 6.

Figure 6. Single-Shell Tank 241-C-106 Waste Volume Reductions.



The post-retrieval waste volume determination presented in Table 8 includes the contribution to the residual waste volume from waste in the tank bottom (liquids and solids), within abandoned in-tank equipment, and on the tank stiffener rings in accordance with the approved data quality objectives (RPP-13889). Based on the CCMS analysis, the remaining solids volume at the 95% UCL, which includes the volume of the tank bottom solids, the volume in the abandoned in-tank equipment, and the volume on the stiffener rings, is 453 ft^3. The remaining liquids volume at the 95% UCL is 14 ft^3. Correspondingly, the residual waste volume at the 95% lower confidence level is 275 ft^3.

Table 9 presents a total curie inventory for SST C-106 at three points: before the 1998-1999 retrieval campaign, after the 1998-1999 retrieval campaign, and after the 2003 retrieval campaign. Table 9 lists analytes, including daughter products, which combine to total 99.9% of the total tank curies. SST C-106 contained approximately 10.1 million Ci prior to the 1998-1999 retrieval campaign. The 1998-1999 retrieval campaign removed approximately 8.2 million Ci, leaving approximately 1.8 million Ci in the residual waste. The 2003 retrieval campaign removed the bulk of the remaining curies resulting in a total current inventory of approximately 135,000 Ci or about 1% of the 1998 inventory.

Table 8. Single-Shell Tank 241-C-106 Waste Volumes Following Completion of Modified Sluicing and Acid Dissolution.

Waste Location	Waste Volume (ft^3)	Estimated Uncertainty (%)		Estimated Uncertainty (ft^3)	
		+	-	+	-
Bottom of tank	336.89	27%	27%	90.96	90.96
Equipment in tank	4.84	0%	25%	0.00	1.21
Stiffener rings	17.30	18%	0%	3.11	0.00
Liquid waste	11.30	27%	27%	3.05	3.05
Total	370.33 [a]	26%	26%	97.12	95.22
Nominal waste ± uncertainty	**370.33 ± uncertainty**	--	--	**467.45** [b]	**275.11**

Notes:
[a] 370 ft^3 is the nominal waste volume remaining after termination of retrieval operations.
[b] The uncertainty shown is for the 95% confidence interval.

Table 9. Estimate of Single-Shell Tank 241-C-106 Inventory of Total Curies Before and After the 1998-1999 and the 2003 Waste Retrieval Campaigns.

Analyte [a]	Pre-1998-1999 Retrieval Campaign Total Tank Inventory (Ci)	Pre-2003 Retrieval Campaign Total Tank Inventory (Ci)	Total Removal 1998-1999 Campaign	Post-2003 Retrieval Campaign Total Tank Inventory (Ci)	Total Removal 1998-12/2003
^{90}Sr	4.77E+06	1.26E+06	3.51E+06	6.61E+04	4.7E+06
^{90}Y	4.77E+06	1.26E+06	3.51E+06	6.61E+04	4.7E+06
^{137}Cs	2.67E+05	3.15E+04	2.36E+05	1.45E+03	2.66E+5
^{137}mBa	2.53E+05	2.99E+04	2.23E+05	1.37E+03	2.52E+5
Total curies [b]	1.01E+07	1.77E+06	8.33E+06	1.35E+05	9.97E+6

Notes:
BBI = best-basis inventory.
[a] Equilibrium ratios of 1 for $^{90}Sr/^{90}Y$ and 0.95 for $^{137}Cs/^{137m}Ba$ are assumed.
[b] Curies of radionuclides contributing to greater than 99% of the pre 1998-1999 retrieval campaign total inventory as calculated by the BBI.

2.3.2 Characteristics of Residual Waste

The SST C-106 post-retrieval risk assessment presented in the RPP-20577, Section 3.0, screened the analytes from the post-retrieval sample analysis for contaminants of potential concern (COPC). For the January 2004 sample, 157 contaminants were evaluated and screened as COPC (RPP-20577, Section 3.2). Of the 157 contaminants, 114 were used in the risk assessment of which 32 were radionuclides and 82 were nonradionuclides. The COPC identification process is discussed in further detail in RPP-20577, Section 3.2.

2.3.2.1. Initial State (April 2003). Initial state conditions are based on data from grab samples (i.e., five solids samples taken with finger traps) taken from Riser 7 of SST C-106 on April 22, 2003, prior to the initiation of retrieval activities in 2003 and presented in RPP-20838, *Tank 241-C-106 Pre-Retrieval Selected Waste Constituent Inventory Estimates to Support the Basis for an Exception to the Waste Retrieval Criteria*. The pre-retrieval inventory of the radionuclide and nonradionuclide contaminants was calculated based on the analyte concentrations in residual solids. The inventory contribution from the residual liquids volume was ignored because the majority of the liquids was transferred during the modified sluicing campaign.

2.3.2.2. Current Conditions (January 2004). The inventory of the 114 COPCs from the analysis of retrieval samples collected following the completion of retrieval activities in December 2003 is presented in RPP-20577, Appendix A.

The post-retrieval inventory was calculated based on the analyte concentrations [calculated per the best-basis inventory (BBI) methodology] and the residual volumes at the median values (359 ft^3 of solids and 11 ft^3 of liquids). In the data quality objectives (DQO) (RPP-13889), Ecology and ORP concurred that sampling from one location is adequate because the retrieval activities mobilized and mixed the solids in the tank. The sampling design was deemed adequate to quantify the variance components associated with sampling and laboratory errors.

Table 10 presents a comparison between the inventory of SST C-106 before and after modified sluicing and acid dissolution for selected constituents. The pre-retrieval inventory is taken from RPP-20838 and the post-retrieval inventory is the average inventory taken from RPP-20577, Appendix A, Table 4.2. The comparison was calculated by dividing the post-retrieval inventory by the estimated pre-retrieval inventory for each selected constituent. Comparison values in Table 10 indicate a net reduction in the inventory.

2.3.3 Conclusions

The volume of residual waste and the chemical and radiological characteristics of that waste is summarized in Section 2.3.1 and presented in RPP-20577, Section 1.2. The volume and inventory were established in accordance with RPP-13889.

To provide perspective, after retrieval of SST-C-106, the BBI of ^{99}Tc, the primary contributor to post-closure human health impacts via the groundwater pathway, in all SSTs was approximately 14,400 Ci (http://twinsweb.pnl.gov/twins.htm 4/6/04). There were 327 Ci of ^{99}Tc in Waste Management Area (WMA) C (SST C-105 had an inventory of 81.4 Ci of ^{99}Tc). The pre-retrieval sample inventory for SST C-106 indicated a total of 3.87 Ci of ^{99}Tc. The post-retrieval sample indicates a total of 0.165 Ci of ^{99}Tc currently in SST C-106 (or 0.05% of the WMA C ^{99}Tc inventory). Figure 7 illustrates the relationship between the inventory of ^{99}Tc in WMA C to the ^{99}Tc inventory in SST C-106 before and after waste retrieval. Figure 8 illustrates the inventory of ^{99}Tc in the waste in each of the tanks in WMA C at the completion of SST C-106 retrieval. SST C-106 residual waste had a lower inventory of ^{99}Tc than the waste in any other 100-series tank in WMA C. Figure 9 illustrates the inventory of chromium in the waste in each of the tanks in WMA C at the completion of SST C-106 retrieval. SST C-106 residual waste had a lower inventory of chromium than the waste in any other tank in WMA C.

Table 10. Comparison between Post-Retrieval Sample Inventory and Pre-Retrieval Inventory for Selected Constituents.

Class	Primary/ Secondary	Constituent	Post-Retrieval Average Inventory	Pre-Retrieval Inventory	Units	Ratio Post/Pre Retrieval
Radionuclide	Primary	^{60}Co	1.82E+01	6.65E+01	Ci	2.74E-01
Radionuclide	Primary	^{63}Ni	7.29E+01	1.05E+03	Ci	6.94E-02
Radionuclide	Primary	^{90}Sr	6.61E+04	1.26E+06	Ci	5.25E-02
Radionuclide	Primary	^{99}Tc	1.65E-01	3.87E+00	Ci	4.26E-02
Radionuclide	Primary	^{137}Cs	1.45E+03	3.15E+04	Ci	4.60E-02
Radionuclide	Primary	^{232}Th	5.60E-04	1.23E-02	Ci	4.55E-02
Radionuclide	Primary	^{233}U	1.83E-03	7.38E-02	Ci	2.48E-02
Radionuclide	Primary	^{234}U	9.46E-04	2.24E-02	Ci	4.22E-02
Radionuclide	Primary	^{235}U	3.86E-05	1.09E-03	Ci	3.54E-02
Radionuclide	Primary	^{236}U	1.73E-05	5.78E-04	Ci	2.99E-02
Radionuclide	Primary	^{238}U	9.02E-04	2.65E-02	Ci	3.40E-02
Radionuclide	Primary	^{237}Np	5.41E-02	1.09E+00	Ci	4.96E-02
Radionuclide	Primary	$^{239/240}$Pu	2.03E+01	4.16E+02	Ci	4.88E-02
Radionuclide	Primary	^{241}Am	6.52E+01	6.60E+02	Ci	9.88E-02
Inorganic	Primary	Chromium	3.78E+00	2.90E+02	kg	1.30E-02
Inorganic	Primary	Mercury	1.93E+00	1.06E+01	kg	1.82E-01
Inorganic	Primary	Nickel	3.02E+01	8.16E+02	kg	3.70E-02
Inorganic	Secondary	Aluminum	3.82E+02	8.50E+03	kg	4.49E-02

Figure 7. Change in Single-Shell Tank 241-C-106 Technetium-99 Residual Waste Inventory, Pre-Retrieval Compared to Post-Retrieval Sample Data and Total Waste Management Area C Inventory.

