Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation

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Abstract: This report presents an evaluation of characterization and closure options for pipelines associated with Waste Management Area (WMA) C. It contains a summary of available information on the history, physical attributes, and inventory associated with WMA C pipelines; an initial scoping analysis of risk associated with WMA C pipeline inventories taking into consideration inventory uncertainties; a discussion of technologies available or in development for characterizing tank farm pipelines; an evaluation of pipeline closure technologies based on implementability within WMA C; and recommendations for performing WMA C pipeline characterization and closure actions, including the need for technology development and demonstration.

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EXECUTIVE SUMMARY

This report presents an evaluation of characterization and closure options for pipelines associated with Waste Management Area (WMA) C. The proposed *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology et al. 1989) Milestone M-045-83 requires that WMA C be closed by mid-2019. Early closure planning and decision making related to pipeline actions is critical to meeting this milestone date. RPP-46484, *Waste Management Area C Closure Demonstration Project Plan* identified this evaluation as a key focus area to support WMA C closure. This report is to be submitted to the State of Washington Department of Ecology in accordance with proposed HFFACO milestone M-045-81 which states:

> "Implement and complete all remaining activities in the June 6, 2007 C-200 Closure Demonstration Plan (with any revisions as agreed to by Ecology and DOE). Provide a report that documents the results of those activities and provides interpretations and recommendations consistent with the Project Goals, Objectives, and Products described in Section 5 of the Plan." (Due 9/30/2014)

This report contains the following:

1. A summary of available information on the history, physical attributes, and inventory associated with WMA C pipelines
2. An initial scoping analysis of risk associated with WMA C pipeline inventories taking into consideration inventory uncertainties
3. A discussion of technologies available or in development for characterizing tank farm pipelines
4. An evaluation of pipeline closure technologies based on implementability within WMA C
5. Recommendations for performing WMA C pipeline characterization and closure actions, including the need for technology development and demonstration.

This report documents and describes key attributes for over 8 miles of pipeline in approximately 230 separate segments in WMA C. According to historical process operation records, pipelines were flushed following a waste transfer and at times prior to a waste transfer. The design and operation of these pipelines are expected to result in insignificant volumes remaining of residual wastes, with the possible exception of pipelines that may have plugged. Pipeline plugging tended to be associated with transfers involving tributyl phosphate and occurred predominately in the cascade lines between tanks. Historical records indicate that 3 to 5 pipelines at WMA C have been plugged with the majority being cascade lines between the 100-series tanks.

Pipeline residual waste volumes in WMA C have been estimated in various past documents. Estimates range from 7.4 to 2,800 gal (adjusted based on revised total pipeline length). This report considers another estimate based on an extrapolation of actual pipeline volume estimates

(700 gal). Constituent inventory estimates were then calculated based on a range of residual volumes and on average Best Basis Inventory radiological and chemical concentrations. An evaluation of inventory uncertainty concludes that current uncertainties in the composition of pipeline residuals are considered low.

The estimated inventory of key radiological and chemical constituents in WMA C pipeline residuals comprises a small fraction of the total inventory of the same constituents estimated in past releases and in the single-shell tanks at the time of closure, and therefore pipeline residual inventory is not expected to significantly contribute to potential long-term impacts to human health and the environment.

An initial scoping analysis was conducted to evaluate potential long-term impacts to human health and the environment from pipeline residual inventories. From the results of the analysis the following general conclusions can be made:

- For the inadvertent drilling intrusion scenario, results of the analysis showed a total acute dose to the intruding receptor well below the generally accepted performance objective for inadvertent intrusion (500 mrem/yr for acute exposure) at closed Low-Level Waste facilities under DOE Order 435.1, *Radioactive Waste Management*
- For the groundwater use scenario, the analysis results indicated a peak chronic total dose to the receptor well below the generally accepted performance objective of 4 mrem/yr for a receptor using groundwater at closed Low-Level Waste facilities under DOE Order 435.1
- The key non-radiological contaminants using the same groundwater use scenario are well below groundwater cleanup levels.

Pipeline characterization technologies are described and evaluated for potential use in WMA C. This evaluation concludes that due to the low impacts to human health and the environment from pipeline residuals, further characterization of pipelines in WMA C is not recommended. However, should characterization be required, the report recommends that in-pipe technologies and tracers in particular be used to gather information. Pipeline segment or residual removal is not recommended. These characterization approaches represent potentially high worker risk and high cost and schedule impacts. A sampling plan developed for pipelines outside of the WMA C area in conjunction with the 200-IS-1 Operable Unit estimated that a 5 site/10 sample design would require approximately $3 million to complete.

Pipeline closure technologies are also described and evaluated. As with characterization activities, closure activities are not recommended for the purposes of reducing impacts to human health and the environment. Estimated cost and schedule impacts from pipeline removal are presented and are significant. Two examples are presented; one to illustrate the activities and cost of removal of a plugged pipeline segment for an encasement which would be within 8 ft of the ground surface, and the other an example of the activities and cost of removing a cascade line at a depth of 15 feet. Costs to remove a 25-ft section of encased pipeline at an 8-ft depth is estimated to be approximately $18.3 million (requiring 39 months to complete). Costs to remove a 25-ft section of cascade pipeline at a 15-ft depth is estimated to be approximately $28.0 million (requiring 42 months to complete). Should closure actions be required for reduction of risk, the evaluation concludes that the various technologies presented may all have application to pipeline removal and should be carried forward as potentially applicable technologies.

Closure actions may be necessary for purposes such as void space removal for engineered surface barrier integrity or for reduction of barrier size. The need for grouting pipeline encasements should be revisited as part of design, construction and maintenance of the WMA C surface barrier.

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ABBREVIATIONS AND ACRONYMS

List of Terms

1C	first-cycle (waste)
2C	second-cycle (waste)
AEC	U.S. Atomic Energy Commission
ALARA	As Low as Reasonably Achievable
BBI	Best Basis Inventory
bgs	below ground surface
BL	intermediate-level waste generated by B Plant from 1967 to 1978
CAW	current acid waste (PUREX)
CB	cement-bentonite (mixture)
CFR	*Code of Federal Regulations*
CWP	PUREX coating waste
DCRT	double-contained receiver tank
DOE	U.S. Department of Energy
DST	double-shell tank
Ecology	State of Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FP	B Plant waste
HAPP	hydraulically activated pipeline pigging
HAW	high(-level) acid waste
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HPGe	high-purity germanium
HPT	Health Physics Technician
HS	Strontium Semiworks (formerly Hot Semiworks)
HWMA	*Hazardous Waste Management Act of 1976*
ID	internal diameter
IH	industrial hygiene
ISV	In situ vitrification
ITS	in-tank solidification
IWW	sulfate free waste
LERF	Liquid Effluent Retention Facility
MW	metal waste
NDA	non-destructive assay

NEPA	*National Environmental Policy Act of 1969*
NOC	Notice of Construction
ORP	(U.S. Department of Energy) Office of River Protection
OSHA	Occupation Safety and Health Administration
OWW	organic wash waste
P	PUREX acid waste (alternate of PAW)
PAS	PUREX acidified sludge
PAW	PUREX acid waste
PCUT	Pipeline characterization using tracers
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest Laboratory
PSN	PUREX supernate waste
PSW	PUREX sludge waste
PUREX	Plutonium Uranium Extraction (Plant)
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	*Revised Code of Washington*
REDOX	Reduction-Oxidation (S Plant)
RI	Remedial Investigation
ROD	Record of Decision
SAP	sampling and analysis plan
SB	soil-bentonite (mixture)
SEPA	State Environmental Policy Act of 1971
SNAP	Space Nuclear Applications Program
SRS	Savannah River Site
SST	single-shell tank
TBP	tributyl phosphate
TC&WM EIS	Tank Closure and Waste Management Environmental Impact Statement
UNH	uranyl nitrate hexahydrate
UPR	unplanned release
VOC	volatile organic compound
WAC	*Washington Administrative Code*
WESF	Waste Encapsulation and Storage Facility
WIDS	Waste Information Data System
WMA	waste management area

1.0 INTRODUCTION

For more than four decades beginning in 1944, the U.S. Department of Energy (DOE) and its predecessors routed waste from spent fuel reprocessing and other operations in the 200 Areas of the Hanford Site through buried transfer pipelines to the single-shell tank (SST) system for storage. The SST system contains one-hundred forty-nine 100- and 200-series tanks and associated components that are grouped into 12 tank farms. These tank farms have been further grouped into seven waste management areas (WMA) (Figure 1-1).

The SST system is undergoing closure. The *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology et al. 1989) closure process emphasizes closure at the WMA level which will include closure of the 100- and 200-series SSTs, the SST components used to transfer and store waste, and the associated contaminated environmental media. According to the HFFACO Milestone M-045-83, WMA C (Figure 1-2) will be the first WMA to complete closure by mid-2019.

This assessment evaluates characterization and closure options specifically applicable to the WMA C transfer pipelines. The need for this feasibility evaluation was identified in RPP-PLAN-46484, *Waste Management Area C Closure Demonstration Project Plan*. The project plan is being developed collaboratively by the State of Washington Department of Ecology (Ecology), DOE, Office of River Protection (ORP), and ORP's contractor (the project team) to provide engineering, cost, and other information on technologies that might be used to close WMA C. Waste Management Area C pipelines were one of seven primary focus areas identified by the project team. The project plan's stated purpose for this pipeline feasibility evaluation is to provide the information that is necessary to make closure decisions or where such information is not available, to identify the characterization or demonstration activities that will provide the information. HFFACO milestone M-045-81 requires that all activities contained in the project plan be completed by September 30, 2014.

1.1 SCOPE

This assessment presents information on the physical attributes of WMA C pipelines and makes an estimate of the inventory of waste remaining within them. Using this information, the assessment evaluates the need for and feasibility of implementing pipeline characterization and/or closure actions and recommends a path forward to meet applicable regulatory requirements including the State of Washington's *Hazardous Waste Management Act of 1976* (HWMA) (*Revised Code of Washington* [RCW] 70.105, "Hazardous Waste Management") and its implementing regulations, *Washington Administrative Code* (WAC) 173-303, "Dangerous Waste Regulations". This information will assist in planning pipeline related actions to support the closure of WMA C by 2019. Recommendations presented in this assessment will be discussed with Ecology and based on these discussions closure activities for pipelines will be developed in a subsequent HWMA closure plan and permit modification request. Permit conditions associated with pipeline closure actions will be approved by Ecology through a modification of WA7 89000 8967, *Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion for the Treatment, Storage, and Disposal of Dangerous Waste* (Hanford Site-Wide Permit).

Figure 1-1. Single-Shell Tank Waste Management Areas and Adjacent Facilities in the 200 East Area and 200 West Area of the Hanford Site

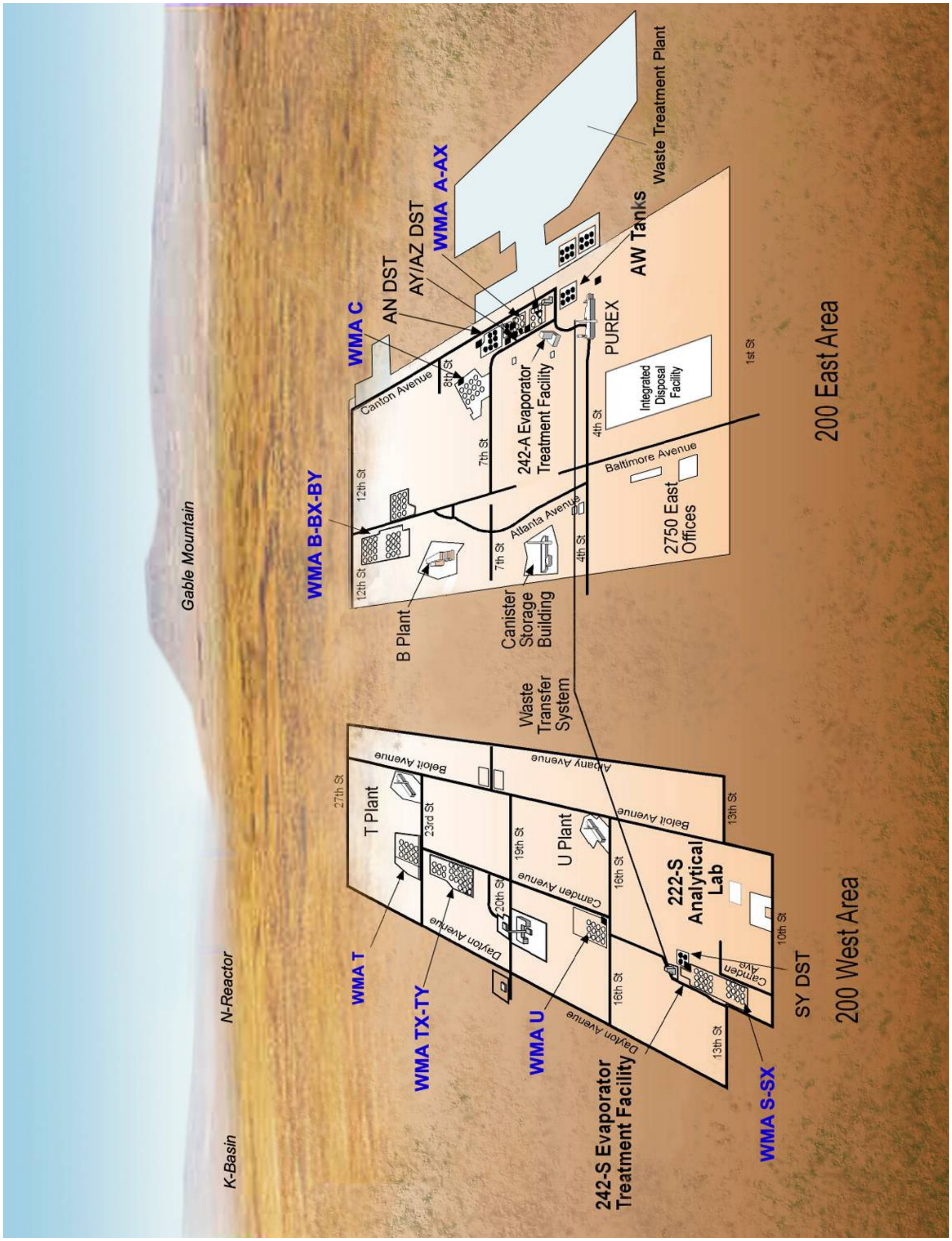
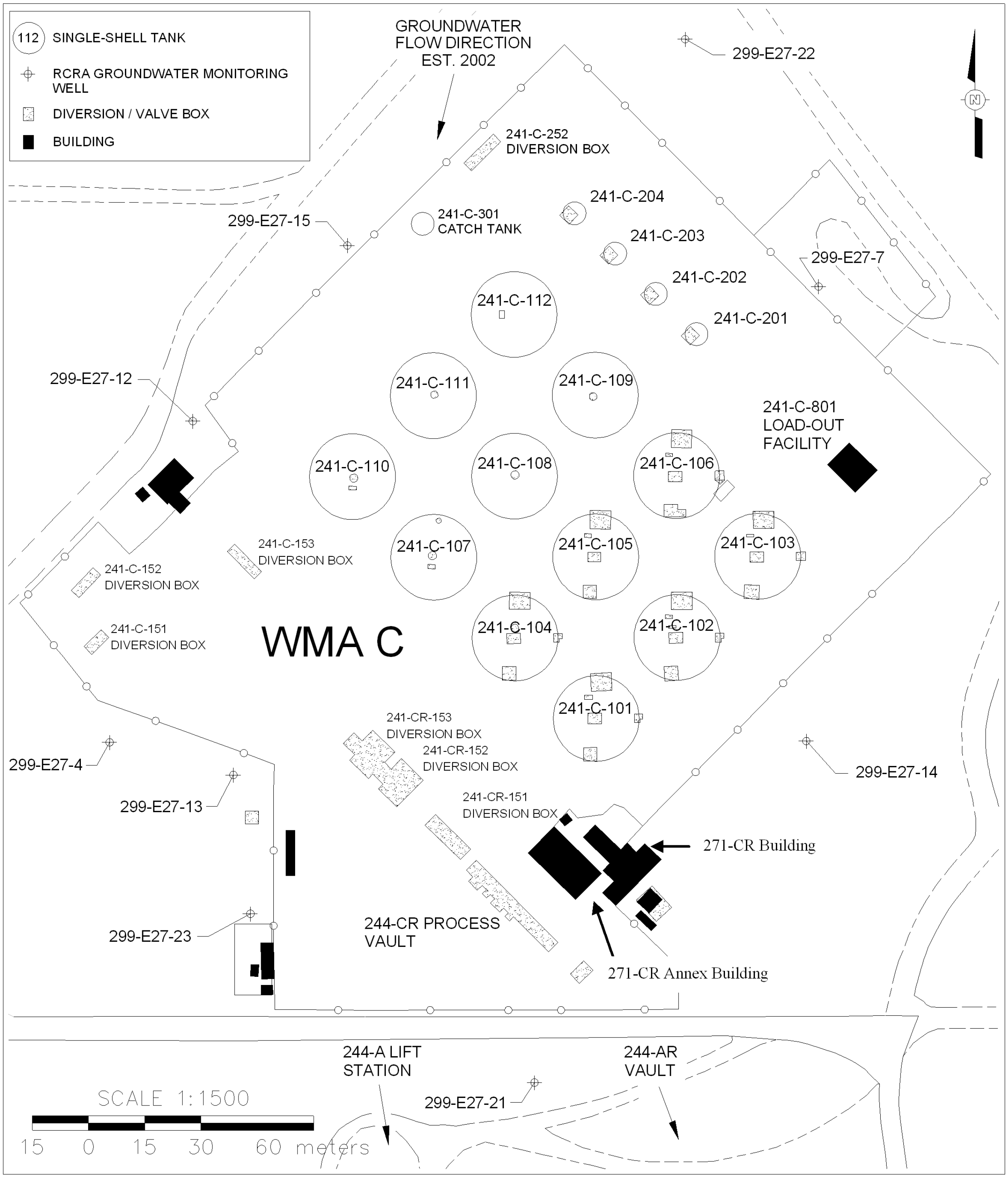


Figure 1-2. Waste Management Area C



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This assessment does not address corrective actions for pipeline releases to environmental media. These actions will be evaluated as part of the ongoing WMA C soil corrective action investigation. This assessment also does not address remedial action decision-making for pipelines at the transecting point between WMA C and the past-practice 200-IS-1 Operable Unit. These assessments will be made as part of a collaborative process between Ecology, ORP, DOE Richland Operations Office, and the DOE contractors. Closure decisions for both soil corrective actions and transect point activities will be made in the Site-Wide Permit. Lastly, this assessment deals only with closure actions for existing abandoned pipelines. New waste transfer systems that will be used for WMA C tank waste retrieval and closure activities will be removed and disposed of in accordance with their specific HFFACO tank waste retrieval work plans.

This feasibility evaluation assumes that a landfill closure decision will be made for WMA C and that this decision will include placement of an engineered surface barrier over the farm. Should landfill closure not be the approved closure remedy for WMA C, removal of the entire WMA C tank system, including the associated pipelines, would be required, thus eliminating the need for evaluation of other pipeline closure alternatives.

1.2 CONTENT

This feasibility evaluation includes a detailed summary of the history and physical attributes of WMA C pipelines including an assessment of their likely inventory and the uncertainty around the inventory information. Information on construction, operation, and termination of pipeline usage in WMA C is summarized where available and includes:

1. When construction occurred, the final constructed configuration and the timeframe of the construction

2. Procedures that directed how waste transfers to WMA C were to be conducted, including pre- and post-transfer procedures (running hot water to warm up the lines and flushing post transfer) and monitoring these operations

3. Explanation of the termination of the use of WMA C and the current status and condition of the pipelines (possible plugs or leaks, etc.).

Additional information is included to describe the likely current state of piping including:

1. Pipeline type (what was it used for, e.g., waste transfer, metal recovery pressurized)

2. Pipeline size and material (stainless steel, vitrified clay, carbon steel, etc.)

3. Physical configuration (direct buried, encased, active line, spare or blank, average depth below ground surface, depth at each end point, slope, connection configuration [jumper connections, jet pump connections], distance/relationship to other tank farm elements [tanks, other pipelines, diversion box, vault, etc.]), operation history, maintenance history (replacement, abandonment, etc.), and locations where inconsistent pipeline materials are joined

4. Summary of RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site* on plugged pipelines
5. Summary of RPP-RPT-29191, *Supplemental Information Hanford Tank Waste Leaks*, and current knowledge of known or suspected releases from pipelines
6. Identification of known or anticipated contaminated pipelines
7. Identification of known or suspected failed or plugged pipelines
8. Identification of flushed pipelines.

An initial scoping analysis of the long-term impacts to human health and the environment based on pipeline attributes, inventories, and uncertainties, provided in this report, will help with decisions regarding the extent of future pipeline characterization and remediation actions and are described in this evaluation.

The pipeline feasibility evaluation includes a detailed discussion on available methods to characterize or verify inventory in a range of buried pipelines as well as estimates of the quality of the characterization data that would result, including sources of uncertainty. As part of this effort, DOE-ORP previously received support from the DOE Headquarters Office of Environmental Management which convened an expert panel on pipeline characterization technologies in October 2006. The panel considered non-destructive and destructive inspection and characterization techniques for pipelines. These technologies are further screened to identify which, if any, would be appropriate technologies in the event further characterization of the pipelines is warranted.

The feasibility evaluation also includes a discussion of available methods to remove or remediate sections of buried pipelines including stabilization and removal technologies. Where available, information on long-term impacts, worker dose, cost, and implementability associated with performing characterization and remediation activities is included.

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2.0 REGULATORY FRAMEWORK

This section provides a summary of key regulatory requirements pertaining to closure of WMA C pipelines.

2.1 *HAZARDOUS WASTE MANAGEMENT ACT OF 1976*

The state program authorized by the U.S. Environmental Protection Agency (EPA) *Resource Conservation and Recovery Act of 1976* (RCRA) is the HWMA. Requirements under this statute are implemented by WAC 173-303. Closure requirements are contained in WAC 173-303-610, "Closure and Post-Closure." All units must comply with the general closure performance standard specified in WAC 173-303-610 subsection (2) "Closure performance standard." It requires that the owner/operator must close the facility in a manner that accomplishes the following.

a. Minimizes the need for further maintenance.

b. Controls, minimizes, or eliminates to the extent necessary to protect human health and the environment: post-closure escape of dangerous waste, dangerous constituents, leachate, contaminated run-off, or dangerous waste decomposition products to the ground, surface water, groundwater, or the atmosphere.

c. Returns the land to the appearance and use of surrounding land areas to the degree possible given the nature of the previous dangerous waste activity.

Unit-specific closure requirements for the WMA C tank system, which include the pipelines, are specified in WAC 173-303-640 subsection (8) "Closure and post-closure care." In addition to meeting the general closure performance standard, owner/operators of tank systems must remove or decontaminate all waste residues, contaminated containment system components (liners, etc.), contaminated soils, and structures and equipment contaminated with dangerous waste unless the owner/operator demonstrates that it is not practicable to remove or decontaminate all contaminated soils at closure, the tank system must be closed as a landfill and post-closure care is required as specified in WAC 173-303-620, "Financial Requirements."

For the purposes of this pipeline feasibility evaluation, it is assumed that removal or decontamination of the WMA C tank system cannot be practically achieved [WAC 173-303-640 subsection (8)(b)] and therefore the tank system (WMA C) will be closed as a landfill pursuant to the regulations contained in WAC 173-303-665, "Landfills" subsection (6) "Closure and post-closure care." Key Policy Determination #1 in the WMA C Closure Demonstration Plan (RPP-PLAN-46484, Attachment 2, "Single-Shell Tank Waste Management Area C Closure White Paper") states:

> "If the demonstration finds that any portion of contaminated soil or any portion of the tank system cannot be practically removed, WMA C will be closed as a landfill in accordance with the SST System permit conditions. Evaluation of

> removal of discrete areas of soil or portions of the tank system that are deemed to be required for further protection of human health and the environment will occur as part of the RCRA Corrective Measures Study and component closure plan applications, respectively, should landfill closure be determined."

Therefore, landfill closure of the SST system WMAs may involve some removal of dangerous waste and waste residues and some removal and/or decontamination of ancillary equipment, including pipelines, or contaminated environmental media to meet the general closure performance standards of HWMA (e.g., the requirements of HFFACO Milestone M-45-00).

Landfill closure requirements state that the affected area must be covered with a final cover designed and constructed to do the following.

a. Provide long-term minimization of migration of liquids through the closed landfill.

b. Function with minimum maintenance.

c. Promote drainage and minimize erosion and abrasion of the cover.

d. Accommodate settling and subsidence so that the cover's integrity is maintained.

e. Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

Once the cover is in place, units that are closed as landfills must be monitored as part of "post-closure care." The purpose of post-closure care is to ensure that caps or covers function as intended and that dangerous waste remains sufficiently contained so as to protect human health and the environment and that post-closure monitoring of the groundwater is provided.

2.2 HANFORD SITE-WIDE PERMIT

Hanford's Site-Wide Permit as authorized under the HWMA is expected to be modified in the near future to include general closure requirements for the SST system. Specific closure activities for individual SST system components or groups of components, including pipelines, will be developed in subsequent HWMA closure plans. These closure plans will form the basis for further modifications to the Site-Wide Permit. Corrective measures for contaminated soil (which may include specific associated pipelines) will also be authorized through the Site-Wide Permit.

The SST system closure plans are depicted in HFFACO Action Plan Appendix I, "Single-Shell Tank System Waste Retrieval and Closure Process" as a three-tiered document process. The highest-level document section (Tier 1) addresses closure actions pertaining to the entire SST system. The mid-level section (Tier 2) addresses specific WMA closure activities. The lowest level document in the hierarchy (Tier 3) addresses closure activities for specific components (or groups of components) within a particular WMA which will include closure activities for pipelines.

2.3 HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER

The HFFACO is a legally enforceable agreement for achieving compliance with the CERCLA and HWMA regulations on the Hanford Site. The HFFACO defines and ranks CERCLA and HWMA cleanup commitments, establishes responsibilities, provides a basis for budgeting, and reflects the goal of EPA, Ecology, and DOE in achieving regulatory compliance and cleanup under its enforceable schedule.

The HFFACO Action Plan Milestone M-045-00 states that closure of the SST system is to occur in accordance with the HWMA-authorized dangerous waste regulations contained in WAC 173-303-610. In addition, the HFFACO requires that all work completed under the Milestone M-45 series be conducted in compliance with HFFACO Action Plan Appendix I. The HFFACO Action Plan Appendix I contains the regulatory process for tank waste retrieval, component closure (including pipelines), WMA closure, WMA soil corrective actions (including pipelines in association with contaminated soil), and groundwater remedial actions.

The HFFACO Milestone M-045-83 specifies completion of closure actions at WMA C by June 30, 2019. The HFFACO Milestone M-045-81 requires completion of portions of the C-200 Demonstration Plan necessary to complete closure plan development, which would include any demonstration activities associated with pipelines, by September 30, 2014. The C-200 Demonstration Project Plan is being revised to include the development of this Pipeline Feasibility evaluation. The HFFACO Milestone M045-082 requires that ORP submit permit modification requests to support final closure of WMA C by September 30, 2015.

2.4 *ATOMIC ENERGY ACT OF 1954* AND DOE O 435.1, *RADIOACTIVE WASTE MANAGEMENT*

Under the authority of the *Atomic Energy Act of 1954*, the DOE regulates the closure of its facilities containing radioactive materials. The primary mechanism for this regulation is DOE O 435.1, *Radioactive Waste Management*, and the associated documents (particularly DOE M 435.1-1, *Radioactive Waste Management Manual*).

The DOE requires a multistep process for the closure of a waste storage facility that was managed as high-level waste:

a. Classification of waste
b. DOE Tier 1 closure plan
c. DOE Tier 2 closure plan
d. Analysis of the as-built system.

At each step, an assessment of long-term human health and environmental impacts is required. For these facilities, DOE O 435.1 establishes a process to determine the actual waste classification for closure. As high-level waste, by law, cannot be disposed near the surface, any residual waste in a near-surface facility must be classified as transuranic or low-level waste. For simple cases, a citation process is used. For facilities like the Hanford tanks, an evaluation process is used. In the evaluation process, the facility must show the following.

a. Waste has been removed from the facility to the maximum extent technically and economically practical.

b. Long-term impacts are low enough not to require geologic isolation.

The DOE Tier 1 closure plan defines the approach and plans by which closure of each facility within the site is to be accomplished. This plan includes the following elements:

a. Identification of the closure standards/performance objectives.

b. A strategy for allocating waste disposal facility performance objectives from the closure standards identified in the closure plan among the facilities/units to be closed at the site.

c. An assessment of the projected performance of each unit to be closed relative to the performance objectives allocated to each unit under the closure plan.

d. An assessment of the projected composite performance of all units to be closed at the site relative to the performance objectives and closure standards identified in the closure plan.

e. Any other relevant closure controls including a monitoring plan, institutional controls, and land use limitations to be maintained in the closure activity.

A DOE Tier 2 closure plan provides the detailed information related to a specific unit or facility closure action that is bounded by the analyses contained in the Tier 1 plan. The Tier 2 closure plan should demonstrate that the performance objectives identified in the Tier 2 closure plan documentation can be met and maintained.

The final analysis must show that the as-closed facility meets the requirements established in the DOE Tier 1 closure plan.

2.5 *NATIONAL ENVIRONMENTAL POLICY ACT OF 1969* AND "STATE ENVIRONMENTAL POLICY ACT OF 1971"

Waste Management Area C closure and corrective actions require determinations under the *National Environmental Policy Act of 1969* (NEPA) and *Revised Code of Washington* (RCW) 43.21C, "State Environmental Policy Act of 1971" (SEPA). Any major Federal action must be evaluated under the NEPA to determine if the proposed action will create any significant impacts prior to a Federal agency making a decision on the proposed action. The SEPA is intended to ensure that environmental values are considered during decision-making by State and local agencies during the permitting process. It gives State and local agencies the tools to allow them to both consider and mitigate environmental impacts of proposed actions. DOE/EIS-0391, *Draft Tank Closure and Waste Management Environmental Impact Statement for the Hanford*

Site, Richland, Washington (TC&WM EIS) will meet both NEPA and SEPA requirements. The TC&WM EIS will in part analyze SST system closure alternatives, including clean and landfill closure. After the final EIS is published, DOE will issue its Record of Decision (ROD) which will described the actions it will implement. The decisions from the TC&WM EIS ROD and SEPA determinations will outline a path for closure of the WMAs.

In lieu of preparing a separate SEPA EIS, Ecology has the option to adopt a NEPA EIS if certain requirements in WAC 197-11-610, "Use of NEPA Documents," section (3) are met or if they cooperated with a Federal agency that is preparing an EIS. As a cooperating agency, Ecology may participate in a range of activities associated with the preparation of an EIS, including co-authoring a document, providing input to development of alternatives, or similar actions. The decisions that are documented in the TC&WM EIS ROD and Ecology's SEPA determinations will affect closure and corrective actions at WMAs.

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3.0 WASTE MANAGEMENT AREA C HISTORY

3.1 OVERVIEW

The 241-C Tank Farm (i.e., WMA C) contains 12 first-generation, reinforced concrete tanks with carbon steel liners covering the sides and bottoms. The tanks are 23 m (75 ft) in diameter and 4.9 m (16 ft) deep, with a capacity of 2 million L (530,000 gal). The tanks are arranged in four rows of three tanks. The tanks in each row are piped together so that when the first tank fills, it overflows (cascades) into the second tank, and the second into the third. The farm also contains four smaller 200-series tanks that are 6.1 m (20 ft) in diameter and hold 0.2 million L (55,000 gal). These four tanks are piped to diversion box 241-C-252. In addition to 241-C-252, three other diversion boxes were originally constructed in C Farm; another three diversion boxes, the 244-CR process vault, the 271-CR control house, 271-CRL laboratory, and the 241-C-801 cesium loadout facility were built later.

Waste Management Area C is part of the A/AX/C complex whose operations can be separated into five operational phases:

- The Manhattan Project and bismuth phosphate operations (1944 to 1952)
- Uranium recovery operations (1952 to 1957)
- PUREX operations (1956 to 1972, 1983 to 1988)
- Waste fractionation operations (1961 to 1978)
- Tank farm interim stabilization and isolation (begun in 1975).

Pipelines built in association with these operations are identified in Appendix A.

3.2 THE MANHATTAN PROJECT AND BISMUTH PHOSPHATE OPERATIONS (1944 TO 1952)

The Hanford Site was constructed as part of the Manhattan Project to produce plutonium by chemically separating it from irradiated fuel slugs using the bismuth phosphate process. Preliminary design (1943) called for four separations plants (B, C, T, and U) and their associated tank farms, but later development reduced that number to three. C Plant construction was cancelled, but by the time it was cancelled 241-C Tank Farm had already been built.

The bismuth phosphate process produced five waste streams, as follows.

- Metal waste (MW) which was the byproduct from the plutonium separation phase of the bismuth phosphate process. Metal waste contained unfissioned uranium and ~90% of the fission products of the irradiated fuel.

- First-cycle waste (1C) was the byproduct from the first plutonium decontamination cycle of the bismuth phosphate process. This waste contained ~10% of the fission products of the irradiated fuel. This waste also contained coating-removal waste.

- Second-cycle waste (2C) was the byproduct from the second and last plutonium decontamination cycle of the bismuth phosphate process. This waste contained less than 0.1% of the fission products of the irradiated fuel. 241-C Tank Farm did not store 2C waste.
- The 224 waste was low-level liquid waste from the 224-B plutonium concentrator building.
- The 5-6 waste was low-level liquid waste from floor drains in individual process cells in B Plant.

Waste Management Area C is located in the 200 East Area of the Central Plateau of the Hanford Site (Figure 3-1). The 241-C Tank Farm was constructed from 1944 to 1945 and originally consisted of the twelve 100-series tanks, four 200-series tanks, catch tank 241-C-301, four diversion boxes (241-C-151, 241-C-152, 241-C-153, and 241-C-252), and interconnecting pipelines. The original layout of WMA C tanks, diversion boxes and pipelines (1943 to 1945) is shown in Figure 3-2.

To utilize the tanks in WMA C, diversion box 241-B-154 was installed to enable connections from the 221-B Bismuth Phosphate Plant to either the 241-B or 241-C Tank Farms (HW-10475-C, *Hanford Technical Manual Section C*, pp. 906-910). Two pipelines (8902 and V130) were installed in late 1945 from diversion box 241-B-154 to diversion boxes 241-C-151 and 241-C-152 to enable use of the tanks in WMA C (H-2-432, *Piping Between 241B and 241C*). Construction of WMA C was completed and turnover of the tank farm structures to operations was conducted on February 10, 1945 (HW-7-1388-DEL, *Hanford Engineer Works Monthly Report February 1945*, page 16, and INDC-356-VOL3, *Construction Hanford Engineer Works U.S. Contract No. W-7412-ENG-1 Du Pont Project 9536 History of the Project Volume III*, pp. 840).

Following completion of construction, the tanks in the WMA C were not put into service until March 1946, beginning with receipt of waste into the 100-series tanks, and receipt of waste in the 200-series tanks in September 1947. Metal waste from B Plant was stored in the 241-C-101 (C-101)/241-C-102 (C-102)/241-C-103 (C-103) and 241-C-104 (C-104)/241-C-105 (C-105)/ 241-C-106 (C-106) tank series cascades, and 1C waste from B Plant was stored in the 241-C-107 (C-107)/241-C-108 (C-108)/241-C-109 (C-109) and 241-C-110 (C-110)/241-C-111 (C-111)/ 241-C-112 (C-112) tank series cascades (RHO-LD-79, *A History of the 200 Areas Tank Farms*).

3.3 URANIUM RECOVERY OPERATIONS (1952 TO 1957)

U Plant was originally constructed during World War II as a bismuth phosphate plant, but was not needed for that purpose, and the facility was used as a simulator. It was modified in 1951 for uranium recovery operations using the tributyl phosphate (TBP) process. For this reason, U Plant was frequently referred to as the "TBP Plant." Beginning in October 1952, MW was sluiced from tanks in C Farm, treated in the 244-CR process vault, and transferred to U Plant via the cross-site transfer line. Metal waste in the 200-series tanks was sluiced out in early 1954. Metal waste from 241-B, 241-T and 241-U Tank Farms was also sent to U Plant for uranium

Figure 3-1. Location Map of Waste Management Area C in the 200 East Area of the Hanford Site

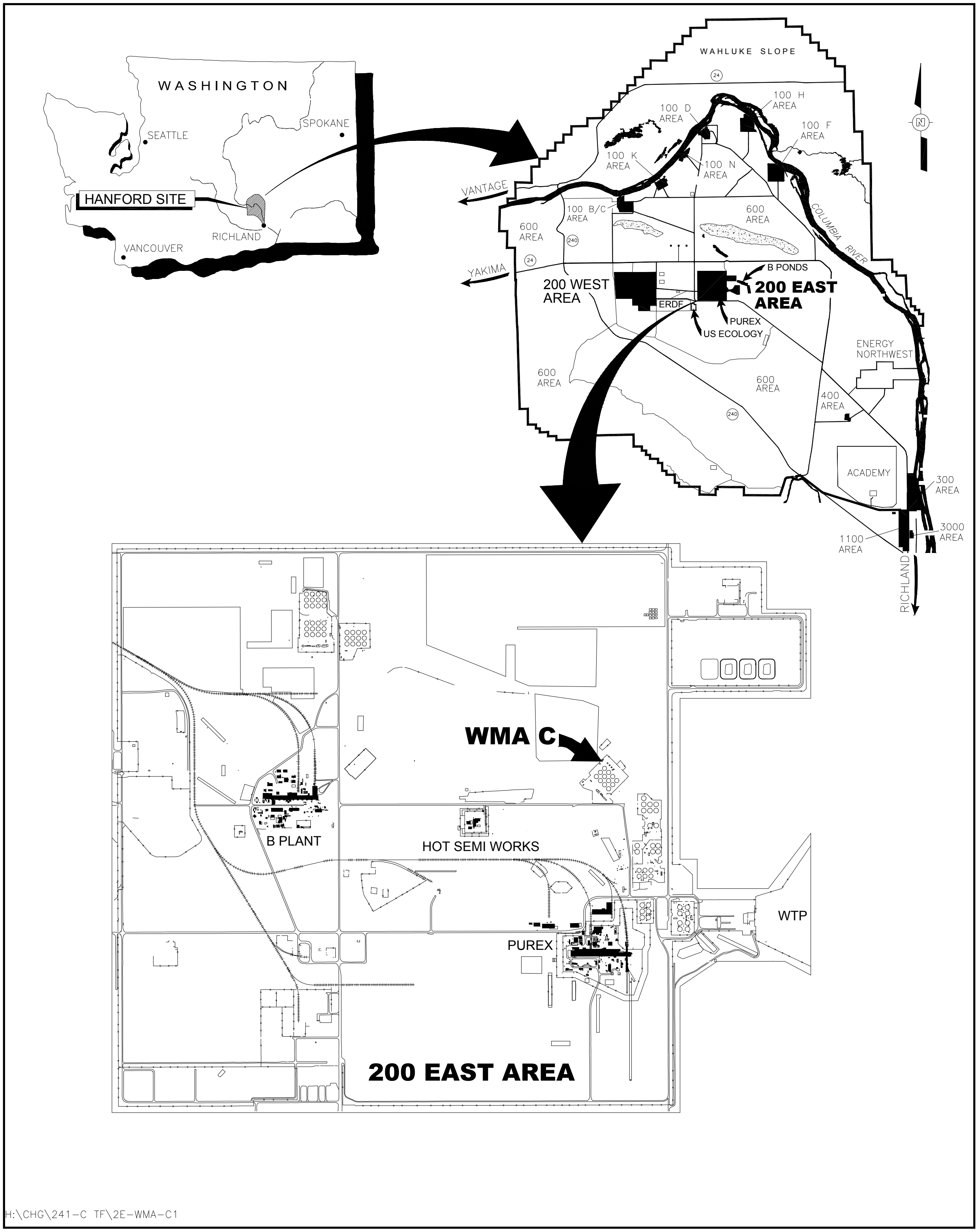
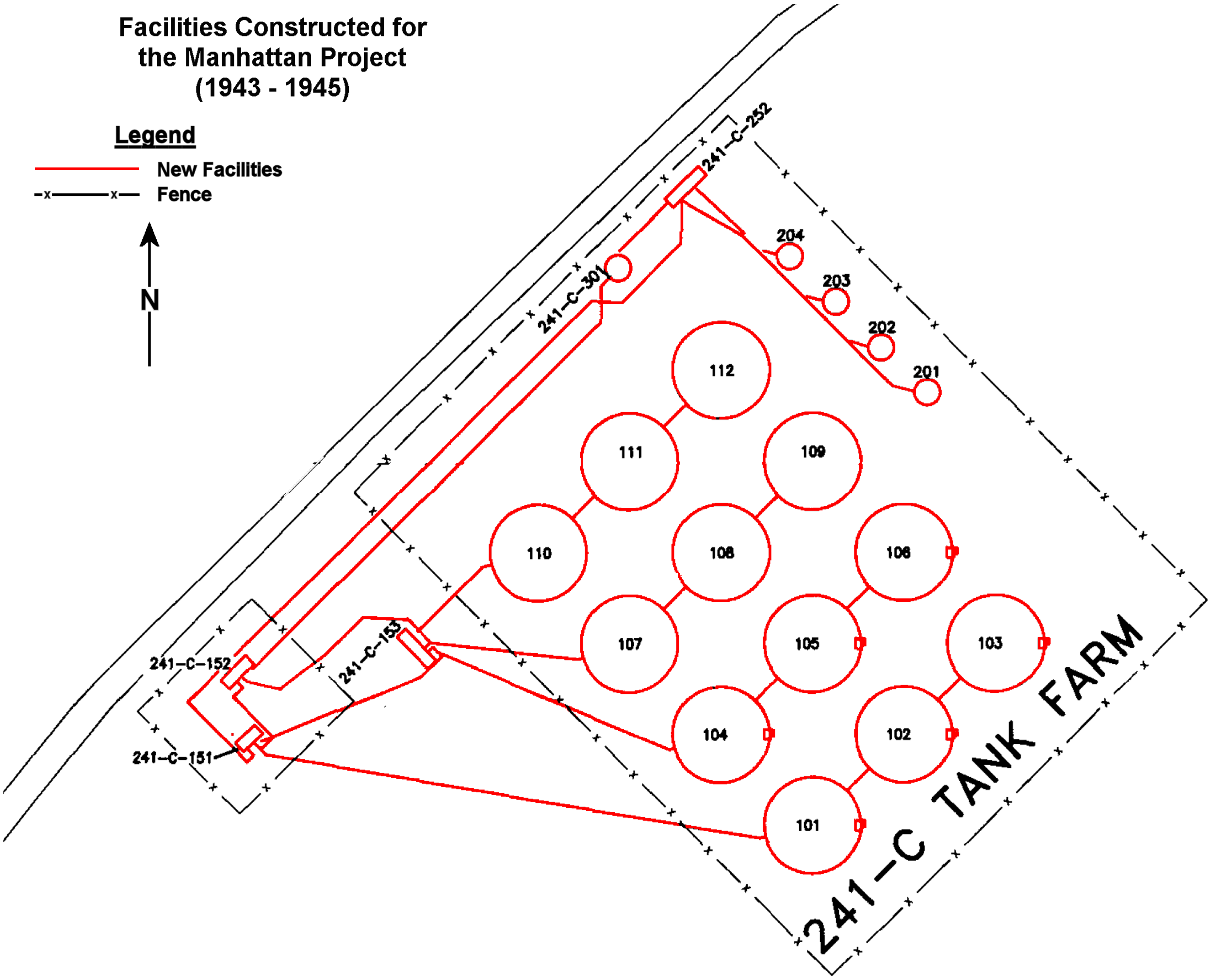


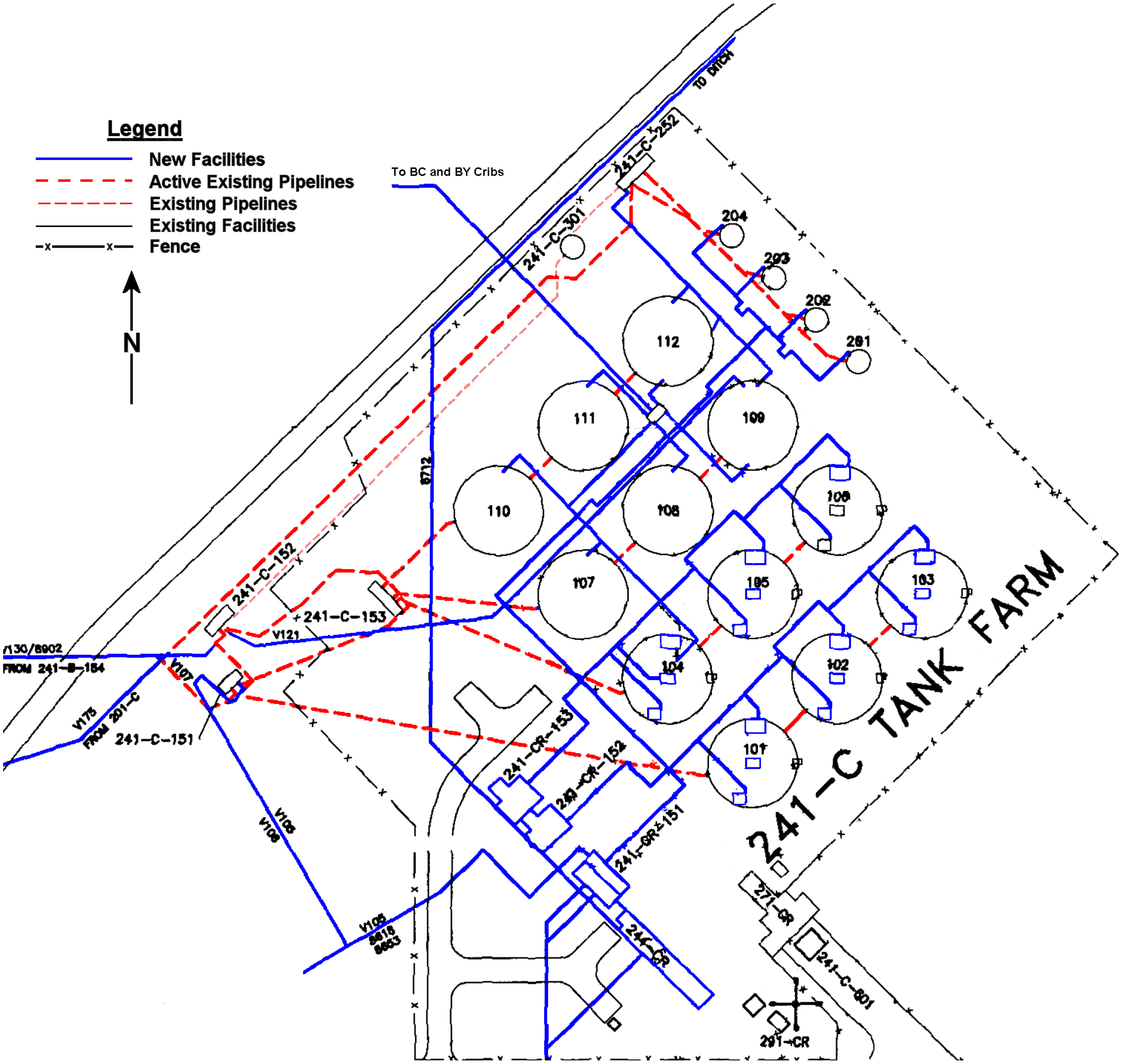
Figure 3-2. Waste Management Area C Components Constructed for the Manhattan Project (1943 to 1945)



recovery. Newly generated MW from T Plant was also sent to U Plant for uranium recovery, until T Plant shut down in 1956. Uranium recovered by this method was in the form of uranyl nitrate hexahydrate (UNH), which was sent to the 224-U building for conversion to UO_3. 224-U building was known as the "UO_3 Plant" (WHC-SD-WM-TI-302, *Hanford Waste Tank Sluicing History*; RHO-LD-79).

The uranium recovery facilities in C Farm include the 271-CR control house, the 244-CR vault, the 241-CR-151, 241-CR-152, and 241-CR-153 diversion boxes, and modifications to the underground piping system. Other facilities which are outside the scope of this report, but relevant, include the cross-site transfer line, the 241-ER-151 diversion box near B Plant, the BY cribs, and the BC cribs. Figure 3-3 shows facilities constructed for uranium recovery.

Figure 3-3. Waste Management Area C Components Constructed for the Bismuth and Uranium Recovery Operation (1946 to 1957)



Uranium recovery operations produced two waste streams: TBP waste and low-level waste. Tributyl phosphate waste, concentrate from the waste concentrator, was returned to the tank farms, including C Farm (all tanks). The design called for the same volume of TBP waste to be produced as the volume of MW processed, but inefficiencies in the process resulted in approximately twice as much TBP waste produced as the MW processed. A total of 215 million L of TBP waste was produced. Low-level waste included condensate from the feed concentrator, waste concentrator, and HNO_3 fractionator. This waste was sent to various cribs that are outside the scope of this report. Cooling water and cell drainage from the TBP Plant were discharged to U Pond, also outside the scope of this report (WHC-MR-0227, *Tank Wastes Discharged Directly to the Soil at the Hanford Site*; WHC-SD-WM-TI-648, *Tank Characterization Reference Guide*; HW-19140, *Uranium Recovery Technical Manual*).

Despite additional tank farm construction and ongoing volume reduction efforts, tank space was not sufficient to support both the uranium recovery mission and plutonium production. To reduce the volume of stored waste, TBP waste was concentrated in the 242-T and 242-B evaporators beginning in July 1953 (very little C Farm waste was evaporated – some from tank C-112 in the third quarter of 1953).

The 244-CR vault was modified in 1955 to scavenge TBP waste that was stored in C Farm, and the 241-C-601 chemical makeup building was constructed. Nickel ferrocyanide was added to the TBP waste, which caused the ^{137}Cs to precipitate and join the ^{90}Sr in sludge settled at the bottom of the vault tank. The scavenged waste supernate could then be discharged to cribs. New piping was installed to facilitate TBP retrieval from the C-107/C-108/C-109 and C-110/C-111/C-112 tank cascades. Tributyl phosphate could be jetted out of these tanks to the 241-C-104 pump pit and transferred to the 244-CR vault via the existing encasements. Beginning November 1955, TBP waste was retrieved from the C Farm tanks and sent to 244-CR, using the encasements and pump pits. The 244-CR vault received TBP waste from only two tanks outside C Farm: 241-BX-108 and 241-BX-109.

Scavenged TBP waste was transferred from 244-CR via the 241-CR-151, 241-C-151, and 241-C-252 diversion boxes to tanks C-109 and C-112 to settle, and from there to the BC cribs and trenches. Cribbing of scavenged TBP waste began in November 1954. Approximately 155 million L (41 million gal) of scavenged TBP waste was discharged into the ground. Of this, ~44 million L (12 million gal) resulted from in-farm scavenging in the 244-CR vault. The BC cribs and trenches are outside the scope of this report. The 241-C-601 building was torn down in August 1973 (RHO-LD-79; WHC-MR-0227).

The 241-CR steam cleaning pit was dug in 1954, northwest of 241-C-103. No further information is available about this facility (HW-60807, *Unconfined Underground Radioactive Waste and Contamination in the 200 Areas–1959*).

Additional infrastructure was added to WMA C between 1946 and 1957 (Figure 3-3). The 244-CR vault, diversion boxes 241-CR-151, 241-CR-152, and 241-CR-153, concrete-encased pipelines, and concrete pits atop tanks C-101 through C-106 (heel jet, pump, and sluicing pits) were constructed from 1951 to 1952 in WMA C. These facilities were part of other facilities constructed in 241-U, 241-T, 241-TX, 241-B, 241-BX, and 241-BY Tank Farms, as well as major modifications of the 221-U Plant, that were used to retrieve and process metal wastes to recover uranium (HW-19140). The pits atop of the tanks connect via concrete-encased underground pipelines to the 241-CR-152 and 241-CR-153 cascade diversion boxes, which have underground piping connections to the 241-CR-151 master diversion box. The 241-CR-151 master diversion box has concrete-encased underground pipelines connecting to the 244-CR vault.

The 244-CR vault contains a sludge accumulation tank (TK-CR-001), two sludge dissolution tanks (TK-CR-002 and TK-CR-003), and a process pump tank (TK-CR-011). An aboveground nitric acid tank (TK-CR-004) was used to add nitric acid to tanks TK-CR-002 and TK-CR-003 for acidifying sludge. Tank TK-CR-004 was relocated into the 271-CR annex building in 1963.

The 244-CR vault was originally equipped with an air supply and exhaust system that included a glass wool filter, exhaust fan, and stack (291-CR). A control house, building 271-CR, was also constructed to contain instrumentation, motor control centers, air compressors, ventilation, and operations and administrative facilities for operation of the 244-CR vault and metal waste retrieval equipment.

3.4 PLUTONIUM URANIUM EXTRACTION PLANT OPERATIONS (1956 TO 1972/ 1983 TO 1988)

The Plutonium Uranium Extraction (PUREX) process was the third and final plutonium separation process used at the Hanford Site, and the PUREX plant ultimately processed ~72% of the irradiated fuel produced at Hanford. The process recovered both plutonium (in the form of plutonium nitrate) and uranium (in the form of UNH) in a continuous solvent extraction process, and also recovered nitric acid and the TBP organic solvent for reuse. This innovation minimized waste generation and resulted in PUREX waste being more highly concentrated than other Hanford waste streams. The PUREX plant, the 241-A Tank Farm (A Farm), and various and waste transfer lines and cribs were constructed for PUREX operations (HW-32413-DEL, *An Introduction to the PUREX Plant*; WHC-MR-0437, *Brief History of the PUREX and UO_3 Facilities*; RHO-LD-79). Figure 3-4 shows the PUREX facilities constructed in C Farm.