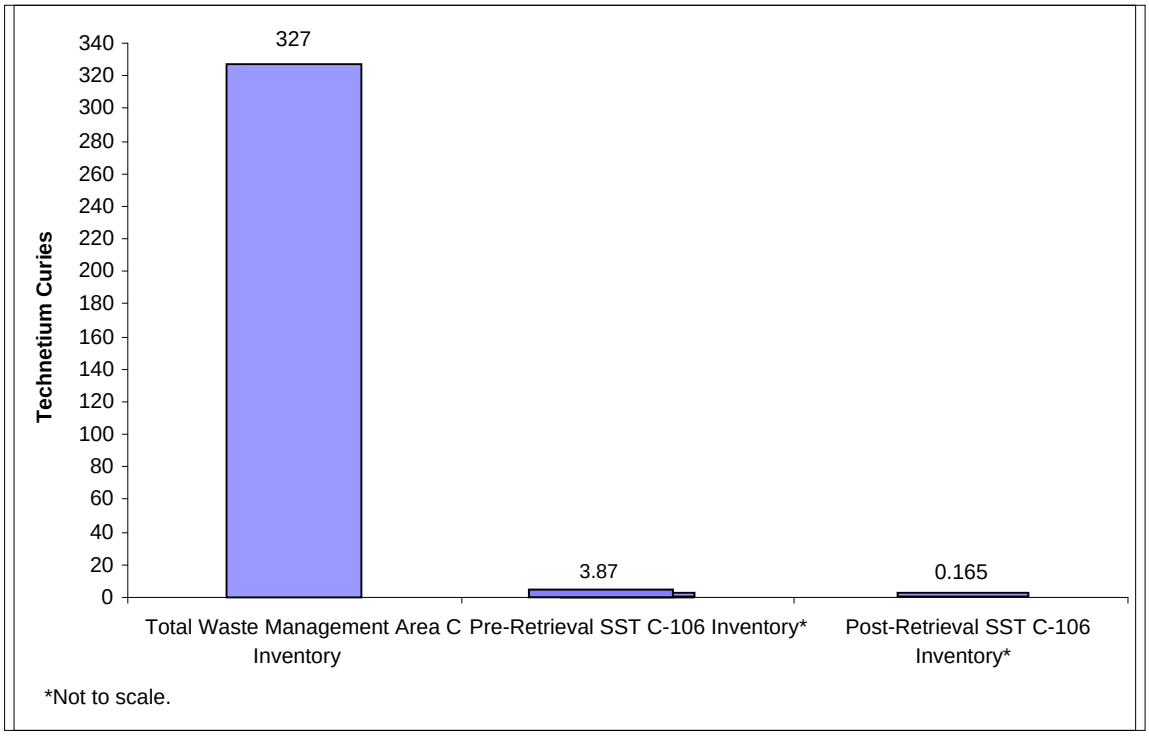


Figure 8. Inventory of Technetium-99 by Single-Shell Tank in Waste Management Area C at Completion of Single-Shell Tank 241-C-106 Retrieval.

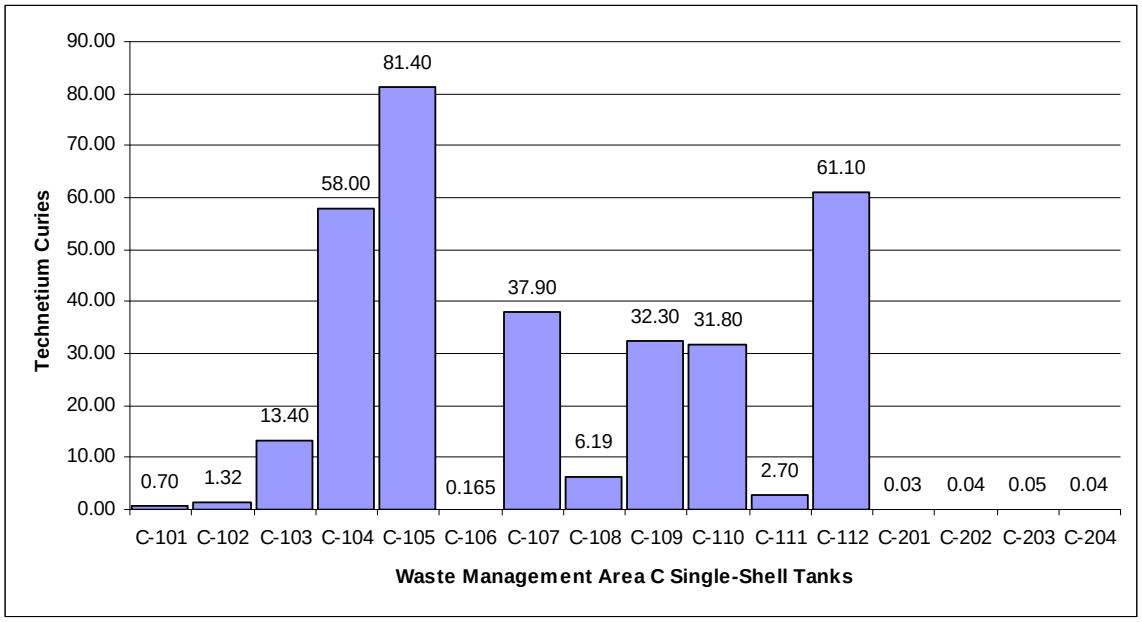
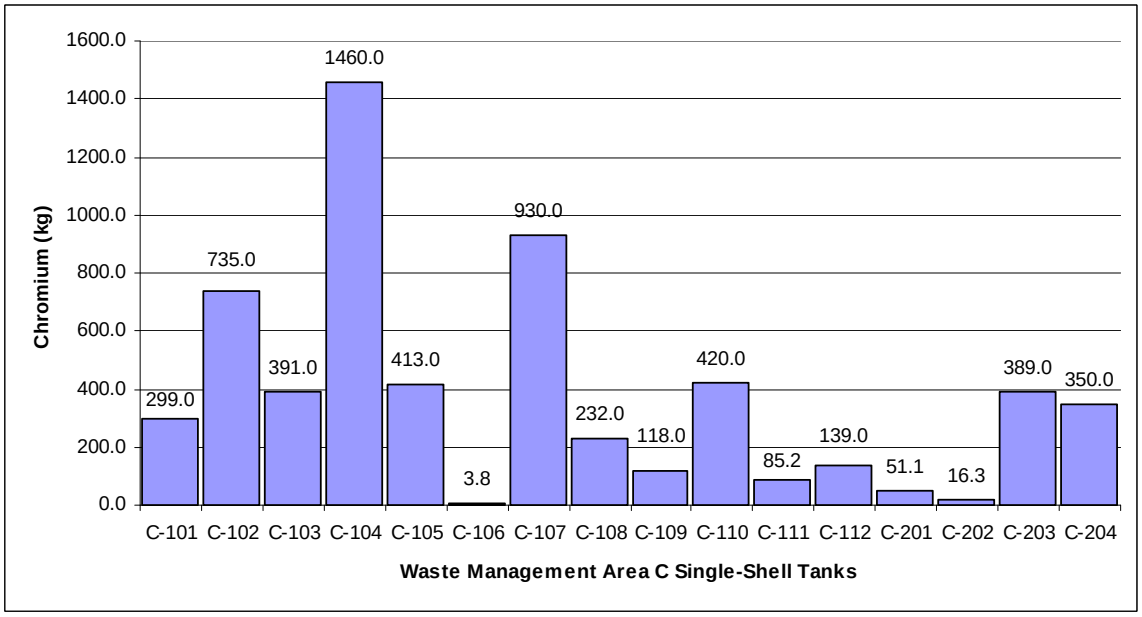


Figure 9. Inventory of Chromium by Single-Shell Tank in Waste Management Area C at Completion of Single-Shell Tank 241-C-106 Retrieval.



2.4 EXPECTED IMPACTS TO HUMAN HEALTH AND THE ENVIRONMENT

This section responds to HFFACO, Appendix H, Attachment 2, Criterion 5: "Expected impacts to human health and the environment if the residual waste is left in place." Expected impacts are based on the results of a post-retrieval assessment of impacts to human health for SST C-106. See RPP-20577, Section 3.0, for the complete post-retrieval risk assessment. This document presents summary information from the post-retrieval risk assessment provided in RPP-20577.