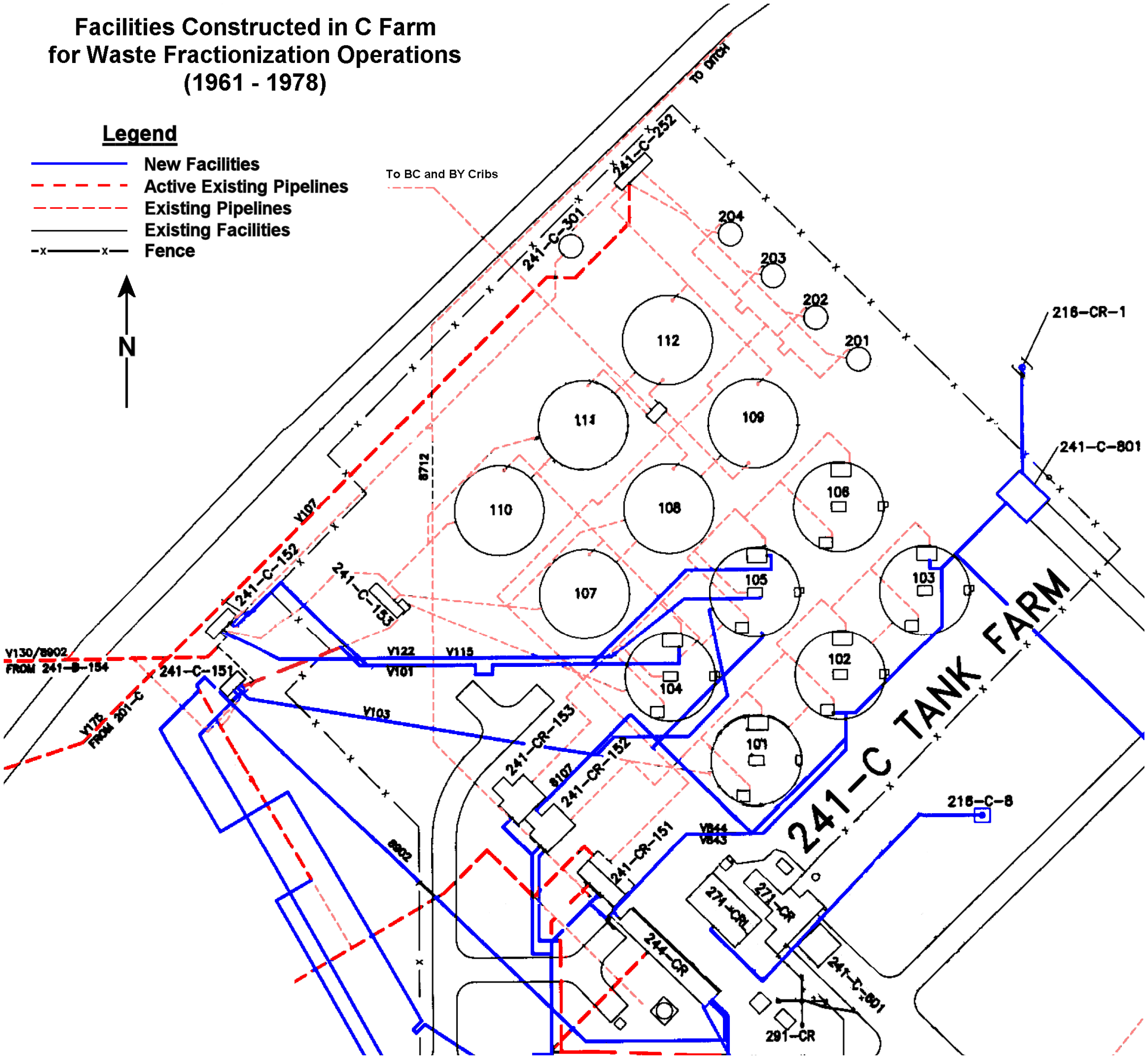
The PUREX plant produced various low-level waste streams and three high-level waste streams: PUREX coating waste (CWP), PUREX acid waste (PAW), and organic wash waste (OWW), also called "carbonate." The PAW, which contained 99% of the fission products, was also known as P, high(-level) acid waste (HAW), current acid waste (CAW), and sulfate free waste (IWW) (HW-32413-DEL; RHO-LD-79).

3.4.1 Plutonium Uranium Extraction Plant High-Level Waste Streams

Self-boiling PAW and OWW from PUREX were stored in A Farm. The first waste discharges to tanks 241-A-101 and 241-A-102 were not sufficiently concentrated to boil, so OWW was temporarily segregated and sent to 241-C-110. Subsequent waste discharges to A Farm did boil (RHO-LD-79).

Non-boiling CWP was sent to now-empty tanks in C Farm. Lines V050 from diversion box 241-A-152 to the 241-CR-151 diversion box, and V051 from 241-A-152 to the 244-CR vault were built for this purpose. As the Uranium Recovery project provided space in B/BX/BY Farms (see HNF-5231, *Historical Vadose Zone Contamination from B, BX, and BY Tank Farm Operations*), CWP was transferred there from C Farm beginning in 1957. In 1962, tank C-102 was designated as the CWP receiver tank, and all CWP from PUREX went there. From tank C-102, CWP was pumped to B/BX/BY Farms via the 241-CR-152, 241-CR-151, 241-C-151 and 241-B-154 diversion boxes (RHO-LD-79).

Figure 3-4. Waste Management Area C Components Constructed for Waste Fractionization Operations (1961 to 1978)



New pump discharge line 8107 was built from tank C-102 to 241-CR-152 diversion box in 1966 for CWP transfer to B/BX/BY. When the Waste Fractionization Program got underway in B Plant in 1968 (see Section 3.4), OWW was sent to tank C-102 along with CWP. Line V843 was built in January 1969 and allowed CWP/OWW to be discharged from 241-CR-151 directly to tank C-102, bypassing the 241-CR-152 diversion box (this simplified the routing to B/BX/BY). Line V844 was built at the same time, tying into 8107 and allowing tank C-102 to discharge to diversion box 241-CR-151 instead of 241-CR-152. Additionally, line V051 from 241-A-152 diversion box to the 244-CR vault was rerouted to 241-CR-151 [RHO-LD-79; H-2-33087, *Ln 8107 (241-CR-152 to 102-C) V843, V844 (241-CR-151 to 102-C) V050, V051 (241-A-152 to 104-C)*, Rev. 7].

Several months later, in October 1969, CWP leaked from line V051 (UPR-200-E-81). Lines V050 and V051 from diversion box 241-A-152 were modified in November 1969 to bypass the 241-CR-151 diversion box and discharge CWP/OWW directly into tank C-104 instead of tank C-102. This waste was transferred from tank C-104 to B/BX/BY Farms from 1969 to 1973, and from tank C-104 to 200 West Area from 1973 to 1976 (RHO-LD-79; H-2-33087).

There is a discrepancy between drawings H-2-33087 and H-2-44502, *Flow Diagram Waste Transfer and Storage Facilities*, sh 7, regarding the piping from the 241-CR-151 and 241-CR-152 diversion boxes to tanks C-102 and C-104. Drawing H-2-44502 shows line 8107 discharging to tank C-102 via a riser along with abandoned line V843, and line V844 connected to V843 and discharging to tank C-104 via a riser. Drawing H-2-33087 shows line V843 discharging to tank C-102 via a riser, and lines 8107 and V844 connected to the pump discharge line from tank C-102. It is believed that drawing H-2-44502, sh 7, is wrong.

The over ground transfer line from tank C-105 to tank C-108 broke sometime between January 1956 and July 1959 and spilled 190 L (50 gal) of CWP to the ground (UPR-200-E-16). On November 1, 1960, during work in the 244-CR vault, wind spread contaminated particles eastward (UPR-200-E-27).

3.4.2 Plutonium Uranium Extraction Plant Shutdown and Restart

The PUREX Plant was placed in standby in 1972 to allow accumulation of N Reactor spent fuel, and sluicing of A and AX Farms (see Section 3.4). The standby was intended to be 18 months, but various events prevented restart until 1983. Final PUREX shutdown was in 1988, and the closure order came in 1992.

3.5 FISSION PRODUCT RECOVERY (1961 TO 1967) AND WASTE FRACTIONIZATION OPERATIONS (1967 TO 1978)

The concept of recovering fission products with industrial uses (primarily ^{137}Cs) began in the mid-1950s. The country's largest source of fission products was at Hanford. Removal of these isotopes from the PUREX waste stream would also make waste storage cheaper and waste disposal easier. Methods for scavenging cesium and strontium from liquid waste were developed during the Uranium Recovery Mission (see Section 3.2), and reduced storage costs so much that immediate research was begun in the mid-1950s on scavenging Reduction-Oxidation (S Plant) (REDOX) and PUREX waste for similar savings. There was also a growing commercial market for these isotopes. Since the isotope separation process involved precipitation and centrifugation, the first idea was to use B Plant to do this, since it had this equipment and was no longer needed. Plans were made to refurbish B Plant to remove cesium and strontium from PUREX waste (HW-43835, *The Isolation and Packaging of Fission Products at Hanford*).

An urgent need for ^{90}Sr by the Space Nuclear Applications Program (SNAP) resulted in an acceleration of the fission product recovery project in August 1960. An improvement in the PUREX process allowed modifications to the plant head-end that facilitated recovery. The 244-CR vault was reactivated for the program, and the Hot Semiworks (HS) complex would be a pilot plant until B Plant modifications were complete. Hot Semiworks was modified and renamed Strontium Semiworks and production began in July 1961. Plutonium Uranium Extraction acid waste was pumped via diversion box 241-A-152 and line V051 to 244-CR vault, allowed to age, then sent via line 8900 to HS for purification. Strontium product was loaded into shipping casks at 201-C for offsite shipment to customers (SNAP generators). Strontium-depleted PAW waste from HS was sent to tanks C-107/C-108/C-109 in C Farm. The 271-CRL laboratory was built in C Farm in 1962 (HW-66297, *Strontium-90 – Recovery and Lag Storage Interim Program*; HW-64105, *Hanford Fission Product Program Plant Improvement Program*; GE 1961; RHO-LD-79; HW-76352, *Waste Management Program Chemical Processing Department*). Figure 3-4 shows facilities constructed in C Farm to support waste fractionization operations.

As well as ^{90}Sr, ^{137}Cs was recovered from PUREX waste during this time. Originally, in 1961, cesium was separated in 212-A. Beginning in 1963, stored PUREX supernate waste (PSN) from tank C-103 was pumped to the 241-C-801 cesium loadout facility in C Farm and cesium product was loaded into shipping casks for offsite shipment. Newly constructed line V109 from tank 241-A-101 to diversion box 241-C-151 allowed PSN from A Farm to refill tank C-103. Depleted PSN was returned to tank C-102 and was eventually transferred (along with CWP) to BY Farm for in-tank solidification (ITS). In-tank solidification is described in HNF-5231. Use of the 241-C-801 facility ended in 1969 (HW-71333, *Process Engineering Cesium Loadout Facility at the 241-C Tank Farm*; HW-81481, *Waste Management Program Chemical Processing Department*; RHO-LD-79; HW-76352).

B Plant was used for partial strontium recovery work from 1963 to 1967. Beginning in August 1963, PAW was sent from the 244-CR vault to B Plant via line 8902 to diversion boxes 241-C-151, 241-B-154, and 241-BX-154. It was precipitated and concentrated, allowed to age, and later sent to HS via line V743 for final purification. Strontium Semiworks waste was sent to C Farm as before. Process condensate and other waste from B Plant (FP) was sent to B Farm, and was also sent (via tank 241-B-112) to tank 241-AX-101 in 1965 (RHO-LD-79; HW-69011, *Project CGC-897 – Title I Design, Fission Product Storage in B-Plant*; GE 1963).

Beginning in late 1967, B Plant went into full operation and began isolating Cs (by ion exchange) and strontium. Strontium purification was also done in B Plant, and so HS was no longer needed and was shut down (the facility was retired in 1967 and was decommissioned from 1983 to 1987). Strontium was now recovered by solvent extraction in B Plant instead of the previous precipitation method. Plutonium Uranium Extraction acid waste was now routed to B Plant via diversion box 241-AX-151 and the new 244-AR vault for strontium recovery, instead of via the 244-CR vault. In addition, B Plant received PSN from feed tank 241-C-105, via line V 130, for cesium recovery by ion exchange. More than 95% of the strontium and cesium in PAW was removed in B Plant. Line V 103 from diversion box 241-C-151 was modified in 1968 to bypass tank C-104 and allow PSN transfer from 241-AX Tank Farm (AX Farm) to tank C-105. Reduction-Oxidation supernate from 241-SX Tank Farm (SX Farm) was also sent to B Plant for fractionization in 1970 to 1971. Organic wash waste was no longer mixed with PAW for storage; it was now mixed with CWP and sent to tank C-102, and from there to 241-BX Tank Farm (BX Farm) for ITS (ISO-100, *Waste Management Technical Manual*;

RHO-LD-79; ERDA-1538, *Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington*).

In between PAW transfers, sludge was sluiced out of the A/AX tanks for strontium recovery. Tank 241-A-101 was sluiced first in 1968, then tank 241-A-104 in 1969, and tank 241-A-106 in 1970. In the 244-AR vault, the sludge, called PUREX sludge waste (PSW), was dissolved in acid. The resulting PUREX acidified sludge (PAS) was pumped to the 244-CR vault via the 241-AX-151 diverter station and line 8656 for lag storage, and from there to B Plant via line 8653. Since PUREX was operating almost constantly, little sluicing was done until PUREX shutdown in 1972. Following shutdown, the 244-AR vault was modified for full-time sludge processing and tank sluicing was accelerated. Strontium and cesium were encapsulated and stored in the Waste Encapsulation and Storage Facility (WESF) beginning in 1974. Encapsulation was completed in 1985 (RHO-LD-79; RHO-ST-30, *Hanford Radioactive Tank Cleanout and Sludge Processing*).

As the tanks were sluiced, the sound tanks were refilled with CWP, OWW, B, and other Hanford waste types, all mixed together. By the mid-1970s, every type of waste was being commingled in A/AX/C Farm, primarily in tanks 241-A-103, C-103, and C-104 (RHO-LD-79).

In the sluicing operations that occurred from 1969 to 1971, the concentrated slurry layer in the 244-AR vault accumulation tank was washed with water prior to transfer to the acidification tank. After agitation and settling, the wash water was pumped to either tank C-105 or C-106. Some solids were transferred to these tanks. The solids in tank C-106 contained several megacuries of ^{90}Sr, which caused the waste to approach boiling temperatures. Tank 241-C-106 had not been designed as a boiling waste tank (ARH-CD-948, *History and Status of Tanks 241-C-105 and 241-C-106*; WHC-SD-WM-TI-302).

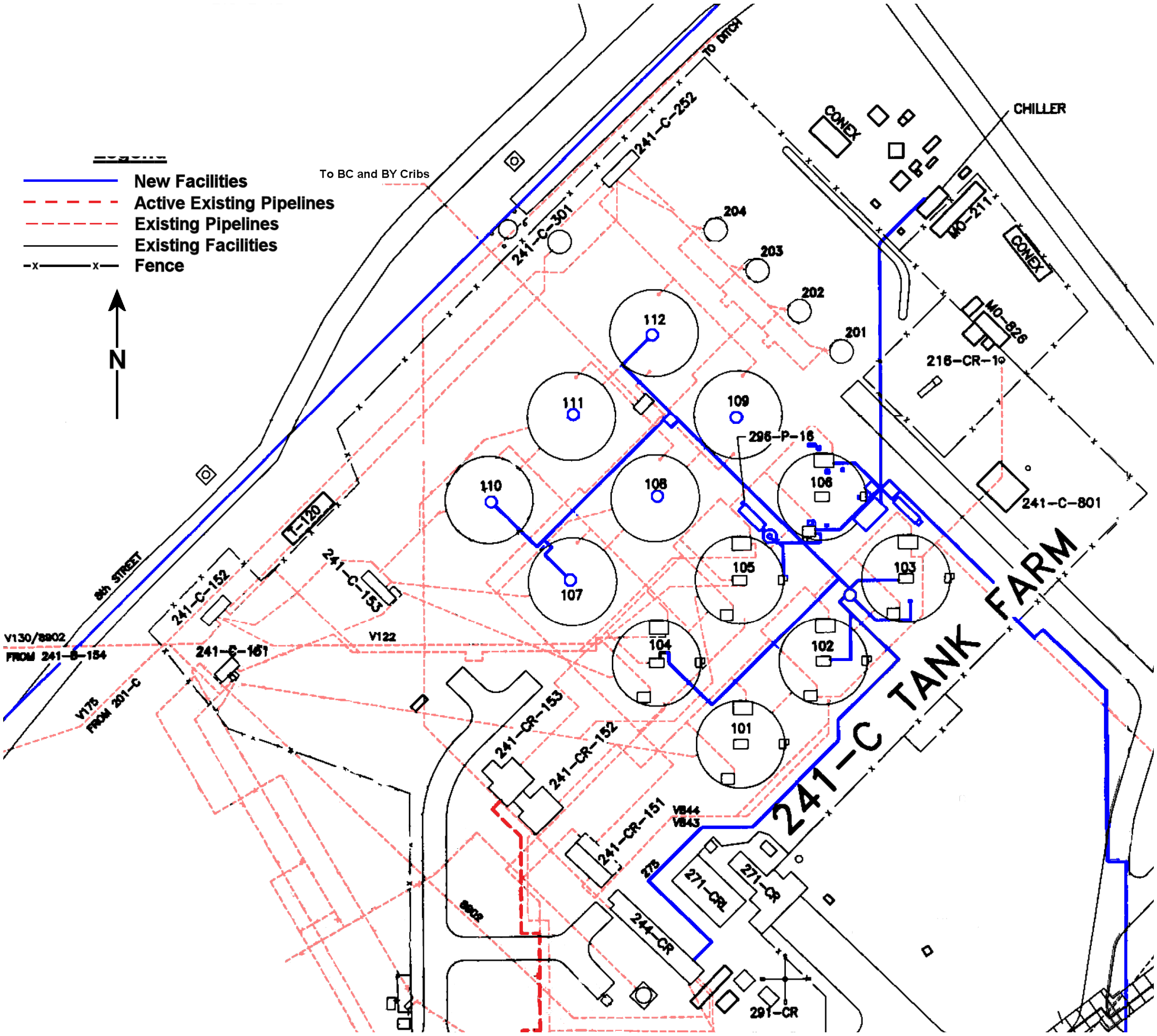
The 216-C-8 French drain received an unknown amount of floor drain waste and ion exchange resin regeneration waste from experiments in the 271-CRL laboratory in C Farm beginning in June 1962. The ion exchange studies were terminated in June 1965 and the equipment removed (ARH-1562, *200 East and North Areas Radioactive Liquid Waste Disposal Sites*; H-2-31890, *Mechanical Piping Plan & Details*). The total volume discharged to the crib is likely to be small, since crib discharge records do not mention 216-C-8.

Line V122 from tank C-105 to diversion box 241-C-152 (the PSN feed line to B Plant) began leaking in 1970 (UPR-200-E-82) and was replaced with line V115. A leak in line 812 from the 244-AR vault to diversion box 241-C-151 in 1971 contaminated a 36-m^2 area with PSN (UPR-200-E- 86).

3.6 STABILIZATION AND ISOLATION 1975 TO PRESENT

Tanks in C Farm have leaked. In accordance with Hanford operating policy at the time, liquid waste removal from a tank of questionable integrity was expedited and the tank was removed from service. Interstitial liquid was removed by saltwell jet pumping (ERDA-1538). Figure 3-5 shows facilities constructed in C Farm for saltwell pumping.

Figure 3-5. Waste Management Area C Components Constructed for Interim Stabilization and Isolation (1975 to 2001)



Interim stabilization is the process of removing all supernatant liquid and as much drainable liquid as possible; this process began in 1972. The saltwell system for C Farm included a pump pit for each tank, the saltwell and jet pump, piping from the pump pits to the receiver tank, and associated instrumentation and controls. Tank 241-C-103 was the receiver tank for C Farm. The 244-A lift station and new encased underground lines were constructed in 1975 that connected C Farm, A Farm, and the cross-site transfer line. The C Farm tanks were interim stabilized beginning in 1976, with the interstitial liquid pumped from tank C-103 to the 242-S evaporator via line V228 from C Farm to the cross-site transfer line. Transfers to 242-S were discontinued when the 242-A evaporator started operations (ERDA-1538; ARH-CD-414 DRAFT, *Waste Tank Utilization Plan*; H-2-65052, *Key Plan – Phase I Salt Well System 241-A & 241-AX*).

The 242-A evaporator began operating in March 1977 with saltwell receiver 241-A-102 as the feed tank and 241-AX-101 as the slurry receiver tank. 241-C Tank Farm saltwell waste was pumped from tank C-103 to 241-A-102 via the 244-A lift station. In April 1989, after final PUREX shutdown, the 242-A evaporator was shut down. Project B-534 renovated the evaporator, and project W-105 built the 200 Area Liquid Effluent Retention Facility (LERF) for evaporator condensate. The evaporator restarted in April 1994 and is still in use (ARH-CD-414 DRAFT; RHO-CD-673, *Handbook 200 Areas Waste Sites*; WHC-SD-W105-CDR-001, *Conceptual Design Report for 242-A Evaporator and PUREX Interim Retention Basin Project W-105*; Letter 94-RPS-229, “242-A Evaporator Restart”).

Since 1968, all waste tanks constructed have been double-shell tanks (DSTs), and U.S. Atomic Energy Commission (AEC) policy in 1975 was to direct all liquid waste to DSTs. Single-shell tanks were removed from service in 1980, and DST 241-AN-101 replaced 241-A-102 as the saltwell waste receiver tank in 1981. Tank 244-CR-003 in the 244-CR vault has been used as a double-contained receiver tank (DCRT) for C Farm since 1979.

A new valve pit was built near tank 241-C-103 that tied into the existing saltwell piping and discharged to 244-CR-003. Waste was transferred from the 244-CR vault to 241-AW Tank Farm (AW Farm) for evaporation via the 244-A lift station, the 241-A valve pits, and the 241-AW valve pits. The 244-CR vault has not been used since 1995. It is not yet scheduled for interim stabilization, but no future use has been identified (H-2-73799, *Engineering Flow Diagram System No. 4*; RHO-CD-1097, *Safety Analysis Report, Salt Well Waste Receiver Facilities*; RPP-6029, *244-CR Vault Interim Stabilization Project Plan*).

Following interim stabilization, SSTs were interim isolated by establishing at least one physical barrier between the tank contents and the environment, to preclude inadvertent addition of liquid. Cutting and blanking process piping to and from the tank, blanking all risers, and equipping the tank with a filtered ventilation system accomplished this. In C Farm, all diversion boxes and the 241-C-301 catch tank were isolated by project B-231 (ERDA-1538; HNF-EP-0182, *Waste Status Summary Report for Month Ending March 31, 2001*, Rev. 156; RPP-RPT-42231, *Summary of Twenty-five Miscellaneous Tanks Associated with the Single-Shell Tank System*).

When the waste in tank C-106 reached boiling temperatures in mid-1971, it was connected to an exhauster to cool the waste. Cooling water was also added to the tank. BL waste (intermediate-level waste generated by B Plant from 1967 to 1978) was added to the tank from 1974 through 1976. The exhauster was replaced twice in 1976 due to excessive contamination.
The 296-P-16 exhauster was installed in 1984 (project B-480).

Because of continuing high temperature in the tank, the sludge was sluiced to tank 241-AY-102 in 1999 (project W-320). A special ventilation system, 296-C-006, and a new transfer line to 241-AY-102 were built for the sluicing operation. Following sluicing, the 296-C-006 ventilation system was abandoned in place. The 296-P-16 system will stay in use pending an interim isolation decision (ARH-CD-948; RHO-LD-79; WHC-EP-0532, *High-Heat Tank Safety Issue Resolution Program Plan*; H-2-93797, *DWG List/HVAC Equipment Plan & Sections*, Sheet 1).

3.7 PLUGGED AND FAILED PIPELINES AND UNPLANNED PIPELINE RELEASES

From 1952 to 1956 cascade lines had a tendency to plug during TBP transfers. Records indicate that the cascade line between tanks C-101 and C-102 (1954 to 1956); C-107 and C-108 (1952 to 1955); and C-110 and C-111 (1952 to 1954) were frequently plugged or partially plugged (RHO-LD-79). RHO-LD-79 also provides an operating history by quarter of WMA C, and it is clear that pipeline flushing was a common practice with both water and acid. Flush volumes were accounted for in the liquids in storage of tanks.

3.7.1 Waste Management Area C Unplanned Releases

There are 14 unplanned release (UPR) sites within or adjacent to WMA C. In addition, there are planned release sites associated with some of the facilities at WMA C. Uncertainties exist in the volume and content of releases in and around WMA C.

The following brief descriptions of the five UPRs that are known or suspected to be related to pipeline leaks or failures and are summarized from the Waste Information Data System (WIDS) General Summary Reports (DOE/RL-88-30) which represent the best information available on the nature and extent of releases. Substantial uncertainty exists in the volume and content of UPRs from components within the WMA C.

- Unplanned release UPR-200-E-81 is located northeast of the 244 CR vault near the CR-151 diversion box. It occurred as a result of a leak in an underground transfer pipeline in October 1969. The estimated 36,000 gal of waste leaked from the pipeline consisted of PUREX coating waste. The site was covered with 0.5 m (18 in.) of backfill and clean gravel.

- Unplanned release UPR-200-E-82 occurred in December 1969. The source was determined to be the feed line running between tank C-105 and the 221-B building. The leak was discovered near the C-152 diversion box. The liquid release, an estimated 2,600 gal, flowed from the vicinity of the C-152 diversion box to the northeast, downgrade, until it pooled into an area, measuring ~0.46 m^2 (5 ft^2), outside the WMA C fence. The contaminated site was covered with 2 ft of dirt in 1969 (RPP-RPT-29191, pp. 128-129). The WIDS report states that additional decontamination of the area was done in 1985. A gunite cap was subsequently installed on the soil surface above this leak location.

- Unplanned release UPR-200-E-86 is a spill that resulted from a leak in a pipeline used to transfer waste from the 244-AR vault to WMA C. The depth of the leaking pipeline was ~2 m (8 ft) below ground surface (bgs). The release occurred in March 1971 near the southwest corner of WMA C, outside the fence. The spill consisted of 25,000 Ci of ^{137}Cs in an estimated 17,385 gal of waste (RHO-CD-673). The soils surrounding the pipeline were sampled, and it was determined the contamination had not penetrated below 6 m (20 ft). The contamination plume volume was estimated at 37 m^3 (1,300 ft^3). The surface of the release site has been stabilized. The release site is demarcated with concrete AC-540 marker posts and signs indicating "Underground Radioactive Material." A gunite cap was subsequently installed on the soil surface above this leak location.

- Unplanned release UPR-200-E-99 is surface contamination that resulted from numerous piping changes associated with the 244-CR vault. It is located south of 7th Street, directly south of the 244-CR vault and was established as a release site in 1980, although the actual occurrence date is unknown. A radiological survey conducted in support of herbicide applications in 1981 found no detectable contamination in the release area. As a result of the radiological survey, surface contamination postings were removed on March 5, 1981, and the area was released from the radiation zone designation.

3.7.2 Waste Losses from Spare Inlet Nozzles and Cascade Lines

The SSTs in WMA C are equipped with spare inlet nozzles. Process waste transfer pipelines were inserted through the inlet nozzle and protruded into the SST. A loose seal was installed around the process waste transfer pipeline at the nozzle. The 100-series SSTs are also arranged in four cascades of three tanks each. After filling, the first tank waste then flows to the second and once filled, the waste flows to the third and final tank in the cascade.

Tank waste may have been discharged from the spare SST inlet nozzles if the waste elevation in the tank exceeded the elevation of the inlet nozzles. Cascade lines that lie below the spare inlets in elevation are also submerged when the waste level exceeds the spare inlet level. When the waste exceeds the operating capacity of the tank, it would appear the waste must find an outlet over the top of the tank liner, breach a weak spot in the cascade (perhaps where it exits or enters the tank liner), or breach the spare inlet lines. Events are identified when the inlet nozzles on an SST were submerged beneath tank waste. Although the inlet nozzles on several SSTs were submerged, there is no record of the waste volume potentially lost to the soil surrounding the SST.

Tanks C-101, C-103, C-104, C-105, C-106, C-109, C-111, 241-C-201, 241-C-202, and 241-C-204 were filled with waste above the elevation of the spare inlet nozzles and cascade lines on several occasions. Waste may have been lost to the ground from these SSTs as a result of overfilling these tanks. The date and waste type present in each SST when the tank was filled with waste above the elevation of the spare inlet nozzles are summarized in Table 3-1.

Several pipelines in the WMA C are known to have failed while transferring tank wastes. Table 3-2 identifies 11 pipelines in WMA C that are known or suspected to have failed. The date the failure was detected, the waste type, and the volume of waste that was leaked to the soil (if known) are listed in Table 3-2. Unplanned releases have been identified for some of the failed pipelines listed in Table 3-2. In some cases, the failed pipeline was contained within a concrete diversion box, vault, or pipeline encasement. The surfaces of the concrete structures were coated with a chemically resistant paint. However, the integrity of the coatings and the concrete structures are unknown. It is not known whether waste leaked from these concrete structures.

Table 3-1. Potential Waste Losses Through Spare Inlets on Waste Management Area C Single-Shell Tanks

Tank	Date	Waste Type Present in Tank
C-101	June 1965 – December 1967	Received waste from CR vault. Tank contains CR vault waste (28 kgal), PUREX P2 (452 kgal), and Coating Waste (CWP2) (94 kgal).
C-103	October 1953 – March 1957	Tributyl Phosphate Plant (TBP) waste
	June 1961 – December 1961	PUREX CWP2
C-104	August 1958	PUREX CWP1
	June 1965 – March 1966	After receiving 15,000 gal of unknown waste type (likely PUREX CWP2 based on RL-SEP-332, page B-2) from 244-CR vault, the tank was filled above the spare inlets. Majority of waste in tank is PUREX CWP2.
C-105	Pre-October 1967	Waste type unknown; soil contamination found beneath spare inlet nozzles during excavation in October 1967.
C-106	November 1951	Water added to metal waste (MW2)
	December 1965 – March 1966	PUREX P2 HLW supernate
C-109	June 1961 – December 1961	PUREX CWP2
	June 1965 – March 1968	Tank received 19,000 gal from 201-C Strontium Semiworks (HS). Tank contains 112,000 gal of evaporator bottoms (BT-SltCk), 300,000 gal of PUREX CWP2, and 142,000 gal of HS waste.
C-111	May 1957	TBP waste
	September 1957	Scavenged 242-B BT-SltCk waste (i.e., concentrated 1C/CW and TBP wastes).
C-201	December 1955 – January 1956 June 1961 – June 1963	201-C Hot Semiworks waste from PUREX flowsheet tests (Note: this is not waste type HS).
C-202	January 1957 – March 1957 June 1957 – October 1958 June 1961 – December 1963	201-C Hot Semiworks waste from PUREX flowsheet tests (Note: this is not waste type HS). Last waste transferred into tank was 201-C building flush solutions.
C-204	March 1968 – March 1970	201-C Hot Semiworks waste from PUREX flowsheet tests (Note: this is not waste type HS) and 201-C building flush solutions.

1C/CW = first-cycle decontamination waste (1C) mixed with cladding (coating) removal waste (CW)
CWP1 = PUREX cladding, aluminum clad fuel (1956-1960)
CWP2 = PUREX cladding, aluminum clad fuel (1961-1972)
HLW = high-level waste
P2 = PUREX HLW (1963-1967)
PUREX = Plutonium Uranium Extraction (Plant)

Reference: RL-SEP-332, *Chemical Processing Department Monthly Report for February, 1965*.

Table 3-2. Failed Pipelines in Waste Management Area C (2 sheets)

Date	Waste Type[a]	Waste Discharged (gal)	Event Description	References[b]
6-1964	HS - 201C Strontium Semiworks Waste	No estimate	"The underground process line from the 252-C diversion box to 112 tank, C Tank farm, failed. The failed pipeline was isolated. Jumpers were fabricated and installed to establish a new process route." The failed pipeline is line V172.	RPP-RPT-29191, pp. 115
11-1964	Cesium Depleted PUREX HLW Supernate (P1)	No estimate	Installation was completed on an alternative effluent return route from the 801-C Cesium Loadout Building to Tank 103-C. See drawing H-2-4574, *Process & Service Piping Tanks to Loadout Station* for details of this piping. A three-way ball valve was inserted in the 801-C effluent return line to SST C-102 to enable routing waste to SST C-103 or C-102.	RPP-RPT-29191, pp. 115
2-1965	PUREX CWP2	No estimate	"On February 18, 1965 the 244-CR vault was found flooded up to approximately the level of the tank tops. Immediate steps were taken to reduce the liquid level by jetting the solution to the 011 Tank. Partial cause of the flooding is attributed to a failure in the coating waste line which enters the 151-CR diversion box. Drainage from this diversion box collects in the 002-CR vault sump. Water from a sampler flush line and drainage from rain and snow contributed to the liquid level in the vault. To date, the 001, 002, and 003 sumps have been emptied, and the 011 sump is being emptied, to the 011 Tank. This liquid is being pumped from the 011 Tank to Tank 103-A in the 241-A Tank Farm. In trying to establish a coating waste routing from the Purex Plant to the 241-C Tank Farm a leak was also discovered in the underground line adjacent to the 152-A Diversion Box. Because of the two apparent leaks in this line it has been abandoned as being unusable."	RPP-RPT-29191, pp. 116
3-1965	PUREX CWP2	No estimate	"A liquid level rise in Tank 103-C, the cesium feed tank, was apparently caused by a failed line in the encasement between the 152-CR diversion box and Tank 102-C which permitted coating waste from the Purex Plant to leak into the encasement and drain to Tanks 101-C, 102-C, and 103-C via the tank pump pits. Coating waste has been routed through a spare line to Tank 102-C and no further leaks have been detected. The coating waste solution accumulated in Tank 103-C did not significantly affect cesium loading capability as a cask was loaded normally following the incident." Note: Pipeline 8041 inside a concrete encasement was used to route the PUREX CW to SST C-102 (see drawing H-2-44501, *Area Map 200 East "A" Plant Facilities*, sheet 92). This encasement traverses from diversion box 241-CR-152 along the west side of SSTs C-101, C-102, and C-103. In order for the PUREX CW to drain into SSTs C-101, C-102, and C-103, the encasement containing the failed transfer pipeline must have partially filled with waste. The integrity of this encasement is unknown and may have leaked waste to the soil. Drawing H-2-2338, *Diverson Box 241-CR-152 Nozzle Information*, sheet 45 indicates pipeline 8041 is out of service. Pipeline 8041 connects from nozzle U-3 in the 241-CR-152 diversion box and nozzle U-2 in pit 02C atop SST C-102.	RPP-RPT-29191, pp. 116

Table 3-2. Failed Pipelines in Waste Management Area C (2 sheets)

Date	Waste Type[a]	Waste Discharged (gal)	Event Description	References[b]
5-1966	PUREX CWP2	No estimate	"A leak in the PUREX coating waste route (152-CR diversion box) was detected by an abnormal liquid level increase of the 002CR vault sump. The leaking flexible jumper in the 152CR diversion box was replaced." Note: Diversion box 241-CR-152 and 244-CR vault sump are concrete structures with painted surfaces. It is uncertain whether leaked waste was contained inside diversion box 241-CR-152 and 244-CR vault sump.	RPP-RPT-29191, pp. 118
Pre-1988	PUREX P2 supernate	No estimate	Pipeline V-103 - "Earlier investigations of the extremely high levels of contamination found between Tanks 104-C and 105-C are described in reference (10). The following observations were documented at the time and were the bases for the conclusion that both tanks were sound: The fill line V-103 was stated to have been abandoned at an earlier date due to pipeline leakage, and the activity noted in DW 30-03-02 could have been due to migration of pre-existing contamination that was first seen in the exploratory scans. This line was part of the old PUREX supernate (PSN) transfer route from Tank 241-AX-101. The material was thermally hot, and water injection was required to maintain a temperature below 60°C. The cause of failure was believed to have been due to thermal shock induced by the intermittent transfers. In-tank photographs failed to show any evidence that either tank was unsound. However, the Tank 241-C-105 photos indicated that the tank had been filled to a level above that of the cascade and sidefill pipelines. The possibility of leakage through the wall penetration seals was discussed. The liquid levels in Tank 241-C-105 and -104 remained at a high level for almost six months after the first exploratory well scans, and the observed activities, including that in DW 30-03-02, had remained stable throughout, whereas seepage from either tank would normally have been seen as steadily increasing radiation at the 35 to 41 feet farm excavation depth. The activity at this depth however has diminished in all wells since 1974."	Internal memo 13331-88-088, "Environmental Protection Deviation Report 87-10, Radiation Level Increase in Drywell 30-03-09," pp. 4
Unknown	Unknown	No estimate	Line V112 is identified as a leaker adjacent to diversion box 241-C-151. The date and amount of waste leaker from this pipeline is unknown.	RPP-25113,[c] pp. 7

[a] Waste types are defined in RPP-26744, *Hanford Soil Inventory*.

[b] The UPRs listed have been combined with UPR-200-E-133, Contaminated Soil at C Farm in accordance with DOE/RL-88-30, *Hanford Site Waste Management Units Report*, Rev. 16, page 665.

[c] RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site*.

Reference: RPP-RPT-29191, *Supplemental Information Hanford Tank Waste Leaks*.

CWP2 = PUREX cladding, aluminum clad fuel (1961-1972)
P2 = PUREX HLW (1963-1967)
HLW = high-level waste
PUREX = Plutonium Uranium Extraction (Plant)

4.0 ESTIMATE OF PIPELINE RESIDUAL INVENTORIES

This section of the report provides inventory estimates for waste residuals remaining in WMA C abandoned piping. Uncertainties in the abandoned pipeline residual estimate are generally discussed in relation to tank residual volumes and composition. Volume and composition of residual waste in the individual pipes are not expected to vary significantly from one pipe to another. This is based on a review of the operating history of the farm which indicates that there was a precise accounting of the volume of waste that was transferred into the tanks, lines were routinely flushed, line plugging was a rare occurrence and all lines were designed to drain into a tank when transfers were completed.

4.1 PREVIOUS PIPELINE RESIDUAL VOLUME AND COMPOSITION ESTIMATES

Previous WMA C pipeline waste residual estimates have been made to establish waste residual volumes and composition. However, these previous estimates were based on generalized assumptions that produced a range in residual volumes from 28 L (7.4 gal) to 7,200 L (1,900 gal) (Table 4-1). The mass or compositions of the residual pipeline waste were determined based on an average composition of the tank farm waste inventory based on the Best Basis Inventory (BBI). These approaches result in an estimate of pipeline waste residual composition that is based on tank waste samples or historical process information. No physical samples of pipeline residuals in WMA C have been taken or analyzed.

The following documentation has provided previous pipeline residual assessments:

a. RPP-15043, *Single-Shell Tank System Description*

b. WHC-SD-WM-ES-259, *Single-Shell Tank Saltwell Transfer Piping Evaluation*

c. RPP-13774, *Single-Shell Tank System Closure Plan*

d. RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford site*.

In addition, an extrapolated volume is included in Table 4-1 based on a characterization study of two vitrified clay pipelines that discharged effluent from the 231-Z Building to the Z Ditches. Discussion of this volume estimate is contained in Section 4.1.2.

Waste Management Area C has undergone at least five discrete processing campaigns ranging from receiving Bismuth Phosphate Plant wastes starting in 1946 to saltwell pumping of stored waste liquids that was concluded in 2004. Various pipelines were installed and abandoned depending on which campaign and waste routings were needed at the time. For these reasons an estimate of the waste composition in the abandoned piping cannot be made based on specific transfer tank samples or historical process information at the time the transfers occurred.

Table 4-1. Summary of Previous Waste Management Area C Pipeline Waste Residual Volume Estimates

Source of Volume Estimate	Source Citation	Parameters Assumed for Estimate	Estimated Volume in WMA C
Single-Shell Tank System Description	RPP-15043	Estimate of adsorbed/fixed residuals (1,000 angstrom) in all piping and 5 plugged lines at 25% full	450 L (120 gal)
TC&WM EIS inventory data package	DOE/ORP-2003-02	Estimate of adsorbed/fixed residuals (1,000 angstrom) in all piping and 5 plugged lines at 25% full	450 L (120 gal)
Single-Shell Tank Saltwell Transfer Piping Evaluation	WHC-SD-WM-ES-259	Estimate of 4% residuals with cross section of 1.9 cm^2 with less than 0.1 cm thickness	1,500 L (400 gal)
WMA C Closure Action Plan – Risk Assessment for WMA C Closure Plan	RPP-13774 Appendix C	Estimate of 25% full for all piping (20,000 linear feet) and all piping averaged to 3 in. in diameter	7,200 L (1,900 gal)
Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site	RPP-25113	Assumes volume insignificant in all piping other than plugged cascade line between 241-C-110 and 241-C-111	28 L (7.4 gal)
Initial Single-Shell Tank System Performance Assessment for the Hanford Site	DOE/ORP-2005-01	Assumes volume insignificant in all piping other than plugged cascade line between 241-C-110 and 241-C-111	28 L (7.4 gal)
Data extrapolation from previous pipeline volume estimates	DOE/RL-2003-11	See Section 4.1.2	2,600 L (700 gal)

TC&WM EIS = Tank Closure and Waste Management Environmental Impact Statement
WMA = Waste Management Area

References:

DOE/ORP-2003-02, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland Washington Inventory and Source Term Data Package*

DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site*

DOE/RL-2003-11, *Remedial Investigation Report for the 200-CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units*

RPP-13774, *Single-Shell Tank System Closure Plan*, Appendix C, "WMA C Closure Action Plan"

RPP-15043, *Single-Shell Tank System Description*

RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site*

WHC-SD-WM-ES-259, *Single-Shell Tank Saltwell Transfer Piping Evaluation*.

4.1.1 Previous Pipeline Waste Residual Volume Estimates

Over 8 miles and ~230 separate pipelines with different diameters and lengths comprise the abandoned pipelines in C Tank Farm. According to historical process operation records, pipelines were flushed following a waste transfer and at times prior to a waste transfer. The original pipelines were constructed with a 1% slope which would allow waste to drain into their receiving vessels without leaving significant residuals. Later pipelines were constructed and pressurized as waste was removed from tanks with jet pumps and vacuum pumps. However, lines were still designed to drain back into the tank after pumping was completed. As a result of the design and operational features of the waste transfer pipelines it is anticipated that the volume of residual wastes remaining is not significant. However, it is reported that a limited number of pipelines plugged. Plugged lines tended to be associated with transfers involving TBP and were predominately in the cascade lines between tanks in WMA C. Table 4-1 summarizes previous WMA C pipeline residual volume estimates which are discussed in further detail in this section.

A residual pipeline volume estimate of 4,500 L (1,200 gal) for adsorbed and fixed residual waste that may remain in the 1,414 pipelines across the SST system was reported in Table A-1 of RPP-15043. Multiplying the total volume times the fraction of lines in C Farm (145 lines associated with C Farm/1,414 total), the residual volume estimate for C Farm pipelines would be ~450 L (120 gal). This was the piping residual waste inventory used in the TC&WM EIS Inventory Data Package (DOE/ORP-2003-02, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland Washington Inventory and Source Term Data Package*).

The residual waste volume estimate in RPP-15043 (and DOE/ORP-2003-02) was based on estimated pipe surface area, adsorption of a thin layer of waste (1,000 angstroms) after flushing, and an estimate for fixed waste and waste retained by a plugged line. RPP-15043 identified only five plugged transfer lines in all the farms and assumed the plugged lines were 25% full of waste.

WHC-SD-WM-ES-259 reported that the residual waste is expected to reside in only 4% of the total piping. This report assumed that the pipelines have a cross section area of 1.9 cm^2 (0.29 in.^2) with less than 0.1 cm thickness. Using this as a basis and the generalized length of WMA C abandoned pipelines of ~25,000 linear feet would result in a waste residual volume of ~1,500 L (400 gal).

The WMA C Closure Action Plan (Appendix C of RPP-13774) utilized a different approach to estimate residual waste volumes in pipelines. That approach used the total length of all pipelines within WMA C (using a piping length of ~20,000 linear feet) then assuming that the average line is 3 in. in diameter and that 25% of the lines were blocked or plugged. This resulted in an estimate of 250 ft^3 of waste or 7,200 L (1,900 gal) (Note: Operating records indicate that waste transfer lines were flushed and maintained in operating conditions unless they were taken out of service due to failure or plugging. Records for WMA C indicate that during its operation period only three cascade lines were plugged. At least two of these cascade lines were opened. Failed lines were either replaced or taken out of service. These records indicate that the assumptions used in RPP-13774 are unrealistically conservative).

In contrast, RPP-25113 estimated abandoned pipeline residual waste volume of 28 L (7.4 gal) based on information about the actual conditions of the pipeline systems in WMA C. This estimate assumed waste residuals in pipelines were insignificant except for the residuals in a plugged cascade line between tanks 241-C-110 and C-111; and because pipelines were designed to gravity drain, even the plugged cascade line was expected to have only a small inventory of residual waste (cascade lines are 3 in. in diameter and ~25 ft long). The information contained in RPP-25113 was used in DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site* to analyze the long-term impacts of residual wastes assumed to remain after retrieval of tank wastes and closure of the SST farms.

DOE/RL-2003-11, *Remedial Investigation Report for the 200-CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units* conducted a characterization study of two vitrified clay pipelines that discharged effluent from the 231-Z Building to the Z Ditches. These pipelines consisted of a 45.7 cm (18-in.) diameter and 38.1 cm- (15-in.) diameter gravity flow pipes. The study reported that 1-½ and 1-¼ inches of residual waste material existed in these pipelines, respectively. Extrapolation of this actual data to WMA C pipelines can be made. However, differences in the hydraulic flow characteristics of the larger diameter, gravity flow, vitrified clay pipe and the small diameter, steel waste transfer lines, operated under a hydraulic head could affect the settling characteristics of the waste and subsequent residual waste deposition. The waste transported in the vitrified clay pipe flows in a conduit under open channel flow conditions across a porous clay surface. As the distance increases, the hydraulic head will drop which results in less velocity to move material in suspension. Subsequently, over distance waste deposition in the pipeline would be expected to increase (*Sediment Engineering, ASCE Manuals and Reports on Engineering Practice No. 54*, Chapter II, "Sediment Transport Mechanics," Section J. Transportation of Sediment in Pipes [Vanoni 2006]). The waste transfer pipelines operated under a pressurized condition, which means the hydraulic head would be maintained throughout the pipe and velocities would be held more constant, thereby reducing the opportunity for material to drop out of suspension and accumulate in the pipe.

Considering these differences in the hydraulics and sediment transport mechanisms between the vitrified clay pipe and the steel waste transfer pipeline, it is reasonable to conclude that the residuals observed in the vitrified clay pipe would be greater than residuals that would accumulate in the waste transfer pipelines in WMA C. However, observations in the clay pipelines do offer an opportunity to use actual data to extrapolate residuals potentially remaining (conservatively) in WMA C pipelines. Extrapolating this data to WMA C pipelines results in a residual volume on the order of 2,300 L to 2,600 L (620 to 700 gal) with 2,600 L (700 gal) used as the technical defensible, conservative estimate. This volume is also identified in Table 4-1 and Table 4-2.

Table 4-2. Estimated Residual Waste Volumes in Waste Management Area C Pipelines Based on Revised Length or Number of Pipelines

Source of Volume Estimate	Initial Estimated Volume	Parameters Adjusted to Standardize Estimate	Revised Estimated Volume in WMA C
RPP-15043, *Single-Shell Tank System Description*	450 L (120 gal)	145 pipelines in WMA C adjusted to 230 pipelines	710 L (190 gal)
TC&WM EIS inventory data package (DOE/ORP-2003-02)	450 L (120 gal)	145 pipelines in WMA C adjusted to 230 pipelines	710 L (190 gal)
WHC-SD-WM-ES-259, *Single-Shell Tank Saltwell Transfer Piping Evaluation*	1,500 L (400 gal)	~25,000 linear feet of pipeline adjusted to ~42,200 linear feet of pipeline	2,400 L (630 gal)
WMA C Closure Action Plan - Risk Assessment for WMA C Closure Plan (RPP-13774 Appendix C)	7,200 L (1,900 gal)	20,000 linear feet of pipeline adjusted to ~42,200 linear feet of pipeline	10,600 L (2,800 gal)
RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site*	28 L (7.4 gal)	No adjustment	28 L (7.4 gal)
DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site*	28 L (7.4 gal)	No adjustment	28 L (7.4 gal)
Data extrapolation from previous pipeline volume estimates (DOE/RL-2003-11)	2,600 L (700 gal)	No adjustment	2,600 L (700 gal)

TC&WM EIS = Tank Closure and Waste Management Environmental Impact Statement
WMA = Waste Management Area

References:
DOE/ORP-2003-02, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland Washington Inventory and Source Term Data Package*
DOE/RL-2003-11, *Remedial Investigation Report for the 200-CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units*
RPP-13774, *Single-Shell Tank System Closure Plan*, Appendix C, "WMA C Closure Action Plan."

4.1.2 Revised Pipeline Volume Estimates Based on Actual Pipeline Length and Other Comparative Data

The estimated values for the volume of residual waste remaining in the WMA C pipelines range from 28 L (7.4 gal) (RPP-25113) to 7,200 L (1,900 gal) (RPP-13774 Appendix C). These values were developed based upon a variety of assumptions including estimates of the length and the number of pipelines in WMA C. These have ranged from 4 miles to 5 miles and 119 pipes. Recent evaluation of the engineering design data indicates that the actual length of pipeline in WMA C is between 7 and 8 miles and ~230 pipes. These revised pipeline lengths and number of pipelines will revise the previous pipeline waste residual volume estimates in Section 4.1.1 accordingly and are shown in Table 4-2.

4.1.3 Previous Pipeline Waste Residual Composition Estimates

A review of the WMA C operational history provides some insight into establishing the composition of pipeline residuals (see RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*). Over half of the total WMA C pipelines were installed for processing campaigns after the initial bismuth phosphate campaign; and over 90% of all WMA C pipelines were used in transfers occurring after that initial processing campaign as well. RPP-RPT-42323 provides a basis for estimating residual compositions by using the BBI waste composition estimate of the average C Farm tank waste residual component concentrations. Residual inventory estimated for the 100- and 200-series tanks can be found in RPP-RPT-42323, Table C-2 of Appendix C.

Any residual waste that is left in the pipelines is going to be from solids that settled out on the bottom of the pipelines or from plug formation. Residual waste accumulation in the pipelines not associated with plugging would likely consist of insoluble constituents deposited on the pipe wall during operation. Waste residuals that accumulated as solids on the bottom of the pipelines and any remaining liquid would likely consist of insoluble and some soluble constituents. This is because following waste transfers the line would be flushed, which would be expected to purge the pipe of the more soluble constituents into the tanks. Operating records for WMA C indicate that during waste transfers involving TBP, three cascade lines between tanks consistently had plugging problems. Records indicate that following the TBP transfers at least two of these cascade lines were unplugged allowing waste to cascade from tank to tank. Plugged cascade lines would likely have accumulated contaminants that included both soluble and insoluble constituents of the waste that was transferred when plugging occurred. Contaminants would include insoluble metal cations (such as silver, bismuth, aluminum, iron, manganese, chromium, mercury, lead, silicon, and zirconium); insoluble radionuclides (such as ^{90}Sr, uranium isotopes, actinides, and ^{60}Co); soluble salts (such as sodium and potassium); and soluble radionuclides (such as ^{137}Cs, ^{129}I, and ^{99}Tc).

4.1.4 Pipeline Waste Residual Inventory Estimates

Average concentrations for WMA C solids have been calculated using the BBI concentrations and a range of pipeline volumes based on various lengths of pipeline. Using the average BBI volumetric concentrations and multiplying by the total assumed volume of contamination provides a bounding estimate of the inventory in the pipelines. These values are shown in Table 4-3 for radionuclides and in Table 4-4 for non-radiological contaminants.

Table 4-3. Inventories of Selected Radiological Constituents for Several Volume Estimates of Waste Residuals Left in Pipelines at Waste Management Area C (2 sheets)

Analyte	Total Pipeline Inventory (μCi) for 150 gal (based on assumed 4 miles of pipelines)[a]	Total Pipeline Inventory (μCi) for 530 gal (based on assumed 6 miles of pipelines)[b]	Total Pipeline Inventory (μCi) for 620 gal (based on assumed 7 miles of pipelines)[c]	Total Pipeline Inventory (μCi) for 700 gal (based on assumed 8 miles of pipelines)[d]
^{106}Ru	1.78E-02	6.28E-02	7.34E-02	8.29E-02
^{113m}Cd	7.31E+03	2.58E+04	3.02E+04	3.41E+04
^{125}Sb	5.56E+03	1.97E+04	2.30E+04	2.60E+04
^{126}Sn	3.01E+03	1.06E+04	1.25E+04	1.41E+04
^{129}I	1.66E+02	5.86E+02	6.86E+02	7.74E+02
^{134}Cs	1.10E+01	3.90E+01	4.57E+01	5.15E+01
^{137}Cs	7.44E+07	2.63E+08	3.08E+08	3.47E+08
^{137m}Ba	7.02E+07	2.48E+08	2.90E+08	3.28E+08
^{14}C	1.18E+03	4.17E+03	4.88E+03	5.50E+03
^{151}Sm	5.30E+07	1.87E+08	2.19E+08	2.47E+08
^{152}Eu	1.36E+04	4.79E+04	5.60E+04	6.33E+04
^{154}Eu	2.48E+05	8.77E+05	1.03E+06	1.16E+06
^{155}Eu	1.35E+05	4.78E+05	5.59E+05	6.31E+05
^{226}Ra	9.12E-01	3.22E+00	3.77E+00	4.26E+00
^{227}Ac	6.05E+02	2.14E+03	2.50E+03	2.83E+03
^{228}Ra	5.17E+02	1.83E+03	2.14E+03	2.41E+03
^{229}Th	1.91E+02	6.74E+02	7.88E+02	8.90E+02
^{231}Pa	6.00E+01	2.12E+02	2.48E+02	2.80E+02
^{232}Th	5.17E+02	1.83E+03	2.14E+03	2.41E+03
^{232}U	9.98E+02	3.52E+03	4.12E+03	4.66E+03
^{233}U	5.87E+04	2.07E+05	2.42E+05	2.74E+05
^{234}U	7.62E+03	2.69E+04	3.15E+04	3.56E+04
^{235}U	2.95E+02	1.04E+03	1.22E+03	1.38E+03
^{236}U	1.42E+02	5.01E+02	5.86E+02	6.62E+02
^{237}Np	6.34E+02	2.24E+03	2.62E+03	2.96E+03

Table 4-3. Inventories of Selected Radiological Constituents for Several Volume Estimates of Waste Residuals Left in Pipelines at Waste Management Area C (2 sheets)

Analyte	Total Pipeline Inventory (µCi) for 150 gal (based on assumed 4 miles of pipelines)[a]	Total Pipeline Inventory (µCi) for 530 gal (based on assumed 6 miles of pipelines)[b]	Total Pipeline Inventory (µCi) for 620 gal (based on assumed 7 miles of pipelines)[c]	Total Pipeline Inventory (µCi) for 700 gal (based on assumed 8 miles of pipelines)[d]
^{238}Pu	6.69E+04	2.36E+05	2.76E+05	3.12E+05
^{238}U	6.73E+03	2.38E+04	2.78E+04	3.14E+04
^{239}Pu	8.05E+05	2.84E+06	3.33E+06	3.76E+06
^{240}Pu	1.94E+05	6.87E+05	8.04E+05	9.07E+05
^{241}Am	1.17E+06	4.12E+06	4.82E+06	5.44E+06
^{241}Pu	1.58E+06	5.59E+06	6.54E+06	7.38E+06
^{242}Cm	6.87E+02	2.43E+03	2.84E+03	3.20E+03
^{242}Pu	1.84E+01	6.49E+01	7.59E+01	8.57E+01
^{243}Am	2.87E+02	1.01E+03	1.19E+03	1.34E+03
^{243}Cm	1.59E+02	5.60E+02	6.55E+02	7.40E+02
^{244}Cm	2.72E+03	9.62E+03	1.13E+04	1.27E+04
^{3}H	1.95E+04	6.89E+04	8.06E+04	9.10E+04
^{59}Ni	2.15E+04	7.59E+04	8.88E+04	1.00E+05
^{60}Co	4.03E+04	1.43E+05	1.67E+05	1.88E+05
^{63}Ni	4.74E+05	1.67E+06	1.96E+06	2.21E+06
^{79}Se	6.76E+02	2.39E+03	2.79E+03	3.16E+03
^{90}Sr	6.53E+08	2.31E+09	2.70E+09	3.05E+09
^{90}Y	6.53E+08	2.31E+09	2.70E+09	3.05E+09
^{93m}Nb	1.75E+04	6.19E+04	7.24E+04	8.18E+04
^{93}Zr	1.85E+04	6.54E+04	7.65E+04	8.64E+04
^{99}Tc	2.83E+04	9.99E+04	1.17E+05	1.32E+05

[a] Volume estimate based on TC&WM EIS Data Package (DOE/ORP-2003-02, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland Washington Inventory and Source Term Data Package*).