The risk assessment summarized in this document used the same methodology as documented in DOE/ORP-2005-01. All contaminants reported in RPP-20699 (provided as Appendix A of RPP-20577) were evaluated for inclusion in the risk assessment.

2.4.1 Inventory and Contaminants of Potential Concern

Following retrieval, a sample of the residual waste from SST C-106 was taken. The analytical results of the sample were used to calculate the inventory of both nonradionuclides and radionuclides left in SST C-106. RPP-20577, Appendix A, provides the methodology for calculating the final residual inventory used to perform this risk assessment. In RPP-20577, Appendix A, two inventory estimates were made, the average inventory and the 95% UCL inventory. A description of each inventory is as follows.

a. **Average Inventory—**best estimate of the residual waste inventory computed using mean sample concentrations, mean sample density, and best estimate of the residual volume.

b. **95% Upper Confidence Level Inventory**—considered the bounding inventory. The 95% UCL of the average inventory was calculated based on uncertainties associated with the concentration, volume, and density (for solids) measurements.

The inventory used in DOE/ORP-2005-01 was downloaded from the Tank Waste Information Network System (TWINS) on April 21, 2005, and is also based on the post-retrieval sample. However, after DOE/ORP-2005-01 was published, RPP-20699, provided in RPP-20577 as Appendix A, was updated, which resulted in differences between the inventory used in DOE/ORP-2005-01 and the inventory used in this analysis. Briefly stated, the two major differences are related to (1) how inventory for nondetects is calculated for closure and (2) an update to the minimum detection limit for semivolatile organic analytes. Appendix E of RPP-20577 provides a complete listing of these differences.

Inventory for 157 constituents was reported in RPP-20699. All of these constituents were screened against available toxicity information (i.e., reference doses and/or cancer potency factors). Of the 157 constituents, 43 did not have toxicity information and therefore were excluded from further consideration in the risk assessment, leaving 114 constituents. For a complete description of the screening process and list of all analytes with the available toxicity information, see Section 3.2 of RPP-20577.

2.4.2 Impacts to Human Health and the Environment

This section provides the long-term human health risks due to residual waste remaining in SST C-106 after retrieval. The same assumptions (e.g., residual immobilization barrier design and

performance) used in DOE/ORP-2005-01 apply. A leak from SST C-106 during retrieval was not included in this analysis because, based on available data, there was no evidence of a leak during retrieval operations.

This analysis uses the SST C-106 residual average and 95% UCL inventories to calculate impacts of residual waste to the groundwater pathway. The impacts per performance metric associated with each inventory are given in Table 11. Only WAC 173-340 Method B was evaluated for the Hazard Index (HI) and incremental lifetime cancer risk (ILCR). Furthermore, ILCR was evaluated and expressed separately for radionuclides and nonradionuclide carcinogens. All impacts associated with both the average and 95% UCL residual tank inventories were two to four orders of magnitude below the performance objectives.

Table 11. Cumulative Incremental Lifetime Cancer Risk, Hazard Index, and Radiological Drinking Water Dose from Peak Groundwater Concentration Related to Post-Retrieval Residual Waste Volume in Single-Shell Tank 241-C-106.

Metric[a]	Average Inventory		95% Upper Confidence Level Inventory		Performance Objective[b]
	Industrial Land Use	Residential Land Use	Industrial Land Use	Residential Land Use	
Radioactive chemicals ILCR (unitless)	9.11E-09[c,d]	2.21E-07[c,d]	1.21E-08[c,d]	2.94E-7[c,d]	1.0E-06 to 1.0E-04[e]
Nonradioactive chemicals ILCR (unitless) WAC 173-340 Method B	Not evaluated	RNC[f]	Not evaluated	RNC[f]	1.0E-05[g]
Hazard Index (unitless) WAC 173-340 Method B	Not evaluated	4.57E-04[c,d]	Not evaluated	6.81E-04[c,d]	1.0[g]
	Average Inventory		95% Upper Confidence Level Inventory		
All-pathways farmer (mrem/yr)	1.18E-03[c,d]		1.62E-03[c,d]		15[e] or 25[h]
EPA MCL beta/photon emitters (mrem/yr target organ dose)	2.94E-03[c,d]		3.92E-03[c,d]		4[i]

ILCR = incremental lifetime cancer risk.

[a] Metric ILCR-rad were evaluated using industrial and residential land use scenarios described in HNF-SD-WM-TI-707. ILCR-nonrad and Hazard Index were evaluated using WAC 173-340-705 (4) Method B (residential).

[b] Performance objectives apply to entire WMA, not just a single component of the WMA.

[c] Analytes with a fenceline concentration of less than either 0.001 pCi/L (radioactive) or 0.001 µg/L (nonradioactive), which is a value that is well below the minimum detection limit for standard analytical methods, are not included in the total.

[d] Total includes nondetects with inventory calculated at one-half the detection limit.

[e] EPA/540/R-99/006, *Radiation Risk Assessment at CERCLA Sites: Q & A, Directive 9200.4-31P*.

[f] RNC = Risk metric was not calculated because no nonradioactive analyte with a cancer slope factor was predicted to have a concentration greater than 0.001 µg/L.

[g] WAC 173-340-705 (4).

[h] DOE O 435.1, *Radioactive Waste Management.*

[i] 65 FR 76708, "National Primary Drinking Water Regulations; Radionuclides; Final Rule."

Technetium-99 is the primary contributor (RPP-20577, Table 3-2) incremental lifetime cancer risk[10] (radiological) (ILCR-rad), all-pathways farmer, and EPA maximum contaminant level (MCL) beta/photon, followed by ^{14}C, which is a nondetect whose inventory is calculated at one-half the minimum detection limit. For all other radionuclides including ^{129}I, the model-predicted concentrations at the WMA C fenceline were below 0.001 pCi/L (effective zero) (see RPP-20577, Section 3.3.2, fourth bullet). At this point, the analyte was dropped from further analysis and neither radiological dose nor ILCR-rad was calculated.

Eighteen nonradionuclide analytes (RPP-20577, Table 3-1) have an oral cancer potency factor. All 18 analytes were reported with a concentration below the laboratory's minimum detection limit. However, they were evaluated with an inventory calculated at one-half the detection limit. Using that inventory, the model-predicted concentrations were below effective zero. For nonradiological constituents, effective zero was set at 0.001 µg/L. At this point, the analyte was dropped from further analysis and ILCR was not calculated.

A total of 80 nonradionuclides analytes (RPP-20577, Table 3-1) have oral reference doses. Of these analytes only chromium (all of it is assumed to be chromium^{+6}) was detected at above the minimum detection limit and had sufficient inventory and mobility to have the model predict a concentration above effective zero (0.001 µg/L). It accounts for approximately 87% of the HI for the average inventory and 75% of the HI for the 95% UCL inventory. The other analytes that contribute to the HI are fluoride, nitrate, and nitrite. These other three analytes are nondetects and were evaluated with an inventory calculated based on one-half the minimum detection limit.

Modeled concentrations that are below effective zero are due to (1) small inventory of contaminant in the residual waste, (2) low mobility of the contaminant in the vadose zone K_d greater than 0.6 mL/g, or (3) in the case of radionuclides, a short half-life.

2.4.2.1 Effects on Drinking Water Standards. Estimated long-term groundwater quality effects for each residual inventory are compared to the primary drinking water standards (maximum contaminant levels) in Table 12. Model estimate concentration at the WMA fenceline is shown for both the average and 95% UCL inventories.

[10] The ILCR is a risk incidence that represents the increased probability of an individual developing cancer over a lifetime (70 years) from exposure to potential carcinogens (both radiological and chemical). For example, an ILCR of 1.0×10^{-6} would indicate that an individual experiencing a lifetime exposure to the contaminants of concern under the exposure scenario analyzed would have a 1 in 1 million potential to experience a cancer that would otherwise have not been experienced if the individual had not been exposed to contaminants under the conditions postulated in the risk assessment scenario. It is important to note that an ILCR does not necessarily equate to a risk of fatality due to cancer. It only expresses the risk of experiencing cancer (fatal and/or nonfatal) due to exposure under the assumptions postulated for the risk scenarios adopted in the risk assessment.

Table 12. Comparison of Estimated Groundwater Concentrations from Single-Shell Tank 241-C-106 between Average and 95% Upper Confidence Level Inventory.