[b] Volume based on extrapolated volume estimate DOE/RL-2003-11, *Remedial Investigation Report for the 200-CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units* and 6 miles of piping.

[c] Volume based on extrapolated volume estimate DOE/RL-2003-11 and 7 miles of piping.

[d] Volume based on extrapolated volume estimate DOE/RL-2003-11 and 8 miles of piping.

Table 4-4. Inventory of Selected Non-Radiological Constituents for Several Volume Estimates of Waste Residuals Left in Pipelines at Waste Management Area C

Analyte	Total Pipeline Inventory (kg) for 150 gal (based on assumed 4 miles of pipelines)[a]	Total Pipeline Inventory (kg) for 530 gal (based on assumed 6 miles of pipelines)[b]	Total Pipeline Inventory (kg) for 620 gal (based on assumed 7 miles of pipelines)[c]	Total Pipeline Inventory (kg) for 700 gal (based on assumed 8 miles of pipelines)[d]
Al	6.10E+01	2.16E+02	2.52E+02	2.85E+02
Bi	2.59E+00	9.16E+00	1.07E+01	1.21E+01
Ca	5.08E+00	1.79E+01	2.10E+01	2.37E+01
Cl	6.94E-01	2.45E+00	2.87E+00	3.24E+00
Cr	4.02E-01	1.42E+00	1.66E+00	1.88E+00
F	5.59E+00	1.98E+01	2.31E+01	2.61E+01
Fe	2.03E+01	7.16E+01	8.38E+01	9.46E+01
Hg	6.94E-02	2.45E-01	2.87E-01	3.24E-01
K	5.75E-01	2.03E+00	2.38E+00	2.68E+00
La	7.54E-02	2.66E-01	3.11E-01	3.52E-01
Mn	2.20E+00	7.77E+00	9.09E+00	1.03E+01
Na	6.91E+01	2.44E+02	2.85E+02	3.22E+02
Ni	4.02E+00	1.42E+01	1.66E+01	1.88E+01
NO_2	1.74E+01	6.15E+01	7.19E+01	8.12E+01
NO_3	4.40E+01	1.56E+02	1.82E+02	2.06E+02
Oxalate	1.64E+00	5.79E+00	6.77E+00	7.64E+00
Pb	1.91E+00	6.75E+00	7.90E+00	8.92E+00
PO_4	3.38E+01	1.19E+02	1.40E+02	1.58E+02
Si	6.97E+00	2.46E+01	2.88E+01	3.25E+01
SO_4	7.07E+00	2.50E+01	2.92E+01	3.30E+01
Sr	1.71E-01	6.05E-01	7.08E-01	7.99E-01
TIC as CO_3	1.59E+01	5.62E+01	6.58E+01	7.43E+01
TOC	2.74E+00	9.70E+00	1.13E+01	1.28E+01
UTOTAL	2.02E+01	7.12E+01	8.33E+01	9.41E+01
Zr	7.10E+00	2.51E+01	2.93E+01	3.31E+01

[a] Volume estimate based on TC&WM EIS Data Package (DOE/ORP-2003-02, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland Washington Inventory and Source Term Data Package*).

[b] Volume based on extrapolated volume estimate DOE/RL-2003-11, *Remedial Investigation Report for the 200-CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units* and 6 miles of piping.

[c] Volume based on extrapolated volume estimate DOE/RL-2003-11 and 7 miles of piping.

[d] Volume based on extrapolated volume estimate DOE/RL-2003-11 and 8 miles of piping.

4.1.5 Comparison of Pipeline and Tank Inventory

A comparison of the estimated pipeline inventories using the technical basis estimate of 700 gal contained in Table 4-4 with the inventories estimated from past releases and in the 100- and 200-series tanks for WMA C is presented in Table 4-5. Note that miscellaneous tank inventories (catch tanks, vaults, pits) are not presented but are estimated to contribute around 1% more to the total chemical and radionuclide inventory in WMA C assuming 90% retrieval.

As shown in Table 4-5, the percent contribution from pipelines for all chemicals and radionuclides constitutes less than 1% of the inventory in WMA C. No key constituent of concern exceeds 2% of the inventory in WMA C with ^{234}U containing the highest percentage of 1.6% of the inventory estimated in pipelines.

4.2 PIPELINE WASTE RESIDUAL UNCERTAINTY ASSESSMENT

To make closure decisions on pipelines in the absence of actual characterization data on the WMA C pipelines requires an understanding of the uncertainty in the available data. This involves an assessment of the acceptability of that uncertainty to determine if additional information and data collection is needed.

4.2.1 Length and Number of Pipelines in Waste Management Area C

Various estimates have been used of the length of pipeline in WMA C. Length of pipeline is important in determining the volume of residual waste potentially remaining in the pipelines. Several studies estimated that there is between 4 and 5 miles of pipelines in WMA C. Previous estimates have listed the number of pipelines in WMA C as 145. Recent information developed from a detailed review of design drawings shows the actual length of pipeline in WMA C is between 7 and 8 miles. This information also has produced a detailed inventory of the number of pipelines. The number of pipelines is ~230.

These updated values have a very small level of uncertainty and are accepted as the length and number of pipelines in WMA C.

4.2.2 Residual Waste Volume Estimates

Different studies have applied a range of assumptions in developing residual waste volume estimates in WMA C pipelines. These assumptions have extrapolated information which has included the following.

- Volume estimate of 4,500 L (1,200 gal) for adsorbed and fixed residual waste that may remain in the 1,414 pipelines across the SST system. Multiplying the total volume times the fraction of lines in C Farm (145 lines associated with C Farm/1,414 total), the residual volume estimate for C Farm pipelines would be ~450 L (120 gal).

Table 4-5. Waste Management Area C Chemical and Radiological Inventory for Pipelines, Past Releases, and 100/200-Series Tanks

Constituent	Total Pipeline Inventory for 700 gal (8 miles)[a]	Total WMA C Inventory from Past Releases[b]	Total WMA C Inventory in Tanks Post-Retrieval[c, d]	Total WMA C Inventory from Past Releases and Tanks Post-Retrieval	Percent Contribution of WMA C Inventory from Pipelines
Key Chemical Constituent (Kg)					
Cr	2	155	266	421	0.5%
NO3	206	31,845	11,100	42,945	0.5%
Total Kg All Chemicals	1,540	81,470	132,000	213,470	0.7%
Key Radionuclide Constituent (Ci)					
Cs-137	347	25,150	44,000	69,150	0.5%
Sr-90	3,050	1,224	389,000	390,224	0.8%
Tc-99	0.13	7.8	5.5	13.3	1.0%
C-14	0.006	0.80	0.066	0.87	0.7%
I-29	0.0008	0.10	0.025	0.13	0.6%
U-234	0.04	0.008	2.53	2.54	1.6%
U-235	0.001	0.0003	0.10	0.10	1.0%
U-238	0.03	0.007	2.28	2.29	1.3%
Total Ci All Radionuclides	7,050	52,800	904,000	956,800	0.7%

[a] From Tables 4-4 and 4-5

[b] From RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates*, Rev. 1.

[c] From RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*, Rev. 0.

[d] Based on 360 ft^3 for 100-series tanks and 30 ft^3 for 200-series tanks and Best Basis Inventory values for retrieved tanks.

WMA = Waste Management Area

- Based on estimated pipe surface area, adsorption of a thin layer of waste (1,000 angstroms) after flushing, and an estimate for fixed waste and waste retained by a plugged line, RPP-15043 identified only five plugged transfer lines in all the farms and assumed the plugged lines were 25% full of waste. This produced a volume of 450 L (120 gal).

- Residual waste is expected to reside in only 4% of the total piping. This report assumed that the pipelines have a cross section area of 1.9 cm^2 (0.29 $in.^2$) with less than 0.1 cm thickness,). Using this as a basis and the generalized length of WMA C abandoned pipelines of ~25,000 linear feet would result in a waste residual volume of ~1,500 L (400 gal).

- Total length of all pipelines within WMA C (using a piping length of ~20,000 linear feet) then assuming that the average line is 3 in. in diameter and that 25% of the lines were blocked or plugged. This resulted in an estimate of 250 ft^3 of waste or 7,200 L (1,900 gal).

- Estimated abandoned pipeline residual waste volume of 28 L (7.4 gal) based on information about the actual conditions of the pipeline systems in WMA C. This estimate assumed waste residuals in pipelines were insignificant except for the residuals in a plugged cascade line between tanks 241-C-110 and C-111; and because pipelines were designed to gravity drain, even the plugged cascade line was expected to have only a small inventory of residual waste (cascade lines are 3 in. in diameter and ~25 ft long).

Each of these volume estimates has inherent errors in the length of pipelines in WMA C and in the manner in which certain information was extrapolated. Specific errors are as follows.

- There is inconsistency in the length of pipeline, which directly influences volume.

- There is inconsistency in the amount of residues and the form of these residues in the pipelines. The assumptions have included:

    - only plugged lines contain residuals and they are 25% full and the balance of the lines have minimal surface scaling;

    - residual waste is only in 4% of the pipelines;

    - 25% of WMA C pipelines are blocked or plugged; and

    - only one cascade line is plugged and there is an insignificant volume in the balance of the lines.

This study has updated the previous volume estimates to be based on a consistent length and number of pipelines in WMA C to reduce some of the uncertainty in comparing these previous estimates. However this study has found that several of the assumptions used in calculating residual waste volume are unsubstantiated by operational data and have resulted in unrealistically conservative estimates. Operational data indicate that only three cascade pipelines have been plugged and at least two of these were unplugged. Operational information also indicates that flushing of the lines followed waste transfers. This was necessary to ensure the lines remained unplugged and operational for subsequent transfers. Existing data indicate that waste transfer lines that plugged were cleared and put back into service, abandoned, or cut/capped and replaced with a new line. Failed lines were either abandoned or cut/capped and replaced with a new line. Other than the cascade lines there is no record to indicate that transfer lines in WMA C are plugged. Therefore the volume of waste residuals in pipelines would be expected to be minimal. Review of pipeline characterization studies indicate that in open channel flow conditions that some settling of waste will occur. Pressurized transfer lines would limit the settling characteristics of the waste and flushing would further clear the lines following a transfer.

By applying operational history for WMA C and the revised length of pipelines and extrapolating the results of previous characterization studies, the uncertainty of the volume of residual waste in WMA C pipelines can be reduced. By applying this information the technical basis estimate of 2,600 L (700 gal) has been developed and still maintains an appropriate degree of conservativism for making closure decisions.

4.2.3 Waste Composition Uncertainty

The chemical and radionuclide composition of pipeline residuals can be estimated based upon the BBI information on tank wastes. The BBI is considered a reasonable estimate which has been validated based on past tank waste residual sampling estimates that have compared favorably to that of the BBI. Therefore, current uncertainties in the composition of pipeline residuals are considered low.

4.3 SCOPING ANALYSIS OF POTENTIAL LONG-TERM IMPACTS FROM PIPELINE RESIDUAL INVENTORIES

Review of data in this section illustrates that the estimated inventory of key radiological and chemical constituents in WMA C pipeline residuals comprises a small fraction of the total inventory of the same constituents estimated in past releases and in the SSTs at the time of closure. Results of this comparison suggest that the pipeline residual inventory will not significantly contribute to potential long-term impacts to human health and the environment.

To evaluate this potential contribution for waste remaining in pipelines, an initial scoping analysis was conducted that considered a range of possible pipeline residual inventories and utilized a number of conservative modeling assumptions. The initial scoping analysis, which is presented in Appendix B, is not intended to support final WMA C risk assessments needed to support closure, but rather provides an initial assessment that attempts to bound potential impacts from these wastes.

The analysis was based on the evaluation of two exposure scenarios that included: (1) an acute human exposure to waste residuals through an inadvertent drilling intrusion into residual wastes in pipelines at WMA C, and (2) a chronic exposure of a member of the public to water pumped from a well completed immediately down gradient from WMA C that receives releases for residual wastes in pipelines. Results of the analysis indicate the following conclusions.

- For the inadvertent drilling intrusion scenario, results of the analysis showed a total acute dose to the intruding receptor to be less than 0.1 mrem/yr after an assumed loss of institutional controls at 150 years and to be less than 0.0001 mrem/yr after 500 years. These doses are well below the generally accepted performance objective for inadvertent intrusion (500 mrem/yr for acute exposure) at closed low-level waste facilities under DOE Order 435.1.

- For the groundwater use scenario, the analysis results indicated a peak chronic total dose to the receptor using groundwater at WMA C to be less than 0.1 mrem/yr. This peak dose is also well below the generally accepted performance objective of 4 mrem/yr for a receptor using groundwater at closed low-level waste facilities under DOE Order 435.1.

- The key non-radiological contaminants using the same groundwater use scenario are well below groundwater cleanup levels which are shown in parentheses:

  - Nitrate – 27.9 µg/L (groundwater cleanup level is 45,000 µg/L [as NO_3])

  - Chromium – 0.26 µg/L [groundwater cleanup level is 100 µg/L for total chromium and 48 µg/L for chromium (VI)].

5.0 PIPELINE CHARACTERIZATION TECHNOLOGIES

This Section describes and evaluates candidate technologies to potentially characterize process waste residuals that may be present in the buried pipelines at WMA C.

At WMA C there are ~8 miles of pipeline in ~230 separate segments. Pipelines are direct buried, encased in a concrete duct or are an integral element of a structure (e.g., CR Vault). These pipes vary in length and width but the majority are either 3 or 6 in. in diameter, and many have one or more 90 degree bends. All have been isolated but may be accessible at one end through a diversion box, pump and valve pits and boxes.

There is a range of technologies that are potential candidates for characterizing pipelines. These technologies have been developed for a variety of applications, from assessing the integrity of a pipeline to cleaning and repairing. These technologies operate in a range of pipeline operating conditions. The specific application and operating environment contribute to the implementation constrains of each of the technologies. The WMA C pipeline attributes identified in Section 2.0 must be considered when evaluating characterization technologies for WMA C pipelines including: the physical condition of the pipe; whether it is encased or direct buried; the degree to which corrosion has compromised the integrity of the pipe and the friction coefficient of the interior pipe surface; size; slope; number of bends and types of bends; accessibility to the pipeline (the depth it is buried, access points such as valve boxes or diversion boxes); and the potential physical and chemical characteristics of any residual wastes in the pipeline (scale, solid, liquid, plugs). Understanding the attributes of the pipelines helps in evaluating the applicability of a technology to the specific pipes in the system, if the technology is deployable in the tank farm environment and if the technology can actually be used to characterize the waste form likely to be encountered in the pipeline.

A comparative evaluation of the characterization technologies identified in this section is contained in Section 7.1.3.

5.1 GENERAL CATEGORIES OF CHARACTERIZATION TECHNOLOGIES

In October 2006 ORP received support from the DOE Headquarters Office of Environmental Management which convened an expert panel on pipeline characterization technologies. The expert panel reviewed a range of characterization technologies for potential applicability to assist with the determination of remedial and closure actions for the pipeline system (Technical Expertise Project #619, *Technical Assessment of Characterization and Sampling Technologies for High Level Waste Buried Pipelines at the Department of Energy Hanford and Savannah River Sites*). While the expert panel did not provide specific recommendations for the use of a particular technology at Hanford, they did stress that ALARA practices must be a primary focus for characterization activities.

Characterization of waste residuals in pipelines can be grouped into the following categories:

- Removal and analysis of piping and residual wastes
- In situ visual analysis and radiological screening

- In situ sampling and analysis
- Modeling.

5.1.1 Pre-Characterization Activities

Characterization of pipelines is not limited to the deployment of a single technology. Characterization activities can include evaluation of the interior of pipelines and adjacent vadose zone soil. There are extensive pre-deployment activities that also must be completed which can involve various technologies for screening and accessing the pipes and adjacent soils for defining worker exposure and risks. Surface geophysical and radiation surveys must be conducted at all sample locations. The surface geophysical surveys will need to be conducted using ground-penetrating radar and/or electromagnetic induction. This will aid in verifying buried pipeline locations, other buried utilities, and subsurface anomalies. Surface radiation surveys will identify areas of surface contamination that might impact intrusive activities and health and safety requirements.

Sampling and geophysical logging of soil would be performed using spectral and gross gamma, passive neutron, and active neutron (moisture) detectors. Direct-push technology (e.g., Geoprobe or equivalent equipment) would be used for vadose soil sampling and geophysical logging. The characterization strategy should be designed to provide focused evaluations on potentially contaminated locations and media inside the pipelines, and in adjacent subsurface soils where leaks may have occurred. Selection of samples in soils used for laboratory analysis is typically guided by field screening results. Field screening results will assist in identifying the sample depths where the most extensive contamination occurs.

5.1.2 Removal and Analysis of Piping and Residual Wastes

Pipeline characterization poses significant difficulties and exposure to the workers. Therefore, the approach for pipeline sampling and analysis is somewhat different from soil sampling. One approach to pipeline characterization would be the removal of a segment of piping for ex-situ characterization. Total length of a section of pipe removed is limited to 10 ft or less, based on a desire to limit excavation and for As Low as Reasonably Achievable (ALARA) concerns. The pipe section may have to be cut into smaller sub-sections for ease of shipping and handling. Residual waste on the interior of the pipe is then removed and analyzed. Liquids, if present in the pipeline, would be collected and shipped to a laboratory for analysis.

After completion of sampling, the pipeline that remains in the ground and the surrounding soil would be placed in a state that is protective of the worker and environment. Activities to achieve the end state will depend on sample location and sampling methods used.

5.1.3 In-Pipe Visual Analysis and Radiological Screening

It may be possible that sufficient characterization data could be obtained by applying screening technologies in lieu of excavation and sampling and analysis. A starting point for characterization would be to run a video camera through a segment of pipeline to identify the physical condition of pipe and any waste residuals. Chemical sensors for volatile contaminants in the air space within a pipeline potentially could be deployed at locations where an exposure to volatile organics is a concern.

The next step would involve conducting a radiation survey, for which several radiation detectors could be deployed inside the pipe. Visual inspection and radiation scanning may be able to occur concurrently by placing both a detector and video system on the same deployment platform, selection of which may be contingent upon pipe diameter as well as orientation. Visual inspection of pipelines at Hanford has been accomplished on a very limited basis.

5.1.4 In-Pipe Sampling and Analysis

Radiological waste characterization involves detecting the presence of individual radionuclides and quantifying their inventories in the waste. This can be done by a variety of techniques, depending on the waste form, radionuclides involved and level of detail/accuracy required. For example, a simple radiation dose rate measurement will give an indication of the total quantity of gamma emitting radionuclides, but will not identify individual radionuclides or their concentrations. Gamma spectroscopy will identify the individual radionuclides and, when properly calibrated, their quantities as well. Other techniques, such as active/passive neutron interrogation, alpha spectroscopy, and liquid scintillation counting are used for other classes of radionuclides. The radiation survey may simply provide a screening value for total radionuclide activity (counts per minute) or exposure rate (rads/hour).

Small high-exposure rate detectors can be deployed to numerous inspection platforms. These platforms and associated detectors can be remotely controlled with direct line (i.e., tethered) or telemetry (i.e., non-tethered).

The collection of physical samples from within the pipe at several locations provides a more robust approach for performing more extensive characterization throughout a segment of pipe by selecting the most appropriate technologies. Remote sampling collection involves introducing inspection platforms with mechanical tools that are compatible with the waste characteristics (brushes, grinding, filing, and/or sanding tools). In some cases it may be necessary to make multiple excursions into the pipeline to collect the sample. For example, the first platform entry could be required to locate the residuals and/or to physically loosen them. The second platform entry would be to collect a sample of waste via specific technology.

It should be noted that currently there are no technologies available for in-situ measuring of chemical waste residuals on the inner surface of buried 2- and 3-in. pipelines.

5.1.5 Modeling

Modeling, using MicroShield®[1] or other software applications, can also be used to characterize process pipelines based upon establishment of a conceptual model of the contamination deposited on surfaces inside pipelines. The conceptual models should be based on process knowledge and historical site assessment, and should incorporate dose rate measurements if available.

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[1] MicroShield is a registered trademark of Grove Software, Inc., 4925 Boonsboro Road #257, Lynchburg, Virginia.

5.2 SPECIFIC CHARACTERIZATION TECHNOLOGIES AND DEPLOYMENT PLATFORMS

The previously referenced expert panel reviewed and cataloged commercially available as well as innovative and/or emerging in-pipe deployment systems. While the majority of the available pipeline characterization technologies and their deployment systems do not lend themselves to small diameter pipelines, which are typically found in the SST system, certain tools and deployment platforms have been miniaturized. The potential also exists that more than one assessment method and/or technology would likely be required to assess waste residuals present in a pipeline or a pipeline segment. Also, technologies must be capable of obtaining the information needed to make closure decisions. For example, a technology to characterize radionuclides in a pipeline may fail if it cannot detect technetium, a key radionuclide that drives the risk (DOE/RL-2002-14, *Tanks/Lines/Pits/Boxes/Septic Tank and Drain Fields Waste Group Operable Unit RI/FS Work Plan and RCRA TSD Unit Sampling Plan; Includes: 200-IS-1 and 200-ST-1 Operable Units*).

Table 5-1 provides examples of mature and certain promising innovative inventory characterization technologies, along with examples of commercially available deployment platforms, which may be potentially applicable to the small diameter pipelines at WMA C. Deploying any technology within the tank farm environment may require further custom adaptation of these technologies and deployment platforms. The quality of the characterization data that would result for any technology in Table 5-1, including sources of uncertainty, depends on site specific conditions and characterization objectives, as well as the operating parameters of a particular tool.

The best approach to the residual waste characterization utilizes deployment platforms that can integrate multiple inspection tools and/or technologies. The deployment platforms fall into three categories:

- mechanically deployed (push-rod or similar to snakes used to unplug sewer systems),
- tethered crawlers,
- blown membrane members.

The inspection platforms and tools can be inserted into the pipelines through diversion boxes, flanges, cut-outs, etc. Technology deployment is usually limited to straight sections of pipelines because tethered or self-propelled inspection tool platforms, or individual tools, may not be able to maneuver around corners with some exceptions. For example the Pipe Explorer®[2] can be maneuvered around corners and bends for in-pipe collection of smears by an inverted membrane system. However, bent sections of a pipeline are a challenge for the Pipe Explorer® when it is used to carry sensors into pipelines for in-situ detection of radioactive contamination on the interior surfaces. Table 5-2 presents examples of deployment platforms potentially available for small diameter pipes.

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[2] Pipe Explorer is registered trademark of Science & Engineering Associates, Inc., Albuquerque, New Mexico.

Table 5-1. Representative Pipeline Inventory Characterization Technologies and Deployment Platforms

Technology Type	Results
Commercial Pipeline Inventory Characterization Technologies	
Removal of a pipe segment	10 ft pipeline segment may be removed and transported to a laboratory for characterization of contamination.
Video cameras with illumination source	Visual inspections for location of debris and corrosion spots in relatively clean pipelines.
Infrared cameras with illumination source	Visual inspections for location of debris and corrosion spots in relatively clean pipelines.
Real-time dosimetry	Initial localization of radioactive spots, measure of overall level of radioactive contamination.
Gamma spectrometry systems	Identification of specific radionuclides. Real-time high-purity germanium (HPGe) spectroscopy can measure “prompt” signature gammas from chemical constituents, which may be correlated to the radiological components.
Special gamma spectrometry systems	Identification of hard to detect radionuclides (e.g., actinides and transuranic [TRU]) with only low energy gamma rays.
Dosimeter string, Geiger-Mueller detector, and plastic scintillator	Gamma logging to identify hot-spots and potential sampling locations.
Electrometers	Measurement of air ionization from alpha particles from TRU isotopes.
Flammable gas sensors	In-situ detection of flammable gases within pipelines.
Miniature chemical sensors	Identification of presence of volatile organic compounds (VOCs), but not quantities, concentrations or locations.
Field-portable analytical chemistry systems	Quick analysis of solid, liquid or gas samples collected from the pipeline.
Remote in-pipe collection of smears: Pipe Explorer®	Pipe Explorer® (developed by Science & Engineering Associates, Inc., Albuquerque, New Mexico) is the only known commercial sampling tool for in-pipe collection of smears. It utilizes a pneumatic membrane to transverse and survey the pipeline. It can be maneuvered around corners and bends. Smear samples collected using this tool can then be characterized in a laboratory setting. http://www.cpeo.org/techtree/ttdescript/pipexp.htm
Remote in-pipe sampling collection	Remote sample collection can be accomplished by a variety of tools (brushes, grinders, files, sanders) installed on various pipeline inspection platforms. The first platform entry is to locate the sediments and/or to physically loosen the sediments. The second platform entry is to collect loosened sediments via a vacuum or adhesive material.
Innovative Pipeline Inventory Characterization Technologies	
Soil/loose particulate sampling for radiological and chemical analysis – Guzzler^{TM}	Guzzler^{TM} is a vacuum-based system, which has been effectively demonstrated at Hanford to selectively remove loose particulates from the subsurface. It could possibly be modified to remove loose materials present from within piping itself for physical sampling. Guzzler is a registered trademark of GUZZLER Manufacturing, Inc., Streator, Illinois.

Table 5-1. Representative Pipeline Inventory Characterization Technologies and Deployment Platforms

Technology Type	Results
Pipeline characterization using tracers (PCUT). Bratton and Maresca 2004	PCUT is an emerging technology, developed by Vista Engineering Technologies, L.L.C. in collaboration with the Pacific Northwest Laboratory (PNNL), for locating and quantification of residual contamination in pipelines. PCUT introduces reactive gaseous tracers into a one end of a pipeline and measures concentrations of contaminants of interest with an on-line gas chromatograph or another analytical instrument at the other end of the pipe. PCUT has been demonstrated at the proof-of-principle level for detection, location, and quantification of residual contamination in pipelines and ducts for chemical liquids (diesel fuel) and semi-solids (mercury) in terms of vapor pressures. PCUT has not been demonstrated in the laboratory for applicability to radiological contamination; however, the developers have proposed to test and demonstrate PCUT to determine the presence, location, and radiological contamination in pipes using reactive gaseous tracers that react with the radiological contaminants of interest (Bratton and Maresca 2004).

References:
"A New Method for Detecting, Locating, and Quantifying Residual Contamination in Pipes and Ducts in Support of D&D Activities" (Bratton and Maresca 2004).

Table 5-2. Examples of Commercial Deployment Platforms Potentially Applicable to the Small Diameter Pipelines at Waste Management Area C

Pipe Explorer® http://www.netl.doe.gov/publications/proceedings/00/ind_part00/lowry.pdf http://www.wmsym.org/archives/2002/Proceedings/40/341.pdf	The Pipe Explorer® (developed by Science & Engineering Associates, Inc., Albuquerque, New Mexico) is a membrane system that can incorporate many samplers and sensors and has been demonstrated widely at U.S. Department of Energy sites. It uses a pneumatically operated airtight tubular membrane to tow radiation detectors and video cameras into pipes. When pressurized, the membrane inverts into a pipe with adequate force to tow the characterization tools through the piping, providing a clean conduit through which the sensors can travel. The system is capable of deploying in pipes as small as 2-in. diameter and up to 375-ft long.
Pipe BTX-II System http://www.p2pays.org/ref/13/12740.pdf	This system (a product of Visual Inspection Technologies, Flanders, New Jersey) includes a video monitor, high-resolution micro color camera with lights and cablings, and a control unit. The complete probe is capable of inspecting pipes with an internal diameter (ID) as small as 1.4". The technology is fully developed and used in commercial applications, and has been demonstrated at nuclear facilities, for example Fernald.
Versatrax-100™ http://www.inuktunusa.com/crawler-vehicles/versatrax-100.html	The Versatrax-100™ (a product of Inuktun USA, Robert, Louisiana) is a miniature crawler system capable of inspecting pipe and ducts as small as 4" in diameter. The system includes a front and rear cameras and auxiliary lighting. The system is readily available and has been used in nuclear power plants.

Deployment technologies will not be evaluated further because the selection of an appropriate deployment platform will be dependent upon the characterization technology.

5.3 PIPELINE CHARACTERIZATION EXPERIENCE AT HANFORD

The following reports identify relevant information about characterization of pipelines at the Hanford Site:

- DOE/RL-2003-11, *Remedial Investigation Report for the 200 CW-5 U Pond/Z Ditches Cooling Water Group, the 200-CW-2 S Pond and Ditches Cooling Water Group, the 200-CW-4 T Pond and Ditches Cooling Water Group, and the 200-SC-1 Steam Condensate Group Operable Units* and

- WHC-SD-NR-ER-103, *Final Report for the Remote CCTV Survey of Abandoned Process Effluent Drain Lines 840 and 840D in Support of the 200 West Area Carbon Tetrachloride ERA*.

In addition, the 200-IS-1 Sampling and Analysis Plan for Pipelines at UPR 200-E-86 (RPP-PLAN-31715, *Phase 1 Sampling and Analysis Plan for 200-IS-1 Operable Unit Tank Farm Pipelines*) provides an evaluation of how pipelines outside of the farm and associated with WMA C would be sampled and analyzed, including preliminary cost and schedule information.

5.3.1 Remedial Investigation Report for 200-CW-5 U Pond/Z Ditches Cooling Water Group

Two pipelines (231-Z and 235-5) were evaluated through manholes 2 and Z8 during the Remedial Investigation (RI). The locations of the pipelines and manholes are shown in Figure 5-1. The 231-Z pipeline is a 45.7 cm (18-in.) diameter vitreous clay pipe that was used to discharge effluent to the Z Ditches from the 231-Z Building. This pipe replaced the upper portion of the original 216-Z-1D Ditch in July 1949 and facilitated relocating the headwall ~457 m (1,500 ft) southeast of the 234-5 Building. The 234-5 pipeline is a 38.1-cm- (15-in.-) diameter, vitreous clay, process sewer pipe that originated from the 234-5 Building and discharged to the Z Ditches.

The investigation to characterize the pipeline consisted of collecting in-situ gamma measurements and smear samples. A sodium iodide gamma detector was lowered to within 15 cm (6 in.) of the bottom of the manholes to collect data on the type of contaminants present. Smear samples were collected to assess the type and concentration of contaminants present in the pipeline. Smear samples were collected by affixing two tech smear pads on either side of a foam paintbrush attached to the end of an extendable metal pole. Swipes were made in both directions across the bottom of the pipe and manhole. The condition of each pipe was documented with a video camera.

5.3.1.1 231-Z Manhole and PFP Z8 Survey. The major objectives of these two surveys were to open the manhole cover, ensure industrial hygiene (IH) and radiation controls were adequate, video tape the inside of the manhole, collect a smear sample for laboratory analysis, and perform an in-situ gamma radiation survey of the bottom of the manhole. The 231-Z "manhole" consisted of a section of the 18-in. vitreous clay pipe in which a 2-ft opening had been cut into the top of the pipe; see Figure 5-2. The pipe was ~3 ft below the ground surface. The opening in the pipe is protected by a concrete vault that has been placed over the cut-away section of pipe.

The inside of the pipe was covered on the bottom with a layer of dry silt ~½ in. thick. Smear sample B14PL7 was collected from the bottom of the manhole for analysis.

Figure 5-1. Pipeline and Manhole Location Map

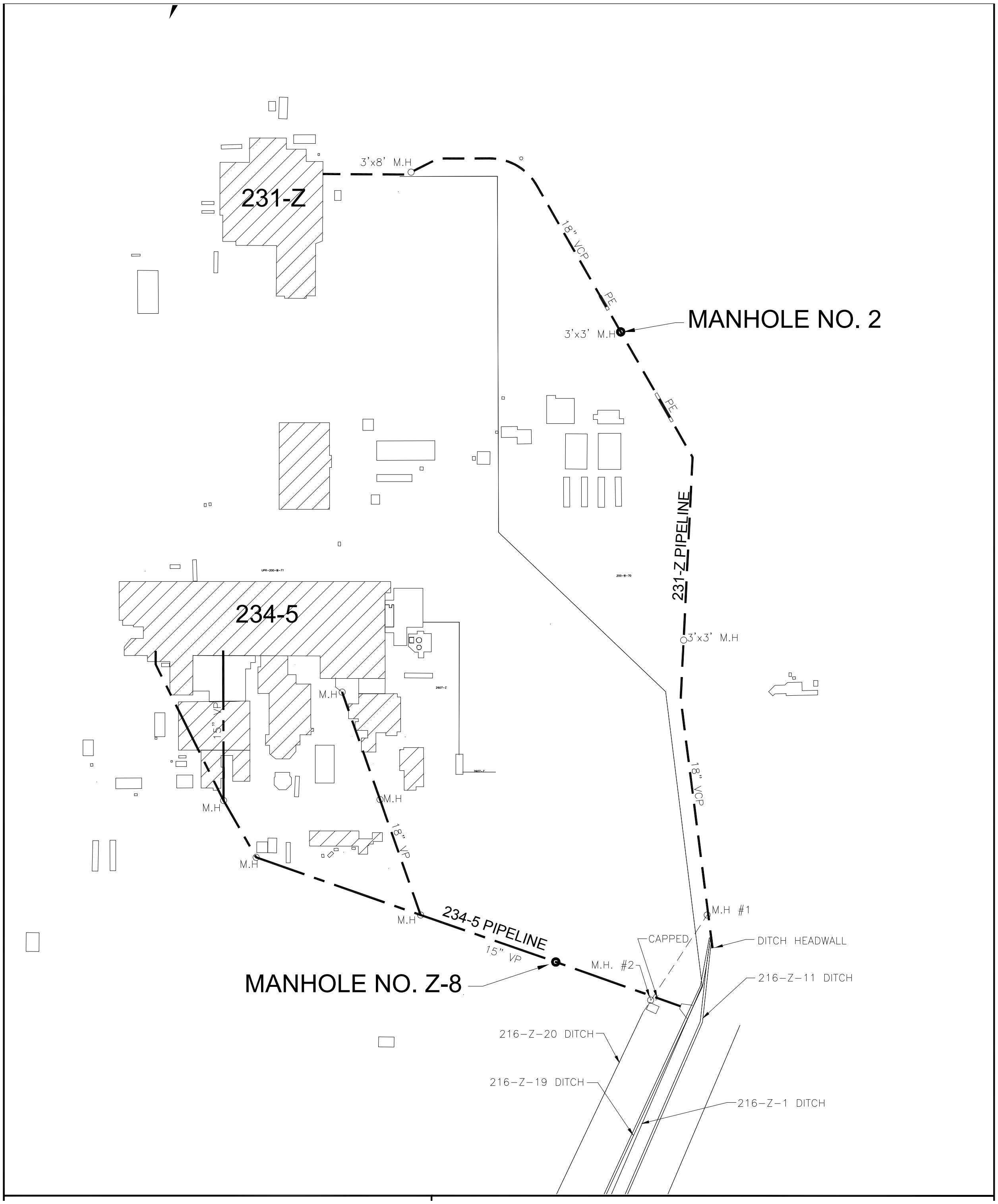


Figure 5-2. 231 Manhole

The PFP Z8 manhole was ~10 ft deep and was constructed of brick. The inlet pipe was configured with a 90-degree bend which served as a trap to ensure the inlet pipe remained full of liquid (see Figure 5-3). The bottom of the manhole was covered with a layer of dry silt ~¼ in. thick. Smear sample B14PL8 was collected from the bottom of the manhole for analysis at an offsite laboratory.

5.3.1.2 Pipeline Characterization Results. Investigation of the 231-Z and 234-5 pipelines indicates that contamination is present. Sodium iodide detector measurements collected from within two pipeline manholes indicated the presence of ^{241}Am. No other gamma-emitting radionuclides were discernable from the recorded spectra.

Figure 5-3. PFP Z8 Manhole

The maximum detected contaminant concentrations were observed in the 231-Z pipeline, with values of 23.5 pCi/sample for ^{238}Pu, 1,210 pCi/sample for ^{239}Pu, and 813 pCi/sample for ^{241}Am. The pipeline data are presented in Appendix C of DOE/RL-2003-11. The results are summarized in the table below.

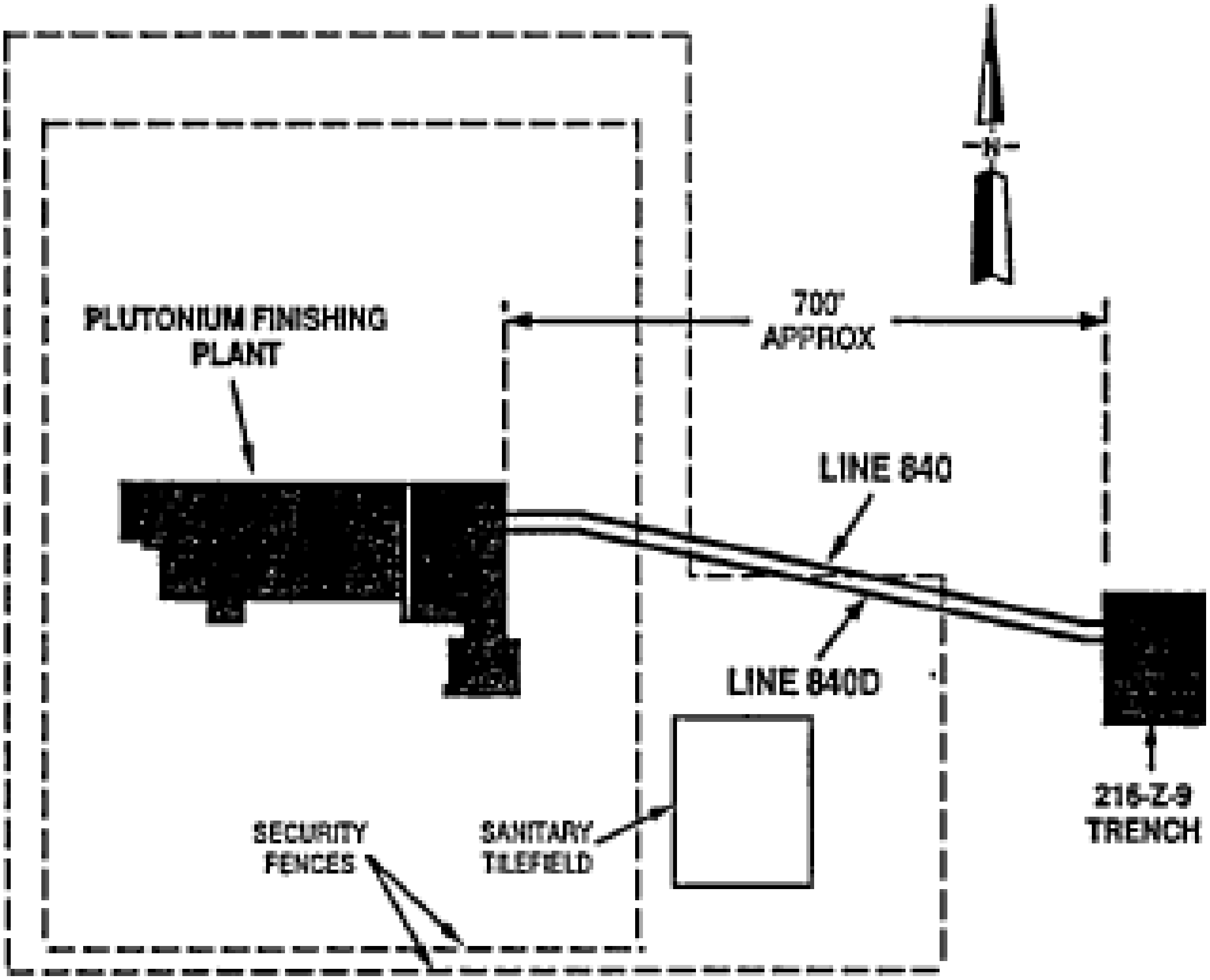
Manhole Sludge Inventory Estimate Summary

Manhole	^{241}Am (nCi/g)	^{238}Pu (nCi/g)	$^{239/240}$Pu (nCi/g)	Total (nCi/g)
CW5-2	579	17	861	1457
CW5-8	31	3	126	160

5.3.2 Remote Closed-Circuit Television Survey of Abandoned Process Effluent Drain Lines

WHC-SD-NR-ER-103 documents the methods used by Westinghouse Hanford Company for the in-pipe survey of retired effluent lines 840 and 840D. These drain lines are located at the Plutonium Finishing Plant (PFP), in the 200 West Area. The Plutonium recovery process performed at PFP's Recuplex facility was the source of the majority of the organic and radioactive waste discharged through drain lines 840 and 840D to the 216-Z-9 Trench. These drain lines and the 216-Z-9 Trench operated from 1955 until 1962. These lines are buried and run essentially parallel to one another through their entire length (see Figure 5-4).

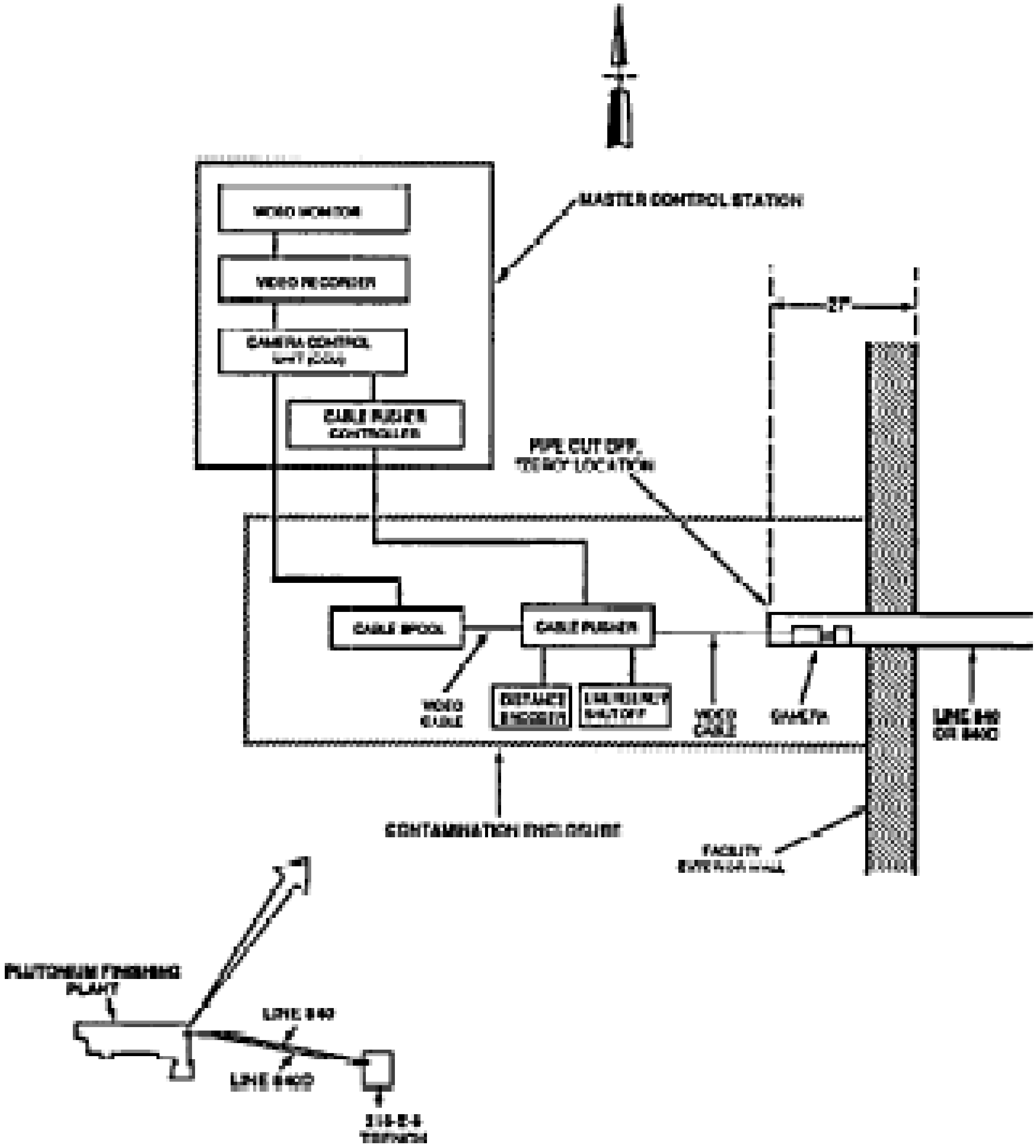
Figure 5-4. Map of Lines 840 and 840D



Two miniature color video cameras, nicknamed "Weasels," were developed for the in-pipe examination of lines 840 and 840D. These cameras are 1-¼ in. in diameter, and 13 in. in length. The Weasel's camera optics are contained in a forward stainless steel housing, and the circuitry is contained in a separate module joined to the camera by a flexible conduit. This arrangement allows the Weasels to negotiate anticipated bends in the piping. Each Weasel also includes an array of eight high intensity variable lights mounted around the camera lens.

Access to drain lines 840 and 840D was gained in January of 1993 when a section was removed from each line. This was accomplished in the basement of the 234-5Z building, at the east end of Tunnel #6 (see Figure 5-5). A small hole was drilled in each line, and the atmosphere contained within the lines was sampled for residual carbon tetrachloride gasses, as well as for explosive gasses. The gas tests were negative, allowing a short piece to be removed from each line. The remaining ends were threaded to accept screw-on type pipe caps. The Weasel cameras were then inserted into each line at the work location in Tunnel #6 by removing the appropriate pipe cap.

Figure 5-5. Equipment Set Up at Tunnel #6



The Weasels were pushed through the lines as far as possible with the aid of fiberglass pushrods. The images from within the lines were recorded on videotape at the control station. An encoding system was used during this survey to accurately determine the location of each Weasel camera within the piping. The encoder produces a footage measurement which was recorded on the video tapes along with the camera images. This enables accurate location of features found within the piping, both real time and during video playback.

5.3.2.1 Survey Results. Line 840D and Line 840 are made up of 20-ft lengths of 1-½-in. diameter, schedule 40, type 304L stainless steel piping. Each section is welded pipe (i.e., it is made from rolled plate that was longitudinally welded by the manufacturer). These 20-ft long sections of pipe were welded together in the field.

The characterization team had determined that lines 840 and 840D, routed from the Recuplex facility in the 234-5Z Building to the 216-Z-9 Trench, would present the "worst case" for waste drain pipe conditions because they were earliest in operation, longest in retirement, and can be accessed without requiring excavation. WHC-SD-NR-ER-103 describes the methodology and results of an in-pipe camera survey of these two retired effluent lines.

The following describes the survey results for lines 840D and 840.

Line 840D

The construction drawings for line 840D indicate the pipe slope is 1% inside the 234-5Z building. The pipe slope outside the 234-5Z building is ~1.9%.

The construction drawings for line 840D indicate the required minimum depth of burial was 6 ft. Due to the surface contours in the vicinity, the depth of burial was estimated to vary from 6 to 10 ft along the piping route.

The area map indicates that line 840D turns slightly southeast ~70 ft east of the 234-5Z building. It appears on the drawing that this change of direction is ~22-½ inches. No pipe fittings were found in the sections of line 840D examined during this survey. It is probable that the field welds were slightly beveled, or the pipe itself was gradually bent to accomplish any required changes of directions in pipe routing.

On February 2, 1993 a Weasel camera was prepared for insertion into line 840D. A fiberglass rod was attached to the camera cable immediately behind the camera. A second fiberglass rod was attached to the cable 100 ft from the camera. This set up had worked well during trial runs in 2-in. diameter PVC mockup piping where the Weasel cameras were deployed for 690 ft.

The pipe cap was removed from line 840D and the camera placed into the open end of the pipe. At this location the encoding system was set to zero. All further footage distances referenced for line 840D are from this location. The exterior of the 234-5Z building is ~27 in. from the zero location.

The camera was then slowly pushed into the pipe for a distance of 283 ft. At that point the camera could not be pushed any farther due to loss of rigidity of the fiberglass rods. On February 3, 1993 the camera was retracted for 103 ft, and a third fiberglass rod was attached to the camera cable 180 ft from the camera. With the pushrods "ganged" in this method the Weasel camera was then pushed into the pipe for a distance of 347.9 ft.

At 347.9 ft the Weasel camera could not be pushed any farther. It is thought that the severe corrosion and inside surface roughness of the piping produced a friction load which could not be overcome. At 347.9 ft the survey of line 840D was stopped, and attention was shifted to line 840.

The following observations were made during a review of the videotape recordings of the line 840D survey (from WHC-SD-NR-ER-103):

> "At the zero location the pipe is inside the 234-5Z building, about two feet above the basement floor. In this area some debris is in the bottom of the pipe, and some very light pitting is apparent. The first circumferential weld in line 840D is at 0.5 feet. The root of this weld is very uneven and rough. At about 1.5 feet the pipe enters the east wall of the building. From this point on the pipe is underground.
>
> The first section of underground pipe has several areas of uniform pitting around the piping circumference. At between nine and ten feet are large pits approximately 1/16 - 1/4 inch in diameter. These pits appear to have considerable depth to them. However, the Weasel camera is not designed to measure pitting depth, but to locate anomalies such as breaks and areas of severe corrosion.
>
> At 16.8 feet is the next circumferential weld. This weld has a fairly smooth root. The section of pipe beyond this weld exhibits several areas of "blistering". This blistering is characterizes by a slightly raised surface area surrounded by a dark discoloration. At 17.1 feet is a single large diameter pit. This pit is approximately 1/8" in diameter and appears to have substantial depth. At 22.2 feet are several blisters which appear to contain pits of approximately 3/16 inch diameter and substantial depth.
>
> At 36.6 feet is the next circumferential weld. This weld is extremely rough, with lots of slag deposited at the weld root. The section of pipe beyond this weld exhibits areas of localized heavy pitting and corrosion. The corrosion is accompanied by "blistering" in many areas. At 42.8 feet are several pits and a blister approximately 1/4 - 1/2 inch in diameter. At approximately 45 feet is an area that exhibits a fine hair-like growth in the pipe. At 48 feet is a "blister" which appears to be flaking off of the pipe wall. Between 55.6 feet and 56.5 feet is a buildup of loose material in the bottom of the pipe.
>
> At 56.5 feet is the next circumferential weld. This weld has a fairly rough root. At 63 feet is a hair-like object on the pipe wall. At 64.7 feet is a whitish "chalk-like" material or "saltcake". At 64.9 feet is a large blister at the top of the pipe. At 65.7 feet a pile of material builds up ahead of the camera and is pushed down the pipe. At 70 feet the pile of debris very nearly obscures the camera view. The camera operator begins the technique of pushing the pile down the pipe several feet, then withdrawing the camera to inspect the cleared area. This process is continued for the next 60 - 70 feet until the pile of material is finally broken up enough to allow the camera to pass.
>
> At 74.4 feet is the next circumferential weld. This weld has a smooth root area. Just beyond this weld is another area of localized pitting of substantial depth. At 87.5 feet an is an area of heavy corrosion, mostly at the bottom of the pipe.

At 94.5 feet is the next circumferential weld. This weld has a fairly rough root. Beyond this weld the pipe has an area of uniform pitting. These pits appear to be approximately 1/16 inch in diameter and many of the pits appear to have substantial depth. At 100 feet the pipe has an area of corrosion along the bottom. At 105.5 feet is localized pitting with substantial depth. At 106 feet is another area of heavy corrosion. At 114.5 feet is the next circumferential weld. This weld has a smooth root. Beyond this weld the pipe contains many pits which are uniformly distributed around the pipe surface. At 126 feet the pitting appears to be shallower and resembles freckling.

At 134.4 feet is the next circumferential weld. This weld has a smooth root. Beyond this weld the freckling covers only the lower half of the pipe surface. At 138.6 feet is an area containing several heavy corrosion sites scattered along the pipe surface. At 143 feet several of the corrosion areas contain pits which appear to have substantial depth. At 146 feet the pipe is freckled with small pits. At 152.5 feet is an area of uniform pitting which appears to have substantial depth.

At 153.6 feet is the next circumferential weld. This weld has a fairly smooth root. Beyond this weld the pipe again contains uniform pitting which appears to have substantial depth. At 162.7 feet is an area of heavy corrosion. At 164 feet the corrosion again contains pits with substantial depth.

At 173.2 feet is the next circumferential weld. This weld is fairly smooth at the root. At 174 feet is an area of several large pits of substantial depth. At 175.6 feet the pipe is again freckled with small pits. At 190.5 feet is another area of several large pits of substantial depth. At 192.7 feet there is debris building up in the bottom of the pipe in front of the camera again.

At 193.2 feet is the next circumferential weld. This weld has a smooth root. Beyond this weld the pipe is again freckled with small pits. At 193.4 feet is a large irregular shaped pit which is located adjacent to the longitudinal weld. This pit is approximately 1/2 inch long and appears to have substantial depth. At 197 feet there is blistering on the pipe surface. Some of the blisters contain pits which appear to have substantial depth.

At 213.2 feet is the next circumferential weld. This weld has a rough root. Beyond this weld is an area of uniform pitting. Some of these pits appear to have substantial depth. At 226.5 feet the debris in the bottom of the pipe builds up in front of the camera again. At 230.5 feet are several large pits approximately 1/8 inch in diameter which appear to have substantial depth. At 232.9 feet is a quantity of debris which is built up ahead of the next circumferential weld.

At 233.1 feet is the next circumferential weld. This weld has a smooth root. Beyond this weld is an area of uniform pitting. Some of these pits appear to have substantial depth. At 244.1 feet is another area of pitting which appears to have substantial depth.

At 252.9 feet is the next circumferential weld. This weld has a rough root. At 261 feet is an area of pitting which appears to have substantial depth. At 265 the debris again builds up in front of the camera.

> At 272.7 feet is the next circumferential weld. This weld has a rough root. There is debris in the pipe beyond this weld and uniform pitting around the pipe surface.
> At 287.5 feet is another hair-like object.
>
> At 292.2 feet is the next circumferential weld. This weld has a very rough root. There is debris accumulated in the bottom of the pipe in front of this weld. Beyond the weld the pipe surface is uniformly covered with pits, many of which appear to have substantial depth. At 305.4 feet is an area of heavy corrosion. At 312 feet there is a sludge-like deposit built up in front of the next circumferential weld.
>
> At 312.7 feet is the next circumferential weld. This weld has a very rough root. This section of pipe is uniformly covered with pitting. Much of the pitting appears to have substantial depth.
>
> At 332.8 feet is the next circumferential weld. This weld has a rough root. There is debris built up in the bottom of the pipe beyond this weld and the pipe is randomly pitted. At 335.5 feet debris again has built up in the bottom of the pipe. At 339.1 feet is an area with several pits approximately 1/8 inch in diameter which appear to have substantial depth.
>
> At 347.9 feet the camera could not be pushed down the pipe any farther, so the survey of line 840D was ended at that point. The last 50 - 60 feet of line 840D that was surveyed contains a very coarse deposit along the bottom of the pipe. It appears likely that this material significantly increased the friction load on the camera and cables. The camera cable and fiberglass rods were left in the piping."