Constituent	Detect	Average Inventory	95% UCL Inventory	Drinking Water Standard (MCL)
Carbon-14	U	0.006 pCi/L	0.019 pCi/L	2,000 pCi/L
Technetium-99	Yes	0.658 pCi/L	0.873 pCi/L	900 pCi/L*
Iodine-129	U	<0.001 pCi/L	<0.001 pCi/L	1 pCi/L[a]
Chromium (assumes hexavalent chromium)	Yes	0.0155 µg/L	0.0197 µg/L	100 µg/L (50 µg/L[b])
Fluoride	U	0.001 µg/L	0.003 µg/L	4,000 µg/L
Nitrate	U	0.095 µg/L	0.285 µg/L	45,000 µg/L
Nitrite	U	0.085 µg/L	0.256 µg/L	3,300 µg/L
Uranium	Yes	0 µg/L	0 µg/L	30 µg/L

Notes:
EPA = U.S. Environmental Protection Agency.
MCL = maximum contaminant level; MCL for chromium is for total chromium, not hexavalent chromium.
U = Laboratory analysis flagged this constituent as nondetect.
[a] 65 FR 76708, "National Primary Drinking Water Regulations; Radionuclides; Final Rule."
[b] WAC 173-340 Cleanup Level.

2.4.2.2 Impacts of Single-Shell Tank 241-C 106 Waste Residuals Related to Total WMA C Tank Residuals. DOE/ORP-2005-01 evaluated the human health impacts (DOE/ORP-2005-01, Section 4.7, p. 4-59, and Section 6.3.6, p. 6-60) of all sources (past leaks, ancillary equipment, and tank residuals within WMA C. This was accomplished by evaluating the impacts from the subset of sources within each tank row within WMA C that is parallel with the groundwater flow direction (DOE/ORP-2005-01, Section 3.2.2.1, p. 3-6). Then using superposition (DOE/ORP-2005-01, p. 3-32), the impacts of individual sources in that tank row and cumulative impacts of those sources were estimated. Furthermore, to evaluate whether or not the sources present along one tank row interacted with sources present along another tank row, three-dimensional modeling was done (DOE/ORP-2005-01, Section 3.2.2.4.9, p. 3-33) that showed very little co-mingling of plumes from different source rows. This led to the conclusion that maximum human health impacts related to all sources within WMA C could be represented by the tank row with the maximum calculated cumulative impact.

Technetium-99 was the only detected radionuclide that contributed to the risk metrics for SST C-106 (RPP-20577, Appendix F, Table F-1). In WMA C, tank row C-103 to C-112 (the tank row containing tanks C-103, C-106, C-109, C-112, and underground storage tank C-301) was identified as the tank row with the maximum impact for ^{99}Tc (DOE/ORP-2005-01, Section 4.7.4, p. 4-64). Chromium, assuming it is all chromium^{+6}, was the only detected nonradionuclide that contributed to the risk metrics for SST C-106 (RPP-20577, Appendix F, Table F-2). However, for chromium^{+6}, the tank row having the maximum impact is not tank row

C-103 to C-112 but is the tank row containing C-201, C-202, C-203, and C-204, which is approximately a factor of three over the tank row C-103 to C-112.[11]

Table 13 provides the human health impacts of tank row C-103 to C-112. For ^{99}Tc, C-106 represents 11.2% of the total impact associated with tank row C-103 to C-112. For chromium^{+6}, C-106 represents 27.4% of the total impact associated with tank row C-103 to C-112, which is 9% of the maximum for chromium^{+6} for WMA C.

Table 13. Human Health Impacts for WMA C using the Post-Retrieval Average Inventory for C-106 and the HTWOS Predicted Final Inventory for Tanks C-103, C-109, C-112, and C-301.

Metric	C-103	C-106	C-109	C-112	C-301	Total	C-106/ Total (%)
Technetium-99 (pCi/L)	2.87E-01	6.58E-01	1.98	2.89	4.99E-02	5.87	11.2
Chromium (µg/L)	2.47E-02	1.55E-02	6.92E-03	7.56E-03	1.88E-03	5.66E-02	27.4
All-pathways farmer (mrem/yr)	5.30E-04	1.18E-03	3.47E-03	5.22E-03	8.94E-03	1.05E-02	11.2
Beta/photon MCL (mrem/yr)	1.28E-03	2.94E-03	8.80E-03	1.29E-02	2.23E-04	2.61E-02	11.2
ILCR-rad (Industrial)	3.99E-09	9.11E-09	2.73E-08	4.00E-08	6.91E-10	8.11E-08	11.2
Hazard Index (WAC 173-340 Method B)	8.04E-04	4.57E-04	5.11E-04	7.02E-04	6.96E-05	2.54E-03	18.0

HTWOS = Hanford Tank Waste Operations Simulator

2.4.2.2.1 Radiological Contaminants for WMA C Tank Residuals: All-Pathways Farmer and Incremental Lifetime Cancer Risk. Figure 10 provides the radiological dose and Figure 11 the ILCR for each component of tank row C-103 to C-112, calculated for the detected analyte ^{99}Tc. Shown in each of these plots is the contribution of each tank's residual to the metric, as well as the cumulative total for the tank row. The peak all-pathways farmer radiological dose for SST C-106 is 1.15E-03 mrem/yr, while the cumulative total for this tank row is 1.03E-02 mrem/yr. Including the nondetected analytes using one-half the detection limit to calculate the inventory would increase the peak for tank C-106 to 1.18E-03 mrem/yr, and cumulative for the tank row would increase to 1.05E-02 mrem/yr. For industrial land use, the peak technetium ILCR of 9.06E-09 for SST -C-106 and 8.08E-08 for the tank row. The nondetected constituents would increase the ILCR to 9.11E-9 for SST C-106 and 8.11E-08 for the tank row. Using a residential land use increases the ILCR by a factor of 24 to 2.21E-07 for SST C-106 and 1.97E-6 for the tank row.

[11] Since the analysis documented in DOE/ORP-2005-01 was completed, tanks C-201, C-202, C-203, and C-204 have been retrieved.

Figure 10. Technetium-99 Radiological Dose for the All-Pathways Farmer at the Waste Management Area C Fenceline.

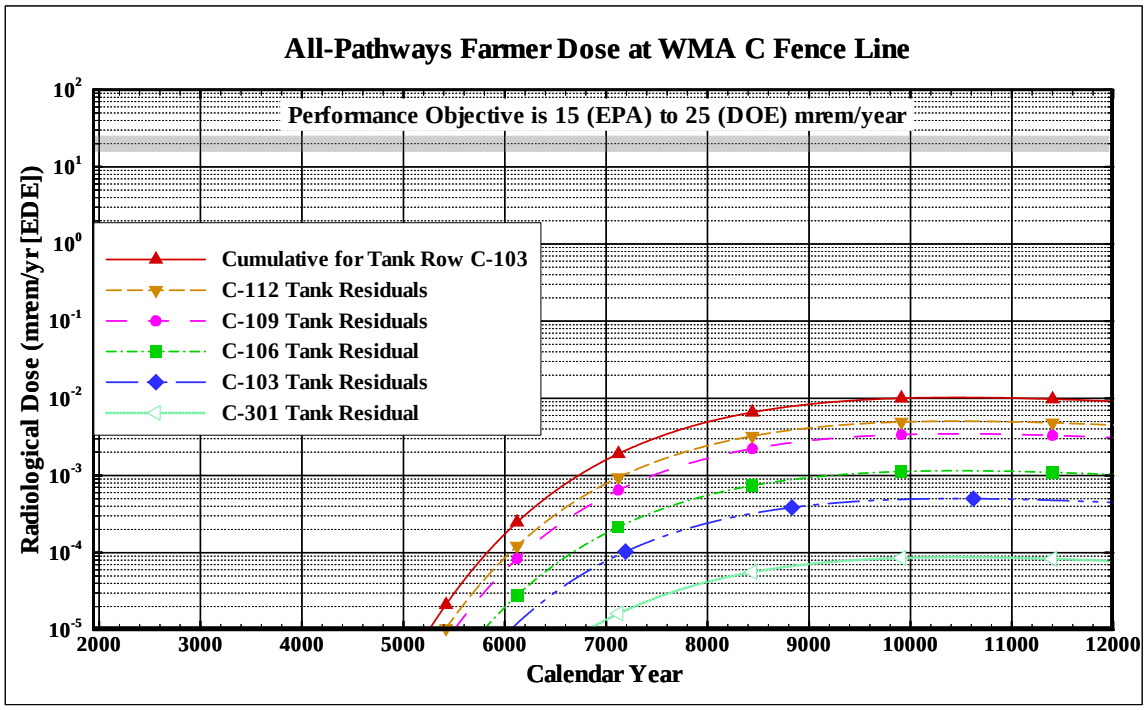
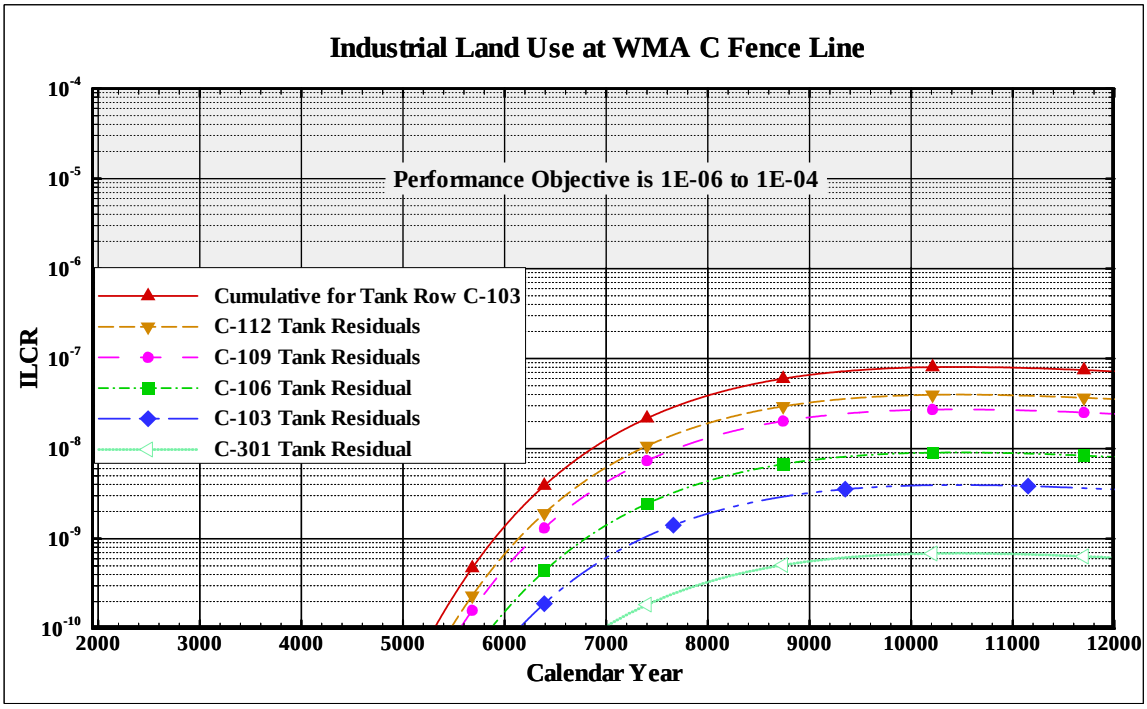
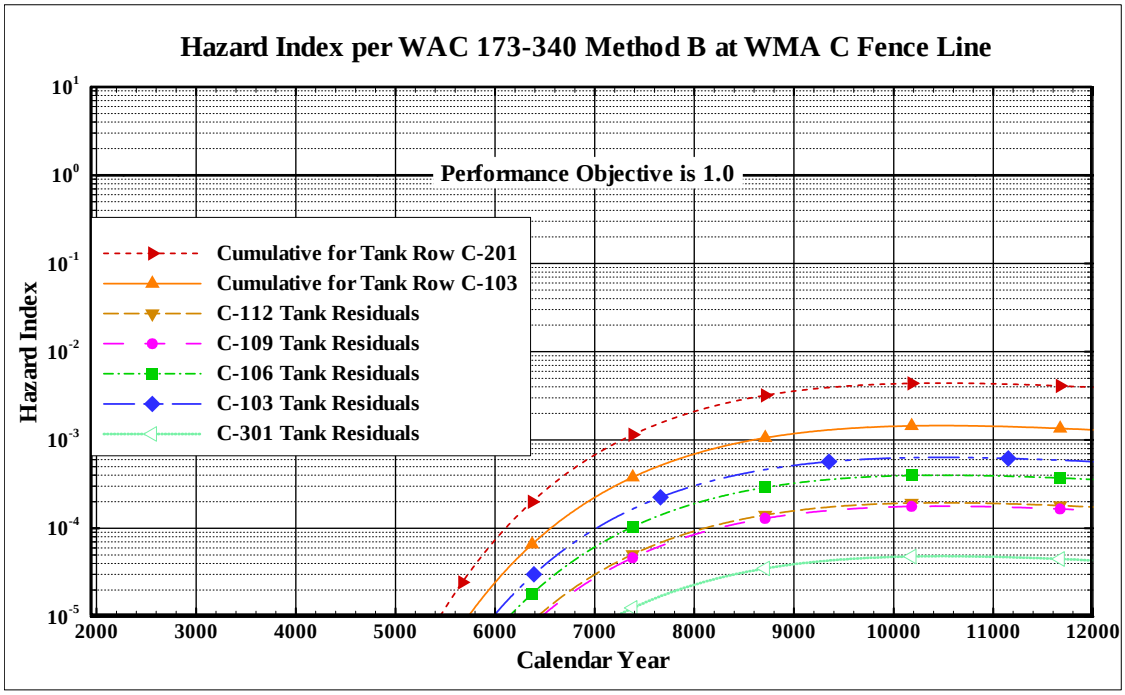


Figure 11. Incremental Lifetime Cancer Risk (Radiological Constituents) for the Industrial Worker at the Waste Management Area C Fenceline.



2.4.2.2.2 Hazard Index. Figure 12 provides the WAC 173-340 Method B HI for each component of tank row C-103, C-106, C-109, and C-112, calculated for the detected analyte chromium and assuming all chromium is chromium^{+6}. Shown in each of these plots is the contribution of each tank's residual to the metric, as well as the cumulative total for the tank row. The peak HI for SST C-106 is 3.99E-04, while the cumulative total for this tank row is 1.45E-3. Including the nondetected analytes using one-half the detection limit to calculate the inventory would increase the peak for SST C-106 to 4.57E-04, and cumulative for the tank row would increase to 2.54E-03. However, as noted in Section 2.4.2.3, tank row C-103 does not provide the maximum impact for chromium in WMA C. Tank row C-201, C-202, C-203, and C-204 does and its HI is 4.73E-03. It is also shown in Figure 12.

Figure 12. Hazard Index for the Industrial Worker at the Waste Management Area C Fenceline.



2.4.2.2.3 Human Health Risk Reduction as a Function of Residual Waste Volume Reduction. Table 14 shows the relative contribution of SST C-106 to the total impacts for the tank residuals along tank row C-103, C-106, C-109, and C-112 at different levels of retrieval for SST C-106. Impacts associated with the residuals source terms other than SST C-106 along this tank row are based on the HTWOS predicted residual inventories given in Appendix C of DOE/ORP-2005-01. Using the 95% UCL inventory, rather than the average inventory, increases the relative dose contribution of C-106 from 11.2% to 14.8% for the all-pathways farmer, from 11.2% to 14.4% for the ILCR-rad industrial metrics, and from 17.9% to 24.6% for the HI. If the SST C-106 residual volume is decreased to the HFFACO goal of 360 ft^3 and the average inventory is reduced proportionately, the contribution of SST C-106 to the tank row would decrease by 0.2% for both the all-pathways farmer and the ILCR-rad industrial, but 0.4% for the HI. The difference in percentages is due to chromium^{+6} being the primary constituent contributing to the HI, while ^{99}Tc is the primary constituent contributing to the all-pathways farmer dose and industrial ILCR-rad.

Table 14. Relative Contribution of Single-Shell Tank 241-C-106 Residual Waste (Includes Nondetected Constituents) to Total WMA C Residual Waste All-Pathways Farmer (Dose), Industrial Receptor (ILCR-Rad), and Hazard Index at the WMA C Fenceline at Selected Retrieval Volumes.

Residual Inventory (volume)[a]	SST C-106 Residual Tank Waste			WMA C Residual Tank Waste Tank Row C-103, C-106, C-109, and C-112			Percentage Contribution of SST C-106 to WMA		
	All-Pathways Farmer Dose (mrem/yr)	ILCR-Rad Industrial	Hazard Index	All-Pathways Farmer Dose (mrem/yr)	ILCR-Rad Industrial	Hazard Index	All-Pathways Farmer Dose (%)	ILCR-Rad Industrial (%)	Hazard Index (%)
95% UCL inventory	1.62E-03	1.21E-08	6.81E-04	1.09E-02	8.41E-08	2.77E-03	14.8	14.4	24.6
Average inventory	1.18E-03	9.11E-09	4.57E-04	1.05E-02	8.11E-08	2.55E-03	11.2	11.2	17.9
Average inventory linearly reduced to a final volume of 360 ft^3 (HFFACO goal)	1.15E-03	8.86E-09	4.44E-04	1.05E-02	8.08E-08	2.53E-03	11.0	11.0	17.5
Average inventory linearly reduced to a final volume of 300 ft^3	9.56E-04	7.38E-09	3.70E-04	1.03E-02	7.94E-08	2.46E-03	9.3	9.3	15.0
Average inventory linearly reduced to a final volume of 250 ft^3	7.97E-04	6.15E-09	3.09E-04	1.01E-02	7.81E-08	2.40E-03	7.9	7.9	12.9
Average inventory linearly reduced to a final volume of 200 ft^3	6.37E-04	4.92E-09	2.47E-04	9.95E-03	7.69E-08	2.34E-03	6.4	6.4	10.6
Average inventory linearly reduced to a final volume of 150 ft^3	4.78E-04	3.69E-09	1.85E-04	9.79E-03	7.57E-08	2.28E-03	4.9	4.9	8.1
Average inventory linearly reduced to a final volume of 100 ft^3	3.19E-04	2.46E-09	1.23E-04	9.63E-0 3	7.44E-08	2.21E-03	3.3	3.3	5.6
Average inventory linearly reduced to a final volume of 50 ft^3	1.59E-04	1.23E-09	6.17E-05	9.47E-03	7.32E-08	2.15E-03	1.7	1.7	2.9

[a] Inventories are provided in RPP-20577, Appendix A and Appendix D.