Line 840

The construction drawings for line 840 indicate the pipe slope is 1% inside the 234-5Z building. Outside, where the pipe emerges from the east end of the building, the pipe elevation is 669.5 ft. Where the pipe enters the 216-Z-9 Trench the elevation is 656.0 ft. The pipe slope outside the 234-5Z building is therefore ~1.9%.

The construction drawings for line 840 indicate the required minimum depth of burial was 6 ft. Due to the surface contours in the vicinity, the depth of burial is estimated to vary from 6 to 10 ft along the piping route.

On February 11, 1993 the second Weasel camera was prepared for insertion into line 840.
A fiberglass rod was attached to the camera cable immediately behind the camera. A second fiberglass rod was attached to the cable 100 ft from the camera. Additional fiberglass rods were on hand for attachment to the camera cable if necessary. The previous experience in line 840D had shown that an additional rod would be necessary once the camera had been inserted ~280 ft.

The pipe cap was removed from line 840 and the camera was placed into the open end of the pipe. At this location the encoding system was set to zero. All further footage distances referenced for line 840 are from this location. The exterior of the 234-5Z building is ~27 in. from the zero location.

The camera was then slowly pushed into the pipe for a distance of 63.3 ft. At that point the camera lens became obscured by a thick sludge-like material in the pipe. The camera was left in the pipe temporarily while a recovery plan was devised.

On February 23, 1993 the Weasel camera was retracted from line 840 in an attempt to wipe off the lens. However, when the camera was pulled from the line several camera lights were found to be shorted out. It was decided to substitute a Gopher camera rather than attempt repairs to the Weasel camera. The Gopher camera was attached to fiberglass rods and inserted into the line to 63 ft. No additional information was obtained, however, because the Gopher camera was also obscured by the sludge.

The following observations were made during a review of the videotape recordings of the line 840 survey (from WHC-SD-NR-ER-103):

> "At the zero location the pipe is inside the 234-5Z building, about two feet above the basement floor. In this area some debris is in the bottom of the pipe, and light corrosion is apparent. The first circumferential weld in line 840 is at 0.3 feet. The root of this weld is fairly smooth. At about 1.5 feet the pipe enters the east wall of the building. From this point on the pipe is underground.
>
> The first section of underground pipe has rather uniform pitting around the piping circumference for the first foot. At 1.1 feet the instances of pitting decrease, and a uniform whitish coating on the piping surface begins. At 3.5 feet the pitting is again apparent. At 9.5 feet the pitting increases in frequency and severity. These pits appear to have substantial depth. However, the Weasel camera is not designed to measure pitting depth, but to locate anomalies such as breaks and areas of severe corrosion.
>
> At 17 feet is the next circumferential weld. This weld has a fairly smooth root. The section of pipe beyond this weld exhibits light pitting and some debris in the bottom of the pipe. At 25.8 feet there is a small root-like object in the pipe. At 27.3 feet the whitish coating fades and corrosion of the piping is apparent. At 28.8 feet there is pitting which appears to have substantial depth. At 35.4 feet is an area where a sludge-like deposit has been pushed up by the camera and another hair-like object is in the pipe.
>
> At 37.1 feet is the next circumferential weld. This weld has a fairly smooth root. This section of pipe exhibits highly reflective silvery deposits randomly scattered along the piping surface. At 40 feet the pipe also has areas of pitting mixed with the deposits. At 44.7 feet the pitting increases in severity, now appearing to have substantial depth. At 46.8 feet, 47.9 feet, and 48.1 feet are small hair-like objects in the top of the pipe. At 49 feet the corrosion of the pipe wall becomes more pronounced. At 50 feet is pitting which appears to have substantial depth. At 55.9 feet a large "flake" is pushed up in front of the camera. The pipe is also very discolored in this vicinity.
>
> At 56.9 feet is the next circumferential weld. This weld has a fairly smooth root. At 60.5 feet is the start of a wet stain on the bottom of the pipe. At 61.6 feet the material on the bottom of the pipe begins to undulate as the camera is pushed along, indicating

> that there is a liquid beneath the material. At 61.8 feet the camera is pulled back slightly, and the debris piled up in front of the camera appears to be sludgy. At 62.8 feet the sludge pile begins to get on the camera lens. At 63.3 feet the lens is obscured by the material."

As noted above, the Weasel camera was withdrawn from line 840 on February 23, 1993. This camera was surveyed for radiation by a PFP Health Physics Technician (HPT) and found to be highly contaminated. A radiation survey report was completed by the HPT and is included in Appendix A of WHC-SD-NR-ER-103.

The survey was discontinued shortly after the second attempt to obtain video information beyond 63 ft in line 840 failed. The camera cable and fiberglass rods were left in the piping.

5.3.2.2 Summary. Video information was obtained in abandoned drain line 840D for a distance of 347.9 ft. This is approximately half of the total pipe length. The Weasel camera could not be deployed beyond that distance due to the friction load on the camera cable and fiberglass push rods. Photographs of the inside of line 840D are contained in Appendix B of the report.

Video information was obtained in abandoned drain line 840 for a distance of 63.3 ft. At that location a thick sludge-like material stopped the advancement of the camera. This material coated and obscured the lenses of two successive cameras. Photographs of the inside of line 840 are contained in Appendix B of WHC-SD-NR-ER-103.

The examination of abandoned carbon tetrachloride lines 840 and 840D was discontinued for ALARA and personnel safety reasons due to the high levels of contamination encountered in line 840. Cameras and cabling, along with the fiberglass pushrods, were subsequently left in the pipes.

No pipe breaks or major cracks were detected in either line 840 or 840D. However, both lines exhibited areas of severe pitting and corrosion throughout the lengths examined. Line 840 appears to be in the more deteriorated condition of the two pipes. Numerous pits are evident with apparent significant depth, however, it cannot be determined if any of the pitting is through-wall.

Based on the two pipeline characterization studies done at Hanford (Section 5.3.1), the value of 1,900 gal is concluded to be a highly conservative estimate of waste residuals in pipelines. The results of these studies also support a conclusion that waste transfer lines that have been out of service for a long time have deteriorated significantly, and if they have not completely lost their integrity are in such a poor condition that the ability to obtain representative characterization data is highly unlikely. In-pipe characterization can be assumed to be difficult due to the friction forces of a corroded and pitted pipe surface which will limit the distance pipes can be penetrated with equipment. This problem will be further exacerbated due to any residual waste being pushed and building up ahead of the in-pipe technology as was experienced in the Z8 investigation.

Removal and exterior characterization can be assumed to be challenging due to the reduced structural integrity from corrosion both inside and outside of the pipeline and in-pipe pitting and blistering which was observed in both pipeline studies. Removal and handling of an unstable pipe that could be subject to breaking would create potential ALARA issues.

5.3.3 200-IS-1 Sampling and Analysis Plan for Pipelines at UPR 200-E-86

RPP-PLAN-31715 describes the Phase 1 sampling and analysis plan (SAP) for 200-IS-1 Operable Unit tank farm pipelines. This SAP was developed to support the characterization of a select number of SST pipelines near WMA C, but outside of the tank farm fence line (at or near UPR 200-E-86), that are part of the 200-IS-1 Operable Unit. A two-phase approach is described in the SAP. Phase 1 is a very high-level screening evaluation and does not represent a statistically representative sampling protocol. The primary objective of Phase 1 sampling is to determine whether or not contamination in a pipeline and in surrounding soil is above preliminary cleanup levels.

Pipelines were selected based on the following:

- Pipelines that have experienced failure
- Represent both direct buried and encased pipelines
- Are constructed of variable materials
- Transferred waste known to have high levels of contamination
- Are representative of a group of pipelines.

Sampling locations were selected based on the following:

- Low point in the line
- End of a long pipe run
- Point where releases have occurred
- Transition point (bend or elbow)
- Mismatched pipe construction materials.

Five pipelines are identified that met these criteria and five candidate sample locations are identified. The SAP describes that up to 10 ft of pipe may be removed for analysis. In addition there would be two direct pushes, one on each side of the pipeline made so that soil grab samples at different depths could be taken. The following is a brief summary of the scope of this characterization effort.

Prior to implementing intrusive activities, surface geophysical and radiation surveys would be conducted at all sample locations. The surface geophysical surveys will be conducted using ground-penetrating radar and/or electromagnetic induction and will aid in verifying buried pipeline locations, other buried utilities, and subsurface anomalies. Surface radiation surveys will identify areas of surface contamination that might impact the intrusive activities and health and safety requirements.

The SAP recognizes that pipeline sampling poses significant difficulties and risks of exposure to the workers. Therefore, the approach for pipeline sampling and analysis is somewhat different from soil sampling. At the first sample location for each pipeline, the SAP states that a section of pipe will be removed and sent to the laboratory for analysis of residue. Total length of the section of pipe removed is limited to 10 ft or less, based on a desire to limit excavation and for ALARA concerns. Actual length of piping removed will be based on field survey results. The pipe section may be cut into smaller sub-sections for ease of shipping and handling.

At the other sample locations for a pipeline, either field-deployed measurements or laboratory non-destructive assay (NDA) of a short section of pipe will be used to obtain limited data. These data may be used directly to confirm whether or not contamination in the pipeline exceeds cleanup levels. For example, if gamma energy data obtained with a field instrument or NDA indicates ^{137}Cs exceeds its cleanup level, then no further evaluation is necessary.

After completion of sampling, the SAP states that the pipeline and the surrounding soil will be placed in a state that is protective of the worker and environment. Activities to achieve the end state will depend on sample location and sampling methods used. The estimated cost of the field work and laboratory analysis as developed is presented in Table 5-4. The schedule to conduct this work, which would be conducted well outside of tank farm boundaries and other surface and subsurface interferences, is estimated to be 18 months for the 5 sample locations.

Table 5-4. Pipeline Characterization Cost Estimate for 200-IS-1

Activity	Cost Estimate
	5 Site/10 Soil Samples
Work Plan and Pre-Project Planning	$210,000
Field Investigation for Tank Farm Pipelines and Soil	$852,000
Management of Investigation Derived Waste	$383,000
Laboratory Analysis	$1.2M
Project Total w/20% contingency	**$3.1M**

5.4 ESTIMATED COST AND SCHEDULE FOR CHARACTERIZATION OF WASTE MANAGEMENT AREA C PIPELINES

The information in Table 5-4 may be used as a basis to estimate the cost of representative sampling within WMA C. Within WMA C there are ~230 pipelines. If a 10% sampling of WMA C pipelines were considered representative, then at a minimum characterization would include 23 pipe segments if based on number of pipes or 420 ft if sampling was based on length. To collect representative data on both the pipeline and any residual waste and soil would require sampling several segments or points along the pipelines, which will require multiple excavations. The average length of pipelines in WMA C is ~200 ft. Segments or sampling points to be considered representative of the single line at a minimum should be 10% of the total length – an average of 20 ft or a minimum of two 10-ft segments at randomly selected locations per pipeline.

In addition, it is estimated that 10 soil samples at various depths would be collected at each sample location. Twenty-three pipelines characterized at 2 locations including pipeline, residual waste and soil characterization would require excavating at ~40 sites within WMA C at an estimated cost of $24 to 26M. Using the information developed in the 200-IS-1 SAP (RPP-PLAN-31715), this sampling design would take at least 48 months to complete following retrieval of the tanks. Completion of tank retrieval is a prerequisite to pipeline characterization at WMA C because of space limitation and interferences with retrieval equipment.

If non-removal characterization activities were to be conducted, the cost would be on the same order of magnitude as removal Work Plan and Pre-Project Planning and Field Investigation activities identified in Table 5-4. Screening activities (non-pipeline removal) would cost on the order of $10M and could take between 36 and 48 months following tank retrieval operations.

Costs and schedules for sampling within the tank farm fence line are expected to be higher per sample than the 200-IS-1 sample costs outside of the farm; however, for conservatism this added unit cost has not been calculated.

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6.0 PIPELINE CLOSURE TECHNOLOGIES

This section presents a description and an evaluation of potential pipeline closure technologies. Each technology is described and an initial screening of viable technologies is performed based on implementability. Recommendations for making closure decisions for the technologies that pass the preliminary screening are presented in Section 7.0.

The evaluation of pipeline closure technologies assumes that WMA C will close as a landfill. Landfill closure will include construction of a surface cap/barrier that will reduce risks to human health and the environment from all remaining contaminated structures, including pipelines, within WMA C. As a cap technology would be a common element to closure of WMA C, it is not separately evaluated in this section. However, the presence of a cap would ultimately be a major factor in determining the need for additional pipeline-specific closure activities.

6.1 CLOSURE TECHNOLOGIES FOR PIPELINES

The following four classes of technologies for closing pipelines are identified.

- **Removal**. This category of technologies includes the physical excavation of the pipelines or potentially segments of pipelines that are considered hot spots that have an unacceptable risk. Implementation of removal technologies would require subsequent stabilization of the removed pipeline, as needed, backfilling of the excavation and disposal at the Environmental Restoration Disposal Facility (ERDF).

- **Grout filling inside of the pipeline**. This technology involves the placement of any variety of materials such as grout, polymers, or scale coatings inside of the pipeline.

- **In situ encapsulation (encased pipelines only).** This technology includes placement of grout into the pipeline encasement with the objective of filling the void space inside of the encasement and encapsulating the pipe and the residual waste inside of the pipe. A variation of this technology would be to encapsulate the entire trench or pipeline through vitrification of the soil surrounding the trench.

- **Pipeline residual extraction.** This category of technologies includes flushing and hydraulically activated pipeline pigging. It involves the introduction of various media which would push the residual waste through the pipe by purging the pipeline of the waste. The mobilization of the residual waste could be accomplished with water, acids or abrasive materials.

6.2 REMOVAL TECHNOLOGIES

Excavation of pipelines traditionally is accomplished with conventional earthmoving equipment, such as backhoes and front-end loaders. However, because of the physical constraints and highly radioactive environment associated with WMA C and tank farms in general, these standard technologies may not be implementable.

The following factors affect the implementability of removal technologies at WMA C.

a. Dome loading requirements. Certain excavation techniques would not be possible to implement until after the SSTs were grout-filled due to dome load limitations on tanks. Dome loading requirements for SSTs and DSTs are identified in OSD-T-151-00007, “Operating Specifications for the Double-Shell Storage Tanks;” OSD-T-151-00013, Operating Specifications for Single-Shell Storage Tanks;” TFC-ENG-FACSUP-C-10, Control of Dome Loading;” and TFC-OPS-OPER-C-10, “Vehicle and Dome Load Control in Tank Farm Facilities.” Per the dome loading requirements, concentrated loads are managed (with discrete limits and requirements on concentrated load limits and vehicular access controls) to maintain the structural integrity of the domes of the DSTs and SSTs. Dome loading requirements at WMA C are assumed to be lifted after the void space in tanks and other below-grade ancillary equipment is grouted (stabilized). This is assumed to occur by fiscal year (FY) 2015, and would be a prerequisite to soil removal associated with pipeline removal.

b. Depth of excavation and shoring requirements. Costs increase with depth, in large part because of the need for adequate benching, laybacks, and shoring. Cost also increases with depth due to the potential for increased radiological exposures from exposed SST surfaces. Excavation below 7 ft in WMA C would require non-standard methods that depend on the location of the removal and the proximity to other structures, especially the SSTs.

c. Presence of subsurface infrastructure, including tanks, vaults, diversion boxes, valve pits, and piping. Major pipeline excavation would only be practical if all tanks and other ancillary equipment were also being removed.

d. Physical characteristics of soil, other infrastructure, and debris.

e. Direct radiation exposure to workers. Excavation of highly radioactive soils can pose significant worker exposure and contamination control issues, both of which increase with depth and size of excavation.

f. Production of fugitive dust and airborne contamination exposures to workers and the public. Soil removal will require the use of administration and engineering controls to reduce risks due to fugitive dust emissions, worker exposures and waste streams. Airborne contamination can be controlled by technologies including confinement through construction of enclosures around the excavation (high cost option), ventilation and vacuum systems (moderate cost option), and application of foams, sprays, misters, fixatives or washes (low cost option).

g. Generation and control of secondary wastes. Removal of pipelines has the potential for releasing additional fluids to WMA C that remains trapped in pipelines. Fluid handling would need to be carefully controlled. Pipelines, residuals and associated contaminated soil would require treatment as needed, packaging, and disposal at ERDF.

h. Fill material. Following excavation there would be additional costs associated with the excavation, hauling and placement of suitable fill material to backfill the excavated site.

Several types of excavation equipment that may be effective and implementable for pipeline removal are discussed below.

6.2.1 Conventional Excavation Equipment

Conventional excavation equipment includes crawler-mounted or tire-mounted excavators, backhoes and front-end loaders, bulldozers, cranes with clamshells and others. Conventional excavation equipment, dependent on the type, could be used to expose and remove pipelines contaminated at relatively lower radiation levels, laying back excavation side slopes in preparation for removal, material handling, clearing surface debris, and general earth moving. Conventional excavation equipment could also be modified, as needed, with end-effectors (i.e., breakers, grapplers, concrete cruncher and hydraulic shear attachments) to remove direct buried and/or concrete encased process pipelines and to reduce the size of retrieved materials prior to disposal. Conventional excavation equipment can be fitted with lead exterior shielding and leaded or Lexan film glass to reduce direct radiation exposures to the operators below allowable levels. Airborne exposures can be minimized using sealed operator cabins and inlet air filtration.

Conventional excavation equipment is considered implementable and is retained for further consideration for WMA C pipeline removal.

6.2.2 Vacuum Systems

Hanford facility operations have used a vacuum system called the Guzzler™[3] in the past to safely remove soil near infrastructure where operating large excavation equipment is not practical or extremely difficult. The Hanford Site has two Guzzler™ vacuum units for excavations. One unit is used only in areas with no potential for radioactive contamination (“non-regulated” Guzzler™) and the other is a radiologically controlled unit (“regulated” Guzzler™) that can be used in areas where there is a potential for radioactive contamination (RPP-13303, *Tank Farms Documented Safety Analysis*). The “regulated” Guzzler™ vacuum truck would be the only unit acceptable to deploy into WMA C for removal of overburden soil to access pipelines. The following is a brief description of the “regulated Guzzler™.

The Guzzler™ is a truck-mounted, industrial vacuum system that is operated pursuant to the Categorical Notice of Construction (NOC) document (Letter 98-EAP-037, “Short Form Radioactive Air Emissions Notice of Construction (NOC) for Guzzler Excavation and Backfilling Activities in Support of the 200 East Area A Farm Complex”). The Guzzler™ consists of a diesel power source, self-contained positive displacement type vacuum pump, hydraulic and pneumatic control systems, multiple air filtration systems, and a dump-type hydraulically sealed payload collection tank. Soils are penetrated, expanded and broken up using either a high pressure air or water stream. The broken soils enter the Guzzler™ unit through an adjustable length, flexible hose. For maximum output, the system is designed to utilize an

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[3] Guzzler is a registered trademark of GUZZLER Manufacturing, Inc., Streator, Illinois.

8-in. diameter hose. Hose sizes smaller than that will cause additional friction losses and a higher percentage of power will be used up in overcoming these inefficiencies. The hose is connected to an 8-in. inlet port at the rear of the machine or through a boom located on the top rear center of the tank. The boom provides the operator with greater ease and efficiency of operation. The boom moves horizontally and up or down, and can be hydraulically extended or retracted in some configurations. The "regulated" Guzzler™ on the Hanford Site is equipped with a boom with an operating range of 330 degrees with 20 ft of vertical play. The boom is operated by switches located on the pendant control, which is attached to the Guzzler™ unit or by wireless remote, if equipped. The maximum distance the radio control can effectively operate from the truck depends a lot on the operating environment. The optimum distance would be ~500 ft under ideal conditions.

Vacuum systems such as the Guzzler™ unit generally excavate less than conventional excavation equipment in the same time period. Based on information provided in RPP-13442, *Offsite Radiological Consequence Analysis for the Bounding Unplanned Excavation/Drilling of 200 Area Soils*, the maximum excavation capability of the "regulated" Guzzler™ unit is ~16 yd^3 (i.e., the capacity of the collection tank) over an estimated 4 hour fill period. As stated in RPP-13442, "*Average duration of fill cycle is established for peak operating efficiencies under optimal conditions and is based on teleconferences with Hanford Site equipment operation and maintenance personnel*." The production rate of the Guzzler™ is limited by the shallow excavation depth (i.e., inches per sweep); however, the shallow excavation depth is ideal when excavating near surface (<8 ft) pipelines and other buried utilities.

Use of the Guzzler™ would require unshielded workers at the dig face. Two operators would be required to handle the hose, as recommended by the manufacturer, and one to operate the air or water wand to break up the soil. As the depth of the excavation increases, so does the difficulty in breaking up the soil and maneuvering the hose; therefore, a crane or other piece of equipment may be required to complete the excavation.

Vacuum systems are considered implementable to remove soil in and around relatively shallow pipelines (e.g., approximately to 8 ft) and are retained for further evaluation under those limitations.

6.2.3 Remotely-Operated Excavation Equipment

Remotely-operated equipment can be used to reduce or eliminate exposure of the equipment operator to high radiation fields during soil removal by allowing the operator to be located at a safe distance from the excavation. Through readily available commercial products and existing design methodologies, conventional excavation equipment can be converted for teleoperated use.[4] Teleoperated equipment can be used in the same manner as the original piece of equipment. Remote excavators have been and are currently used on the Hanford Site.

The conversion of conventional excavation equipment to be teleoperated involves a range of modifications including hydraulic conversion, wireless data transmission, software design, safety

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[4] The term teleoperation simply means "doing work at a distance."

considerations and electronics. Any conventional excavation equipment converted for teleoperated use at WMA C would meet, at the minimum, the following requirements:

a. Operation capability at a line-of-sight range of 1,500 ft;

b. Control modifications that are as similar as possible to conventional operation;

c. Controls would be augmented with a visual and auditory feedback system;

d. Equipment would need to be reliable and resistant to all weather elements;

e. Equipment would need to be easy to service; and

f. Conversion back to a conventional operation configuration should take no longer than thirty minutes.

Remotely-operated equipment is commercially available, although limited, and implementable. Remotely-operated excavation equipment requires specially-trained operators and generally can be expected to excavate less than conventional excavation equipment over the same time period. To achieve the same volume of excavated material will take longer with remotely operated equipment. Operators require less or no contamination controls because they are not in the exposure zone. Removal by remotely-operated excavation equipment will be retained for further evaluation.

6.2.4 Excavation Support Technologies

The Occupation Safety and Health Administration (OSHA) requires that any excavation not made entirely in stable rock or that is greater than 5 ft in depth be provided with an adequate excavation support (protective) system to protect workers from cave-ins. Protective systems for use in excavations 20 ft or less in depth are required to be designed and constructed in accordance with the requirements set forth in Title 29, *Code of Federal Regulations* (CFR), Part 1926, “Safety and Health Regulations for Construction,” Subpart P, “Excavations,” 1926.652 – Requirements for protective systems. Protective systems for use in excavations more than 20 ft in depth must be designed by a registered professional engineer in accordance with 29 CFR 1926.652 (b) and (c).

There are a number of conditions that must be taken into account before a protective system is selected. Conditions that must be evaluated include:

a. Depth of excavation required;

b. Length of time the excavation will be open;

c. Presence of subsurface and aboveground infrastructure, including tanks, vaults, diversion boxes, valve pits, pipe encasements, piping, drywells, power lines and trees;

d. Physical characteristics of soil;

e. Surcharge loading including spoil pile, material storage, and equipment size;

f. Construction accessibility; and

g. Worker safety.

Several types of excavation support technologies that may be effective and implementable at the WMA C are discussed below.

6.2.4.1 Sloping and Benching. Sloping (open cut) is a method of cutting back the excavation walls at such an angle that there is little chance of collapse. This is referred to as an "angle of repose," and must be suitable to the type of soil. Benching is a process of stepping off the earthen walls of an excavation. Sloping can be used as a system by itself or in conjunction with benching.

When excavation depths exceed 20 ft (i.e., for cascade lines), sloping and/or benching systems must be designed by a registered professional engineer in accordance with 1926.652 (b) and (c). Engineered excavations are based on soil mechanics and not on OSHA soil type determinations. An engineered design generally results in more slope options and more favorable slopes with less excavation required than those allowed in the OSHA Appendix A design.

If there is sufficient space available, sloping and benching can be used in almost any soil condition. Sloping requires minimal design efforts (i.e., design of the cut bank slope) and provides for continuous excavation, laying and backfill operations and easy access to the work, due to minimized equipment and construction materials. However, sloping requires more excavation and backfill volume, which consequently may force the use of larger equipment, and a larger work area.

Sloping and benching require large areas to accommodate layback of excavated soil and equipment bench and therefore are not implementable within WMA C. Closure of pipelines at WMA C will address pipelines that transect the WMA boundary and sloping and benching are considered implementable for pipeline removal in these isolated areas outside the fence line of WMA C and will be retained for further evaluation under that application.

6.2.4.2 Shoring. Shoring, such as through use of a soldier pile (H-pile) and lagging technology, is part of a family of fixed shoring systems to support excavations. There are two basic configurations for pile type shoring: cantilever or braced. The cantilever method relies entirely on the passive resistance of the soil below the excavation line to support the excavation loads, whereas, the braced system uses internal bracing and the embedded pile to share the support of the excavation loads. The cantilever method is the simplest from a construction standpoint; however, requires pile penetration below the excavation at least equal to the height of the excavation. The braced system is a more efficient structural support system than a cantilever system. There is no limit on the depth of excavation for a braced system because walers and struts can be added as needed; however they may interfere with other construction operations. Within the two basic configurations there are a number of variations including a cantilever system with the use of tie-backs, which would provide lateral restraint and replace the need for walers and struts.

Soldier piles can be installed in almost any ground condition. The soldier piles can be spaced at odd intervals to avoid utilities or obstructions both overhead and underground. There are different methods for installing the soldier piles. One method is to push the pile using an excavator. The soil must be fairly soft and often requires a dig and push operation. The advantages are that no special equipment is necessary and the noise level is no greater than the excavator exhaust. The disadvantages are that it is difficult to control the pile alignment especially if there are cobbles present. Another method is to drill a borehole and place the H-pile within. This adds additional equipment and the operation is fairly slow. Another method is to drive the pile using impact or vibrating hammers. Impact (i.e., air or steam driven) hammers are very noisy and can easily damage the pile if cobbles or obstructions are encountered. Vibro hammers are very efficient at installing piles and are usually much quicker and do less damage than impact hammers.

The soldier pile lagging can be timber, steel plates or concrete panels. Steel plate lagging is less labor intensive than timber and concrete lagging and can be reused any number of times; therefore, steel lagging will be the preferred lagging. However, if soil conditions permit, sheeting may also be installed between the H-piles.

Shoring provides for a near vertical excavation wall thus minimizing the amount of excavation, backfill and work area. Soldier piles can be installed in almost any ground condition, can be spaced at odd intervals to avoid utilities or obstructions, and require no special equipment to install.

For the reasons stated above, shoring is considered implementable and will be retained for further evaluation.