Notes:
ILCR = incremental lifetime cancer risk.
SST = single-shell tank.
UCL = upper confidence limit.
WMA = Waste Management Area.

If a comparison is made of the results for the average inventory and 95% UCL inventory to the performance objective of 15 mrem/yr (EPA) to 25 mrem/yr (DOE), the all-pathways farmer dose calculated for tank row C-103, C-106, C-109, and C-112 is three orders of magnitude below the performance objectives and for C-106 alone, four orders of magnitude below the performance objectives. For ILCR-rad, tank row C-103, C-106, C-109, and C-112, it is two to three orders of magnitude below the performance objective of 1.0E-04 to 1.0E-06 for the WMA. For the HI, tank row C-103, C-106, C-109, and C-112 is approximately 2.5 orders of magnitude below the performance objective of 1.0, and for C-106 alone, it is 3.5 orders of magnitude below the performance objective.

Figure 13 illustrates the reduction of radiological dose for the all-pathways farmer (upper plot) ILCR-rad (middle plot), and HI (lower plot) as a function of SST C-106 residual waste volume. At each level of retrieval below the nominal volume (of 370 ft^3), the inventory for contaminants in SST C-106 is reduced linearly. Also included in the figure are results from the inventory calculated using the 95% UCL volume (467 ft^3). This analysis assumes that no waste will be lost during additional retrievals.

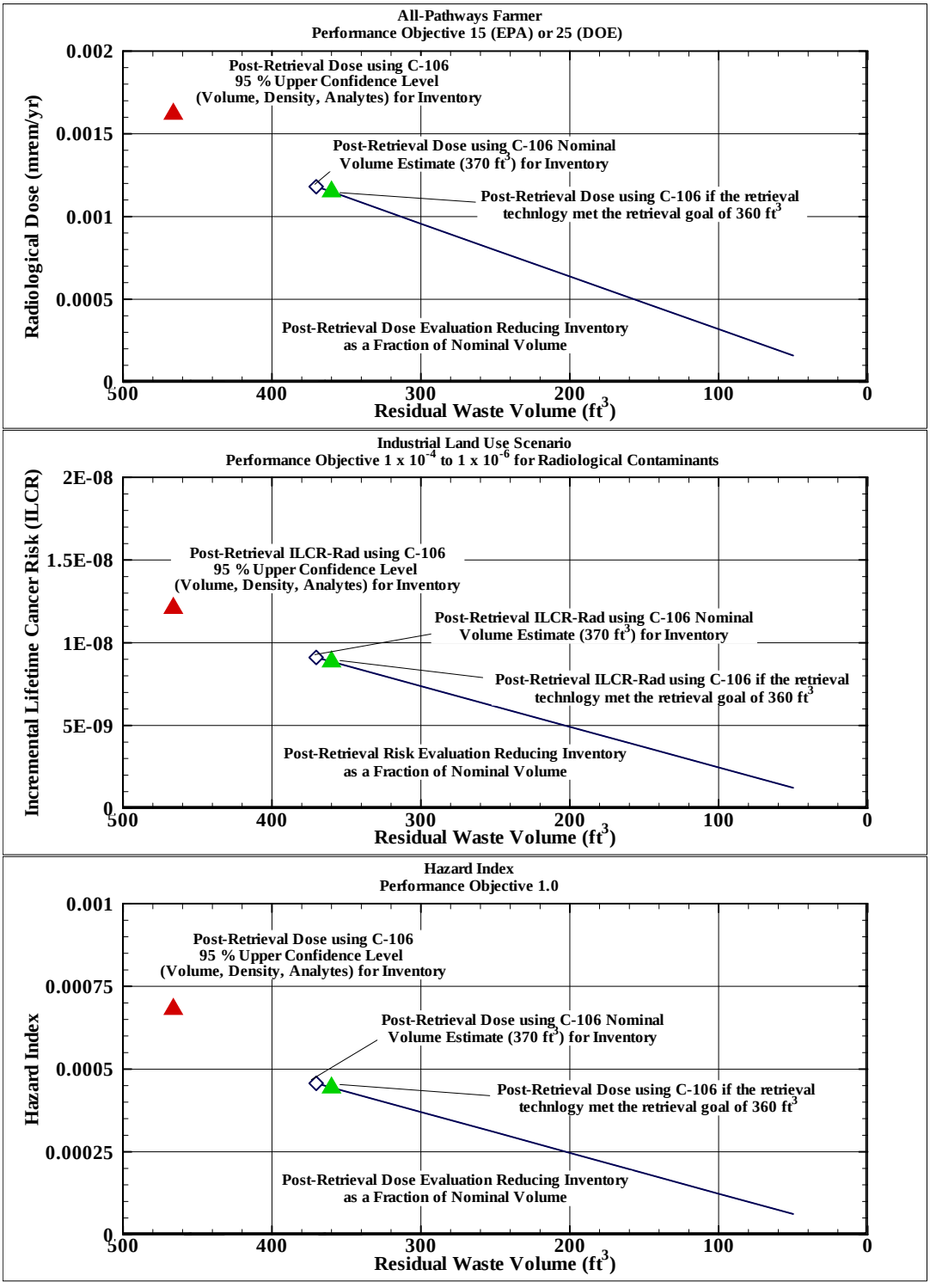
2.4.2.3 Inadvertent Intruder. This section presents a summary of the analysis of estimated doses to a hypothetical individual who inadvertently exhumes waste remaining in SST C-106. This individual is referred to as an “inadvertent intruder.” Inadvertent intrusion into the closed WMAs will be minimized by active and passive controls as required by DOE, state, and federal requirements. The exact nature of the passive controls has not yet been defined but is likely to include a combination of monolithic warning structures, markers buried in the physical barrier, and formalized records.

In DOE/ORP-2005-01 (Section 5.2, p. 5-1), two inadvertent intruder cases are evaluated. The first case involves excavating for a basement, building foundation, or highway. Because the WMA will be covered with at least a 15-ft soil surface barrier and the depth to the top of the tank is 7 ft (DOE/ORP-2005-01, p. 2-158) below ground surface, the proposed excavations would not extend far enough below ground surface to uncover waste. The excavation case gives no radiation dose and is not evaluated further. The second inadvertent intruder case involves drilling a well through the buried waste.

For the well drilling case, two general types of intruder exposures were evaluated. The first considers the radiation dose to an individual who drills a well into the closed WMA and brings some of the waste to the surface receiving an acute dose (contact with the waste for a relatively short period of time). The second considers the radiation dose to an individual who lives near the completed well receiving a chronic dose (exposure over a number of years). The reference case for the chronic dose is the rural farmer with pasture (DOE/ORP-2005-01).

The dose calculated for each intruder scenario is provided in Table 15 for the average and 95% UCL inventories at 100 years and 500 years after closure. RPP-20577, Appendix F, Tables F-5 through F-8, provides the dose by analyte and the principal exposure pathways for the well driller, rural farmer with pasture, suburban garden, and commercial farmer using the average inventory.

Figure 13. Change in All-Pathways Farmer's Dose, Radiological Incremental Lifetime Cancer Risk for the Industrial Worker, and Hazard Index for Single-Shell Tank 241-C-106 Residual Waste as a Function of Waste Volume Reduction.



Note: See Table 14 for values presented.

Table 15. Intruder Dose Summary for Single-Shell Tank 241-C-106.

Years after Closure	Inventory	Inadvertent Intruder Scenario			
		SST PA Reference Case		SST PA Sensitivity Cases	
		Well Driller (mrem)	Rural Farmer with Pasture (mrem/yr)	Suburban Garden (mrem/yr)	Commercial Farm (mrem/yr)
100	Average	23.5	376	5,330	0.11
	95% UCL	31	470	6,700	0.14
500	Average	3.3	0.845	18.5	0.023
	95% UCL	4.3	1.1	24	0.030

Notes:
Site closure is assumed to occur on 1/1/2032.
The performance objective for the well driller is 500 mrem. The performance objective for the other scenarios is 100 mrem/y.

For the SST performance assessment reference cases at 100 years, the well driller case is a factor of approximately 20 times below the performance objective of 500 mrem; but the rural farmer with pasture case is approximately four to five times above the performance objective (100 mrem/yr). This is primarily due to ^{90}Sr left in the tank residual. For the sensitivity cases at 100 years, the suburban garden case is approximately a factor of 50 to 70 times over the performance objective, while the commercial farm case is approximately two orders of magnitude below the performance objective.

At 500 years, the well driller case is a factor of approximately 150 to 120 times below the performance objective (500 mrem) for the average and 95% UCL inventories, respectively. At 500 years, the rural farmer with pasture case is a factor of 90 to 120 times below the performance objective (100 mrem/yr) for the average and 95% UCL inventories, respectively. For the sensitivity cases at 500 years, the suburban garden case is approximately a factor of five to four times below the performance objective, while the commercial farm case is about three orders of magnitude below the performance objective.

2.4.3 Conclusions

The five main conclusions from the risk assessment are the following:

a. The all-pathways farmer dose drinking water MCL, ILCR-rad, and HI metrics calculated for the groundwater pathway are three to four orders of magnitude below their respective performance objectives.

b. The calculated dose for the inadvertent intruder (both acute and chronic) is two orders of magnitude below the performance objective at 500 years.

c. Removal of the additional 10 ft^3 of waste to reach the HFFACO retrieval goal of 360 ft^3 would reduce the ILCR from 9.11E-09 to 8.86E-09 for the average inventory, yielding a net benefit of 2.5E-10 ILCR averted, a reduction of less than 3%. In terms of all-

pathways farmer dose, the corresponding risk reduction would be from 0.00118 mrem/year to 0.00115 mrem/year, yielding a net benefit of 0.00003 mrem/year of dose averted. (Based on data presented in Table 14.)

d. Of the 114 COPC evaluated for the groundwater pathway, ^{99}Tc is the primary contributor to dose and ILCR-rad, and chromium is the primary contributor to the HI.

e. For the inadvertent intruder pathway ^{90}Sr and ^{137}Cs are the primary contributors at 100 years after closure, with plutonium and americium isotopes becoming the primary contributors at 500 years after closure.

2.5 ADDITIONAL INFORMATION REGARDING CONFORMANCE WITH RELEVANT REQUIREMENTS

This section responds to HFFACO, Attachment 2, Criterion 6: "Additional information as required by EPA and/or Ecology." At the time of meetings with Ecology staff in May 2004, no additional information or documents beyond that provided in this document were identified. The remainder of this section provides information regarding conformance with relevant requirements as identified in HFFACO, Appendix H.

Ecology and DOE are currently working to address aspects of the HFFACO, Appendix H, that present an interface role for the NRC associated with allowable residual wastes. In 2003, interface with the NRC staff regarding SST C-106 residual waste was initiated. The DOE is currently pursuing additional interface with the NRC.

3.0 CONCLUSIONS

This section responds to HFFACO, Appendix H, Attachment 2, Criterion 1: "The reason DOE does not believe the retrieval criteria can be met." Based on the information provided in Section 2.0 in response to Criteria 2 through 5, DOE concludes that there is no technical, risk reduction, or economic justification supporting deployment of additional technologies for additional waste removal from SST C-106. This conclusion is the basis of DOE's request that Ecology and EPA concur that retrieval of SST C-106 is complete.

Information summarized in this report and presented in detail in supporting documents establishes that

a. In response to HFFACO, Appendix H, Attachment 2, Criterion 2: The limits of technology for retrieval of waste from SST C-106 have been reached for deployment of sluicing (initial retrieval technology deployed in 1998-1999 to resolve high-heat safety issues) and modified sluicing and acid dissolution (retrieval technology demonstration under the HFFACO for modified sluicing in a sludge tank), using the available riser configuration.

b. In response to HFFACO, Appendix H, Attachment 2, Criterion 3: The impacts of implementing any retrieval technology to remove additional waste from SST C-106 would include a minimum $5.7 million in cost, 12 months in additional retrieval time, exposing tank farm workers to additional radiological, chemical, and industrial risk, and placing constraints on DST storage space. These impacts are not offset by proportionate reductions in long-term human health and environmental risk. In addition, there is uncertainty whether the deployment would result in the removal of waste to the HFFACO retrieval criteria.

c. The analysis of potentially available retrieval technologies identified the VRS and MRS and determined that their deployment in support of additional retrieval of waste from SST C-106 was not technically or economically practical and would not result in further risk reduction at levels that would warrant deployment.

d. The deployment of the vacuum retrieval and mobile retrieval technologies into SST C-106 present uncertainty regarding how much waste could be retrieved and whether the retrieval campaign would result in attainment of the HFFACO retrieval goal. In addition, deployment of these retrieval technologies in the field, based on the additional constraints of working in the tank farms, would result in lower efficiencies than experienced in the Cold Test Facility.

e. In response to HFFACO, Appendix H, Attachment 2, Criterion 4: The waste remaining in SST C-106 exceeds 360 ft^3. However, the nominal value of the measured waste volume is approximately 370 ft^3. This volume includes the volume of the tank bottom solids, the volume in the abandoned in-tank equipment, the volume on the stiffener rings, and the volume of liquids. The 95% UCL volume is 467 ft^3. The 95% lower confidence level volume is 275 ft^3. The chemical and radiological characteristics of that waste have been analyzed in accordance with the approved DQOs (RPP-13889).

f. In response to HFFACO, Appendix H, Attachment 2, Criterion 5: The expected impacts to human health if the residual waste is left in place were analyzed consistent with the methodology used in DOE/ORP-2005-01. The results of the risk assessment are summarized herein and presented in its entirety in RPP-20577. The ILCR human health impacts from the residual waste do not exceed EPA ILCR threshold values of 1.0×10^{-4} to 1.0×10^{-6} for the industrial receptor at the WMA C fenceline. The maximum human health impacts for WMA C, inclusive of the SST C-106 residual inventory, is 8.11×10^{-8} for the industrial receptor scenario. Based on the current residual inventory, no groundwater quality standards would be exceeded under assumptions consistent with the tank farm closure approach identified in DOE/ORP-2005-001.

g. In response to HFFACO, Appendix H, Attachment 2, Criterion 6: No additional information beyond that presented in this document has been identified for submission. However, RPP-13774, *Single-Shell Tank System Closure Plan*, identifies and provides a pathway to resolution of all currently unresolved regulatory issues and securing all necessary permits and approvals under the authority of Ecology, DOE, and other agencies.

In response to HFFACO, Appendix H, Attachment 2, Criterion 1, this document concludes that if one of the four additional available waste retrieval technologies were to be deployed in SST C-106, the benefit gained in the reduction of impacts to human health or the environment would not justify the cost of additional waste removal. The 2003 waste retrieval campaign resulted in the removal of 4,340 ft^3 of tank waste at a cost of approximately $22.4 million. Removal of the additional 160 ft^3 of waste discussed in Section 2.2.1.1 would cost from $5.7 to $13.5 million. This additional waste removal, assuming a corresponding reduction in the contaminants that drive risk, would reduce the ILCR from 9.11E-09 to 5.17E-09 for the average inventory, yielding a net benefit of only 3.94E-09 ILCR averted, or 3.9 in 1 billion. In terms of all-pathways farmer dose, the corresponding risk reduction would be from 0.00118 mrem/year to 0.00067 mrem/year, yielding a net benefit of only 0.0005 mrem/year of dose averted. (Based on data presented in Table 14.)

On the basis of information presented in this document, DOE requests Ecology and EPA concur that retrieval of waste from SST C-106 is complete. This request is pursuant to criteria set forth in HFFACO, Appendix H, Attachment 2.

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APPENDIX

RELATIVE COMPARISON OF THE RETRIEVAL ALTERNATIVES AND NO ACTION

Table A-1. Paired Comparison.

Numerical Evaluation								SUMMARY EVALUATION		Base 100 Score
	B	C	D	E	F		ID	DESCRIPTION	VALUE	
A	b3	c5	a1	e3	a1		A	Cost	2	5
	B	c5	d1	e3	f1		B	Schedule	3	7
		C	c5	c3	c5		C	Risk to Workers	23	53
			D	e3	f1		D	Ease of Implementation	1	2
				E	e3		E	Risk to Public	12	28
					F		F	Impacts to Mission	2	5
IMPORTANCE									43	100

5 = Significantly More
3 = Moderately More
1 = Minimally More

A. Cost of the Alternative. This criterion includes all facets of the alternative. A higher value means the total cost for installing, operating, and demobilizing the particular technology is less than other technologies that are being considered. A higher value also means that the total estimated cost contains a higher level of confidence for completing within the indicated estimate at completion.
B. Schedule for the Alternative. This criterion includes all facets of the alternative. A higher value means the total duration for installing, operating, and demobilizing of the particular technology is shorter than other technologies that are being considered and that the schedule contains a higher level of confidence for achieving the scheduled end date.
C. Risk to Workers for the Alternative. This criterion includes ALARA considerations for both industrial (e.g., structural, chemical, electrical) and radiological safety and health. A higher value means lower risk to the worker for implementing that particular technology.
D. Ease of Implementation for the Alternative. This criterion refers to the level of difficulty that each alternative may include when installing, operating, and demobilizing equipment, instruments, etc. It also includes the level of project and technical risk associated with implementation. A higher value means comparatively less difficulty for implementing and less risk for that particular alternative.
E. The Risks to the Public or Non-Occupational Personnel for the Alternative. Usually this criterion includes near-term or long-term releases to the air or surrounding soils that account for the potential risk to the environment. A higher value means comparatively lower risk to the public for the particular alternative.
F. Impacts of each Alternative to the RPP Mission. This criterion assesses the potential for each alternative to divert or delay other activities or programs that would otherwise be completed. A higher value means comparatively lower impacts for that particular alternative.

Note: The analysis was supported by subject matter experts from the DOE Office of River Protection and CH2M HILL Hanford Group, Inc., and included representatives of retrieval engineering, strategic planning, process engineering, tank closure, and regulatory compliance. The analysis was based on available knowledge and engineering judgment relevant to SST C-106.

Table A-2. Criteria Blank. (2 Sheets)

10 = HIGHEST 1 = LOWEST		A. Cost	**Cost Comments:** A higher value means the cost is lower than the other alternatives and that the total estimated cost contains a higher level of confidence for completing within the indicated estimate at completion.	B. Schedule	**Schedule Comments:** A higher value means the total duration for installing, operating, and demobilization of the particular technology is shorter than other technologies and that the schedule contains a higher level of confidence for achieving the scheduled end-date.	C. Risk to Workers	**Risk to Workers Comments:** A higher value means lower risk to the worker for implementing that particular technology.	D. Ease of Implementation	**Ease of Implementation and Confidence in Technical Success Comments:** A higher value means comparatively less difficulty for implementing and less risk for that particular alternative to actually do what it is designed to do.	E. Risk to Public	**Risk to Public Comments:** A higher value means comparatively lower risk to the public and non-occupational personnel for that particular alternative.	F. Impacts to Mission.	**Impacts to Mission Comments**: A higher value means comparatively lower impacts to other activities or programs that would otherwise be completed.	TOTAL
ID	**Criteria Weight**	**5**		**7**		**53**		**2**		**28**		**5**		
A	Raw Water Modified Sluicing (Current Equipment)	5	$1,925,950 Retrieval System Cost (reconnecting and operating) Evaporator Costs Increase by $3,740,000 Total Storage and Retrieval Life-Cycle Costs of $5,665,950 (does not include demobilization and disposal of equipment)	4	12 months start to finish duration (2 to 3 months of operating time) (1) The greater amount of evaporator use and transfers to DSTs may increase indicated duration. (2) If the operation of this alternative occurs during the maintenance outage, then the duration may be impacted.	7	Since this equipment is already installed, the increase in potential risk to the work force is small. As duration increases, potential for exposure or injury increases.	6	Because the results of earlier modified sluicing campaigns indicate that the limits of technology have been achieved, there is a low probability of technical success in continuing to use modified sluicing.	7	Continuing to add large volumes of water to achieve further reduction in residual waste volume increases the probability of a leak occurring either during the modified sluicing operation or a subsequent transfer of waste to the DST receiver. Approximately 1,496 gal of residual would remain.	1	DST Storage Impact of 1,870,000 gal. Resumption of modified sluicing in SST C-106 will divert people and $$ resources from other planned retrievals. Also uses evaporator capacity.	**640**
B	New Modified Sluicing with New Slurry Pump	5	$5,668,735 Retrieval System Cost Evaporator Costs Increase by $180,000 Total Storage and Retrieval Life-Cycle Costs of $5,848,735	5	12 months start to finish duration. With limited DST impacts, schedule confidence is good. However installations of new risers have not been done recently.	5	This option would add potential risk for the workers, since two new risers would need to be installed, the current equipment removed, and the new equipment (pump, nozzles) installed based on the expert judgment of engineers currently working to deploy the retrieval systems considered in this evaluation.	6	There is extensive experience in installing new nozzles and pumps. There is limited experience and some difficulties with new riser installation.	7	Adding limited quantities of recycled supernate as the sluicing medium to achieve further reduction in residual waste volume increases the probability of a leak occurring either during the modified sluicing operation or the transfers of waste between the DST receiver tank and C-106. Approximately 1,496 gal of residual would remain.	6	DST Storage Impact of 90,000 gal. Additional modified sluicing of SST C-106 will divert people and $$ resources from other planned retrievals. Also uses evaporator capacity.	**563**
C	New Modified Sluicing Followed by New Vacuum Retrieval System	2	$10,171,593 Retrieval System Cost Evaporator Costs Increase by $450,000 Total Storage and Retrieval Life-Cycle Costs of $10,621,593	2	16 months start to finish duration (additional time for installing and operating the vacuum system and two new risers, plus the time for sluicing)	3	This option would add potential risk for the workers, since two new risers would need to be installed to support the installation and operation of the vacuum system.	4	Limited experience and some difficulty for installation of new risers. Higher mechanical complexity of the system. Operational experience will be gained from the C-200-series tank retrievals.	8	Adding limited quantities of water to move the waste to the vacuum intake results in a small potential impact from a leak occurring during the retrieval operation or during a transfer of waste to the DST receiver. Approximately 1,496 gal of residual would remain.	4	DST Storage Impact of 225,000 gal. Additional modified sluicing/vacuum retrieval of SST C-106 will divert people and $$ resources from other planned retrievals. Also uses evaporator capacity.	**435**

Table A-2. Criteria Blank. (2 Sheets)

10 = HIGHEST 1 = LOWEST		**A. Cost**	**Cost Comments:** A higher value means the cost is lower than the other alternatives and that the total estimated cost contains a higher level of confidence for completing within the indicated estimate at completion.	**B. Schedule**	**Schedule Comments:** A higher value means the total duration for installing, operating, and demobilization of the particular technology is shorter than other technologies and that the schedule contains a higher level of confidence for achieving the scheduled end-date.	**C. Risk to Workers**	**Risk to Workers Comments:** A higher value means lower risk to the worker for implementing that particular technology.	**D. Ease of Implementation**	**Ease of Implementation and Confidence in Technical Success Comments:** A higher value means comparatively less difficulty for implementing and less risk for that particular alternative to actually do what it is designed to do.	**E. Risk to Public**	**Risk to Public Comments:** A higher value means comparatively lower risk to the public and non-occupational personnel for that particular alternative.	**F. Impacts to Mission.**	**Impacts to Mission Comments**: A higher value means comparatively lower impacts to other activities or programs that would otherwise be completed.	**TOTAL**
ID	**Criteria Weight**	**5**		**7**		**53**		**2**		**28**		**5**		
D	Mobile Retrieval System Technology	1	$13,131,774 Retrieval System Cost Evaporator Costs Increase by $350,000 Total Retrieval and Storage Life-Cycle Costs of $13,481,774	1	18 months start to finish duration [increase time for readiness review for first time use of in-tank vehicle (ITV)]	3	This option would add potential risk for the workers, since one new riser (42-in.) would need to be installed to support the installation and operation of the mobile retrieval system (MRS). The installation of first-of-a-kind equipment, i.e., ITV, adds another dimension to the risk to workers.	3	The only Hanford experience with the MRS equipment is in the Cold Test Facility.	10	Adding small quantities of water to assist the MRS system in moving the waste to the center of the tank for subsequent retrieval by the vacuum system results in a small potential impact from a leak occurring either during the retrieval operation or a transfer of waste to the DST receiver. Approximately 1,496 gal of residual would remain.	4	DST Storage Impact of 175,000 gal. Additional retrieval from SST C-106 using MRS will divert people and $$ resources from other planned retrievals.	**477**
E	No Action	10	No additional cost for waste retrieval.	10	No additional time needed for retrieval.	10	Negligible additional risk to workers.	10	Easiest to implement and no technical risk.	9	No environmental risk due to leaking during retrieval. Approximately 2,770 gal of residual would remain. However initial performance assessment results indicate no significant risk difference from other alternatives.	10	This alternative allows the mission to proceed as planned.	**972**

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

Part I: Background Information

Title: 241-C-103 and 241-C-109 Tanks Waste Retrieval Work Plan

Information Category:
☐ Abstract ☐ Journal Article ☐ Summary
☐ Internet ☐ Visual Aid ☐ Software
☐ Full Paper ☐ Report ☒ Other WMA C Closure WIR Reference

Publish to OSTI? ☐ Yes ☒ No

Trademark/Copyright "Right to Use" Information or Permission Documentation	Yes ☐	NA ☒

Document Number: RPP-20658 Revision 3 Date: April 2008

Author: Darling, David (Dave) B

Part II: External/Public Presentation Information

Conference Name:

Sponsoring Organization(s): Rebecca Blackwell

Date of Conference: Conference Location:

Will Material be Handed Out? ☐ Yes ☒ No Will Information be Published? ☐ Yes ☒ No *(If Yes, attach copy of Conference format instructions/guidance.)*

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Responsible Manager	WRPS	12/16/2024	Levitt, Marc T Approved - IDMS data file att.
Other:			

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DOE – ORP Public Affairs/Communications	☒	☐	Dawson, Edward M	Approved - IDMS data file att.
Other: DOE SME	☒	☐	Millikin, Emily J	Approved - IDMS data file att.
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    Waste Retrieval Work Plan, Revision 3, submitted by Dave Darling for public release. This
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