6.2.4.3 Reinforced Concrete Drilled Shafts. Drilled shafts are reinforced concrete columns poured in holes drilled into soil and rock. Drilled shafts are constructed using drilling (excavating) equipment capable of auguring or coring 30-in. to 120-in. diameter excavations into soil and rock. Drilled shafts are drilled with various tools including dirt augers, rock augers, core barrels, rock buckets, and clean out buckets. The types of materials being drilled drive the choice of tools to use. After the excavation is completed, a reinforcing cage is placed in the excavation and the excavation is filled with high slump concrete. Drilled shafts are excavated using either cased or uncased methods. If the excavation will stay “open” without caving, then generally no casing is required. However, if soils are prone to caving, casings are used to support the sides of the excavation. The casing may be either permanent or temporary casing. Temporary casings are heavy-walled pipes that are usually driven, screwed or vibrated into the earth. Drilling may occur either before or after the casing is in place. A bentonite or polymer slurry may also be used to keep the excavation open or to assist in the advancement of a temporary casing.

Drilled shafts will not be retained for further consideration due to the large volume of concrete required and the additional personnel and facilities that may be required to construct rebar cages, which would increase the number of unshielded personnel near the dig face.

6.2.4.4 Injected Grout Curtain Walls. Grout curtains are narrow, vertical grout walls installed in the ground. They are constructed by drilling holes to the desired depth and injecting grout by the use of special equipment. In curtain grouting, a line of holes are drilled in single or doubled staggered rows and grouting is then accomplished. The spacing of injection holes is site specific and is determined by the penetration radius of the grout out from the holes. Ideally, the spacing is selected so that each "pillar" of grout intersects the next, thus forming a continuous wall or curtain. Typical grouting materials include hydraulic cements, clays, bentonite and silicates. The grout type is determined by conditions of soil permeability, soil grain size, chemistry of environment being grouted and rate of groundwater flow. Grout curtains are generally used at shallow depths (30 to 40 ft maximum depth) and are relatively expensive when compared to other shoring methods.

Injected grout curtain walls will not be retained for further evaluation due to the specialized equipment required to inject the grout and the potential for leaching of grout mix water, which could result in the uncontrolled migration of contaminants in the subsurface.

6.2.4.5 Slurry Walls. Slurry walls involve the excavation of a vertical trench using bentonite-water slurry to hydraulically shore up the trench during construction and seal the pores in the trench walls via formation of a "filter cake." Typical slurry wall construction involves soil-bentonite (SB) or cement-bentonite (CB) mixtures. Slurry walls are generally 20 to 80 ft deep with widths of 2 to 3 ft. The construction of slurry walls requires a variety of conventional construction equipment for excavation, earth moving, mixing and pumping. Depending on the depth of the trench, excavation equipment may include extended reach excavators, clamshells or draglines. For depths less than 70 ft, excavators are generally the most efficient. Dozers or graders are used for mixing and placement of backfill. Preparation of slurries requires batch mixers, hydration ponds, pumps and hoses. An adequate supply of water and storage tanks is needed as well as electricity for the operation of the mixers, pump and lighting. Slurry wall construction requires a great deal of open space to provide room for equipment, slurry hydration ponds, and slurry mixing areas.

Due to the large space and extensive equipment requirements needed and the potential for leaching of the bentonite mixture, which could result in the uncontrolled migration of contaminants in the subsurface, slurry walls will not be retained for further consideration.

6.3 ACTIVITIES AND COSTS ASSOCIATED WITH PIPELINE REMOVAL

In order to gain an understanding of the resources and time that would be required to remove pipeline segments in WMA C, two examples have been developed that describe the activities and costs associated with pipeline removal (encased and direct buried) using assumptions for soil excavation and pipeline removal. The examples are for the hot spot removal of plugged pipelines. This waste configuration represents the most probable risk associated with residual waste pipeline inventory that would be removed to support barrier construction, improve barrier performance and reduce risk.

Example A: Encased Pipeline Segment Excavation and Removal

This example illustrates the challenges and costs associated with removing pipeline segments from a pipeline encasement in the interior of WMA C prior to placement of the engineered surface barrier. Perhaps the worst scenario would involve the lines that exist in the encasements from 241-CR-152 diversion box and 241-CR-153 diversion box. Each encasement contains 14 pipelines. These lines are generally 3 in. in diameter and were constructed when the 244-CR Vault was installed. These lines were subject to routine flushing. The encasement was constructed in an excavated trench with ~7 ft of backfill over it. For purposes of this example it is assumed that all lines within a 25 ft segment would be removed to ensure the plugged portion is acquired.

Example B: Direct Buried Pipeline Segment Excavation and Removal

This example illustrates the challenges and costs associated with removing a direct buried pipeline segment from the interior of WMA C prior to placement of the engineered surface barrier. Historic information indicates that within WMA C direct buried cascade lines have plugged. These lines exist between the 100-series tanks in the farm and allow waste to gravity flow from one tank to the next in the cascade series. These lines are 3 in. in diameter and were part of the original tank farm construction. While these lines have clean-outs they were not routinely flushed since transfers occurred as overflows from one tank to the next. Each line was constructed on a concrete pedestal which supported the line during the farm construction and was left in-place when the farm was backfilled. These lines exist at the top of the steel tank liner, are ~25 ft long and are at a depth of ~15 ft below ground surface. For purposes of this example it is assumed that the entire 25 ft of cascade line would be removed to ensure the plugged portion is acquired.

6.3.1 Enabling Assumptions

Assumptions that apply to each of the examples include:

- The work and operations are performed in accordance with the WMA C closure requirements. In developing the scope of the activities represented by the two examples a range of functional areas and personnel categories were considered including management, labor, supervision, technical, safety, and professional services, materials, tools, equipment, and consumables necessary to perform pipeline closure activities at the Hanford Site.

- Plugged lines are assumed to contain extremely high concentrations of residual waste and will require a containment structure and the use of remotely controlled equipment.

- Excavation to the pipeline can employ a variety of technologies recognizing that deeper excavations in and around the tanks will have a greater number of interferences to contend with than the shallower excavations. For these examples, use of the Guzzler™ will be assumed for all excavations.

- To avoid the time and cost of characterizing excavated soil to determine if it has been contaminated, all excavated soil will be assumed to be contaminated and handled and disposed of accordingly.

- The concrete encasements containing the steel transfer lines are nominally 8 in.-thick reinforced concrete with reinforced concrete cover blocks. Encased pipelines will be more complicated to remove because of the risks of higher exposures created by multiple pipelines in an encased structure with no shielding, and because of the potential for encountering a contaminated environment inside of the encasement. Furthermore, the encased lines traverse through those portions of the farm with the largest SSTs. Because of the potential that pipeline excavations could expose the tank dome tops, further safety and construction considerations will be required.

- Direct buried pipelines will likely have more subsurface interferences during excavation and removal because they generally are deeper buried than encased lines. The potential for exposing portions of tanks during direct buried pipeline excavations will also need to be addressed.

6.3.2 Enclosure Facility Concepts

Work would be performed in a contaminated and hazardous waste environment. For purposes of both examples it is assumed that the concentration and volume of residual waste in the pipelines and the potential for encountering contaminated soil would be such that control of the potential airborne radiological emissions will require a structural enclosure that will support control of the airspace surrounding the excavation and removal activities. Airspace control relies on negative air pressure zones necessary to capture and filter airborne contaminants to the extent necessary to meet regulatory requirements.

Tension membrane or fabric-covered structures may be necessary. These structures are aligned with the need for a temporary structure and are engineered to meet snow and wind loading requirements, would require a ventilation system with HEPA filtration and dust removal equipment necessary to remove contaminants in the air stream, and would need to be anchored to the ground.

6.3.3 Removal Approach

The following summarizes the approach and explains the process for removal of highly contaminated pipeline segments. All supporting infrastructure such as utilities, staging areas, and support trailers is assumed to already be in place to support barrier placement and are not included as separate actions unique to pipeline segment removal. On-going operations and support would involve a range of activities including fire protection, emergency response, sampling and analysis, records retention, reports and permitting, periodic operational QA audit, road egress, dust suppression, and road up-keep.

6.3.3.1 Mobilization/Infrastructure. Infrastructure to support piping removal activities would be in place from tank closure activities and it would be maintained over the duration of pipeline segment removal. Personnel would undergo training for the following: initial start-up training, on-going refresher training, and periodic special training. Special operation equipment would be deployed which would include long reach surveillance tools, and remote excavation equipment (remote handling excavators for high radiation work and remote operated Guzzler™ vacuum excavators).

6.3.3.2 Special Processing Area/Facility for Classifying and Packaging Waste. This project would require a special on-site handling area and facility for classifying and packaging removed pipeline segments. The facility would include waste identification and evaluation instrumentation, grouting equipment for encapsulating high-level radiation waste and to meet RCRA land disposal restriction requirements, container overpack area, and a pre-transport preparation area for shipment to ERDF.

Fixative spray application equipment would be required to mitigate the potential for the release of any airborne waste from the handling of potentially contaminated soil and contaminated pipeline segments. This equipment would include spray trailers equipped with 2,000-gal tanks, pressure pump, spraying hose, personnel protective cage with spray shield, and trailer anchor braces to secure equipment during operations. Special waste containers would be designed for housing highly contaminated sections of pipe and highly contaminated soils.

6.3.3.3 Other Special Support Facilities. An excavation containment facility would be engineered and designed as a temporary structure (estimated to be 75 ft × 75 ft for shallow pipeline segment removal section and 75 ft × 100 ft for the deep pipeline segment removal). Structures would be supported by a reinforced concrete footing on-grade. This facility would house a portable exhauster with HEPA filtration.

6.3.3.4 Pipeline Segment Removal. The general activities associated with these examples include an administrative assessment of work items to be performed, removal of pipeline segments, placement in an ERDF container, staging of the container, transport to ERDF, and disposal in ERDF. The assumption is that a 25-ft section of transfer line will be removed/packaged, grouted, overpacked and transported to ERDF for disposal. Pipeline segment removal would be accomplished using remotely operated equipment which would require increasing the excavation access ramp to 12% and limiting the layback to 1:1.

Pipeline segment removal for Example A and Example B is described below.

Example A: Shallow Pipeline Segment Removal from Encasement

For shallow pipe removal, activities would include vacuum excavation of overburden down to expose a section of the encasement trench ~10 ft wide by 40 ft long. Excavated material would be 240 yd^3 (320 tons). Once the excavation has exposed the cover blocks, they would be removed and set aside. Because it would be difficult to isolate a single line as the plugged line and because of space limitations in the encasement, all lines would be sheared and removed in the segment. Pipeline segments would be sheared into lengths appropriate for placement in the disposal box. Boxes would be surveyed, grouted, and overpacked at the site prior to transport to ERDF.

The shearing process is intended to crimp the pipeline so that there would be no release once the pipeline is severed. There would be a requirement to place a secondary containment structure beneath the pipelines to capture any releases from the severed pipelines in the event one were to occur.

Once the pipe segments have been removed and boxed the open excavation would be grouted to cover the encasement. This would provide an additional seal of the crimped pipelines that remain in the encasement. The concrete cover blocks would be placed back into the excavation and the remaining open area backfilled with clean fill and compact.

Example B: Deep Direct Buried Pipeline Segment Removal

For deep direct buried pipe removal, activities would include vacuum excavation down to a depth of ~25 ft bgs to remove the 25 ft section of cascade line between two SSTs. Excavated material would be 2,500 yd^3 (3,375 tons). It is assumed that the pipe would be filled with waste and that one section of pipe goes into each of four boxes. Boxes would be surveyed, grouted, and overpacked at the site prior to transport to ERDF.

The shearing process is intended to crimp the pipeline so that there would be no release once the pipeline is severed. Prior to cutting the pipe there would be an assessment of the integrity of the direct buried cascade line and there would be a requirement to place a secondary containment structure beneath the pipelines to capture any releases from the severed pipeline in the event one were to occur. Placement of this containment structure would be either between the pipe and the concrete pedestal or constructed around the pedestal. If there were integrity concerns a secondary containment system may be required as part of the support system to remove the cascade line.

Once the pipe segments have been removed and boxed, the open excavation would be grouted to seal the sheared ends of the removed pipe that penetrate the SSTs. The remaining open area would be backfilled with clean fill and compacted.

6.3.3.5 Demobilization/Infrastructure. It is assumed that demobilization of the support infrastructure is covered by general tank farm closure. Project-specific actions would be to remove temporary structures, decontaminate any equipment, and conduct project close-out activities including close-out reporting, closure meetings and briefings, close-out procurements, and finalizing financial processing.

6.3.4 Cost Estimates for Pipeline Segment Removal

Estimate Methodology

A rough order of magnitude (ROM) estimate has been developed for pipeline segment removal for both the encased pipeline and the cascade pipeline examples. The following estimates provide an estimate of costs for all necessary plant, labor, supervision, technical and professional services, materials, tools, equipment, and consumables expected to be necessary to perform the scope of work described in each of these examples in the previous section.

Costs used in the estimates were developed from Means estimating manuals[5], vendor's quotes (Rubb Building Systems[6]) and discussions, previous tank farm estimates, previous URS Corporation ROM estimate for a tank farm enclosure, survey tent estimate, Project Team discussions, and estimator's experience.

Subcontractor craft labor and subcontractor labor rates were taken from current FY2010 Hanford Site Labor rates (Hanford Site Stabilization Agreement/Building Trades Agreement). Base wage rates and fringes for manual craft are published rates from the Hanford Stabilization agreement, Appendix A. Rates include fringes, applicable taxes and insurance. Labor job hours are estimated by crews and against production rates. Subcontractor Non-Manual labor rates were taken from FY2010 historical rates used on awarded projects, based on estimator's experience, and as a percentage of the total construction and procurement costs.

Material and equipment pricing is based on Means estimating manuals, vendor quotes and discussions, current pricing information from other projects, and estimator's experience. Construction equipment costs were taken from July 7, 2010 Equipment Watch Blue Book, and assuming the equipment ownership was 80%/20% rental, and operating cost would be assessed at 100% unless expressed otherwise.

Additional cost multipliers include: Subcontractor overhead and profit multiplier (applied @ 15%); Washington State Business and Operating Tax (applied @ 0.471%); and Contractor Bond (applied @ 1.75% based on estimator's experience for contracts containing significant risk factors surrounding hazardous and contaminated waste decommissioning scope). Washington State sales tax was applied to Site non-support services labor, material, equipment, and subcontracts at 8.3%.

Table 6-1 presents a summary of the cost estimate for the removal of encased pipeline segments (Example A) and Table 6-2 presents a summary of the cost estimate for the removal of a cascade line (Example B).

6.4 GROUT FILLING INSIDE OF THE PIPELINE

There are several reasons that grouting the inside of pipelines may be deemed for closure, including:

- void space filling to prevent or minimize landfill cap subsidence
- eliminating preferential pathways
- stabilizing residual waste for risk reduction.

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[5] Refers to products of RSMeans, 63 Smiths Lane, P.O. Box 800, Kingston, Massachusetts and Reed Construction Data, 30 Technology Parkway South
Norcross, Georgia.

[6] Rubb, Inc. is the United States subsidiary of Rubb Building Systems, located at P.O. Box 711, Old Airport Road, Sanford Airport, Sanford, Maine.

Table 6-1. Example A: Cost Estimate for Encased Pipeline Segment Excavation and Removal

Description	Total Labor Hrs	Labor & Subcontract Dollars	Material Dollars	Equip Dollars	Total Dollars
Project Management/Engineering					
01 Project Management	**9,651**	**711,476**	**10,672**	**0**	**722,148**
02 Engineering, Design and Inspection	**308**	**196,823**	**0**	**0**	**196,823**
03 Project Support	**2,151**	**202,254**	**0**	**0**	**202,254**
04 Procurement	**0**	**0**	**0**	**0**	**133,751**
05 Procurement Support	**392**	**35,211**	**0**	**0**	**35,211**
06 Field Work (Plant Forces)	**576**	**1,025,823**	**800**	**100,800**	**1,127,423**
08 WRPS Construction Management	**8,756**	**719,778**	**10,797**	**0**	**730,575**
09 WRPS Construction Support	**7,282**	**457,289**	**0**	**0**	**457,289**
Total Project Support Cost	**29,116**	**3,482,405**	**22,269**	**100,800**	**3,605,473**
Field Construction					
Mobilization Scope	**2,844**	**242,458**	**17,770**	**24,055**	**284,283**
Construction Mgmt & Infrastructure Support Staff	**19,293**	**1,423,934**	**112,553**	**415,064**	**1,951,551**
Support Trailers OPS Rental, Cleaning, & Maintenance	**0**	**0**	**4,802**	**0**	**192,074**
Pit & Waste Handling Equipment	**18,558**	**0**	**0**	**550,978**	**550,978**
Pit & Waste Handling OPS Labor	**8,969**	**670,990**	**59,740**	**0**	**730,730**
Install & Remove Weather Enclosure	**0**	**0**	**0**	**0**	**1,047,938**
Install & Remove HEPA Filter Systems On Weather Enclosure	**0**	**0**	**0**	**0**	**2,736,979**
Waste Processing Facility	**0**	**0**	**0**	**0**	**150,000**
Waste Disposal SubK $	**0**	**0**	**0**	**0**	**22,511**
Remote Operated D&D Equipment	**0**	**0**	**0**	**0**	**791,999**
Apply Fixative to Inside of Concrete Piping Containment	**0**	**0**	**0**	**0**	**25,000**
Back-fill Soil After Tank/s Are Removed	**462**	**34,913**	**34,491**	**2,409**	**71,812**
Demobilization Scope 25% of Mobilization	**711**	**60,614**	**4,442**	**6,014**	**71,071**
Total Field Construction Cost	**50,836**	**7,394,609**	**233,797**	**998,520**	**8,626,926**
Total Project Cost	**79,952**	**10,877,013**	**256,066**	**1,099,320**	**12,232,399**
Contingency 50%		**5,438,507**	**128,033**	**549,660**	**6,116,200**
Escalation All Segment of Costs Priced Using FY2010 Rates and No Escalation Has Been Applied For Out Years.		**0**	**0**	**0**	**0**
Total Project		**$16,315,520**	**$384,099**	**$1,648,980**	**$18,348,599**

Table 6-2. Example B: Cost Estimate for Direct Buried Pipeline Segment Excavation and Removal

Description	Total Labor Hrs	Labor & Subcontract Dollars	Material Dollars	Equip Dollars	Total Dollars
Project Management/Engineering					
01 Project Management	15,076	1,111,451	16,672	0	1,128,123
02 Engineering, Design and Inspection	2,727	1,744,789	0	0	1,744,789
03 Project Support	2,272	279,655	0	0	279,655
04 Procurement	0	133,751	0	0	133,751
05 Procurement Support	568	35,211	0	0	35,211
06 Field Work (Plant Forces)	834	1,037,416	1,100	101,100	1,139,616
08 Construction Management	13,677	1,124,414	16,866	0	1,141,280
09 Construction Support	9,431	570,842	0	0	570,842
Total Project Support Cost	44,586	6,053,332	34,638	101,100	6,189,070
Field Construction					
Mobilization Scope	3,374	273,007	20,083	24,055	317,145
Construction Mgmt & Infrastructure Support Staff	30,780	2,310,256	160,660	415,064	2,893,232
Support Trailers OPS Rental, Cleaning, & Maintenance	0	292,750	7,506	0	300,256
Pit & Waste Handling Equipment	28,714	0	0	1,021,067	1,021,067
Pit & Waste Handling OPS Labor	17,000	1,224,203	162,241	0	1,386,444
Install & Remove Weather Enclosure	0	1,047,938	0	0	1,047,938
Install & Remove HEPA Filter Systems On Weather Enclosure	0	3,649,305	0	0	3,649,305
Waste Processing Facility	0	150,000	0	0	150,000
Waste Disposal SubK $	0	22,511	0	0	22,511
Remote Operated D&D Equipment	0	791,999	0	0	791,999
Apply Fixative to Inside of Concrete Piping Containment	0	25,000	0	0	25,000
Back-fill Soil After Tank/s Are Removed	1,119	121,076	87,425	6,341	214,842
Demobilization Scope 25% of Mobilization	844	68,252	5,021	6,014	79,286
Total Field Construction Cost	88,063	10,395,462	524,423	1,632,574	12,499,127
Total Project Cost	132,649	16,395,462	559,061	1,733,674	18,688,197
Contingency 50%		8,197,731	279,530	866,837	9,344,099
Escalation All Segment of Costs Priced Using FY2010 Rates and No Escalation Has Been Applied For Out Years.		0	0	0	0
Total Project		$24,593,194	$838,591	$2,600,512	$28,032,296

In 2004, two proof-of-principle large-scale tests were performed to simulate grout filling of Hanford SSTs and associated interconnecting cascade lines. The goal of the testing was to determine whether the tank grout can enter the cascade line and solidify prior to flowing into an adjacent tank, thereby stabilizing any residual waste in the cascade line. The first cascade line test proved that self-sealing of the line is achievable for a grout mix designed with an ASTM D-6103 flow of 13 in. which meets Hanford grout specification of 12 to 15 in. flow. However, this mix did not flow sufficiently to completely fill the cascade line; only 4.5 ft of the 16 ft line was filled (cascade lines in the farm are actually ~27 ft). The second test increased the water content to achieve a flow of a little over 14 inches. The flow ability of this mixture allowed the grout to easily flow the distance of the 16 ft of test line but did not plug the line to stabilize residual waste (WSRC-TR-2004-00626, *Cascade Line Testing for Hanford Single-Shell HLW Tank Closure*).

The results from a 2009 Hanford Site grout demonstration test using a different grout formulation were very similar to the 2004 Savannah River Site (SRS) test also showing grout flow restrictions in unvented pipelines (RPP-RPT-41550, *Closure Demonstration Grout Test Report*).

There are several factors that must be considered to safely grout fill abandoned pipeline. In some operations, the strength of the grout is usually of little importance, but stability and resistance to shrinkage are crucial because of the primary objective of providing 100% complete filling with no remaining void or trapped content. The air in the pipeline void space will tend to float to the highest areas as the grout displaces it or it is pushed forward in advance of the grout during injection and must be provided with a means of release. Furthermore, the pipelines will be pressurized, leading to the potential for grout, bleed water, and waste to be released to the ground due to questionable pipeline integrity. In addition, pressurization would require dealing with containment/control of the pipeline vent gases.

Grouting inside pipelines for miles within and outside of WMA C would require highly fluid grout formulations. Such grouts are on the edge of physical stability where slight variations in water content can result in higher permeability and increased bleed water. Many considerations are required in the development of grout formulas suitable for grouting extensive pipeline systems. Several competing factors must be balanced in the design of a low permeability, fluidity of the grout or concrete suitable for large ancillary systems and transfer piping. These requirements include: highly flowable material, no bleed water, low permeability, low-heat of hydration for mass pour application, low water/cement ratio, and set time that can be adjusted to minimize cold joints assuming daily pours (SRNL-STI-2009-00064, *Technology Needs and Status on Closure of DOE Radioactive Waste Tank Ancillary Systems – 9312*).

In the past several years, some test work for ancillary systems has been conducted (WSRC-TR-2004-00626; WSRC-STI-2008-00298, *Closure of HLW Tanks – Phase 2, Full Scale Cooling Coils Grout Fill Demonstrations*; WSRC-STI-2008-00172, *Closure of HLW Tanks – Formulation for a Cooling Coil Grout*). Even though progress has been made, several key grouting needs have been identified for future ancillary system closures by subject matter experts in cementitious materials (SRNL-STI-2009-00064). These grouting needs for ancillary systems include:

a. Grout design mixes to meet requirements and improve properties and durability,

b. Development and demonstration of tools for unique challenges (e.g., void spaces in ancillary systems in tanks),

c. Revised specification for ancillary system closure utilizing supplier experience, and

d. Testing grout methodologies for removed ancillary components.

Implementability challenges associated with grouting inside WMA C pipelines are summarized below:

a. The WMA C waste transfer pipelines are generally 3 in. in diameter. Void space filling of pipelines to limit subsidence does not become a consideration until pipelines have significantly larger diameters of 12 in. or greater. ("Pipeline Abandonment – A Discussion Paper on Technical and Environmental Issues" [Energy Resources Conservation Board 1996]) http://www.ercb.ca/docs/documents/reports/PLAbandDiscPaper_199611.htm#Technical). However, grouting pipeline encasements may be necessary due to the void space they create (200-series tank encasements are either 24 in. × 24 in. and 24 in. × 12 in. [H-2-41389, *Piping Plan Underground Process 200 Series Tanks*] and the 100-series tank pipeline encasements have a void space of ~14 in. × 10 in. [H-2-41590, *Piping – Underground Process Sections & Support Details Sheet#1*]) to prevent or minimize subsidence and to meet cap performance requirements (see Section 6.2.5.1).

b. The waste transfer pipelines have been designated as unfit for use (service) because of their questionable integrity. It is common for abandoned pipelines to accumulate dirt, debris and/or thick sludge. This material tends to build up ahead of the advancing grout front and can completely plug the line during injection (*Practical Handbook of Grouting: Soil, Rock, and Structures* [Warner 2004]). There is no practical way to determine if the pipelines were completely grouted, nor is there assurance of containment of the residual wastes. Finally, vent gases will need to be managed, and that will require extensive design and proof of principle testing.

c. Because the tanks, diversion boxes and pits in WMA C are expected to be grout filled, this will isolate the pipelines and eliminate preferential pathways. Again, it would be difficult to confirm grouting of the pipelines actually did eliminate them as preferential pathways.

For these reasons, grout filling inside pipelines is not considered technically implementable for WMA C pipelines and will not be retained for further consideration.

6.5 IN SITU ENCAPSULATION (ENCASED PIPELINES ONLY)

6.5.1 Grout Filling

Grouting pipeline encasements may be necessary due to the void space they create (200-series tank encasements are either 24 in. × 24 in. and 24 in. × 12 in. [H-2-41389] and the 100-series tank pipeline encasements have a void space of ~14 in. × 10 in. [H-2-41590]) to prevent or minimize subsidence and to meet cap performance requirements.

Therefore, in situ encapsulation of encased pipelines has been retained for further consideration.

6.5.2 In Situ Vitrification

In situ vitrification (ISV) uses electric power to create the heat needed to melt soil (http://www.cpeo.org/techtree/ttdescript/ssvit.htm). Electrodes are inserted in the contaminated area and an electric current is passed between them, melting the soil between them. In situ vitrification uses extremely high temperatures (1,600 to 2,000 °C or 2,900 to 3,650 °F). Melting starts near the ground surface and moves down. As the soil melts, the electrodes sink further into the ground causing deeper soil to melt. When the power is turned off, the melted soil cools and vitrifies turning into a solid block of glass-like material. The electrodes become part of the block. Any harmful chemicals that remain underground become trapped in the vitrified block, which is left in place.

In situ vitrification destroys or volatizes most organic pollutants by pyrolysis (i.e., application of heat without oxygen). A vacuum hood is often placed over the treated area to collect off-gases, which are treated before release. The conventional method of top-down melting in ISV typically results in substantial over-melting of the remediation area. Planar-ISV involves starting the melting process in specific areas of the subsurface. Consequently, the melting process can be focused directly on the region requiring treatment, and it can attain greater melt depths.

There are specific limitations to ISV that include the following.

- ISV cannot be used with buried pipes or drums and rubble exceeding 20% by weight.
- Heating the soil may cause the subsurface migration of contaminants into clean areas.
- ISV cannot be used where there are large accumulations of flammable or explosive materials.
- ISV rapidly volatilizes some organic compounds and volatile radionuclides, including ^{137}Cs, ^{90}Sr, and ^{3}H. Control of these off-gases, as well as the high voltage used, presents significant health and safety risks.
- ISV reduces the volume and mobility of radionuclides, but it does not reduce their radioactivity. Therefore, protective barriers that limit exposure to radioactive emissions may still be required at some sites.

For these reason ISV is not considered technically or administratively implementable for WMA C pipelines and will not be retained for further consideration.

6.6 PIPELINE RESIDUAL EXTRACTION

6.6.1 Flushing

Flushing of pipeline was an integrated part of process waste transfers within the SST System. Flushes were done with water and in some cases with acidic fluids. Flushing was done for a variety of reasons including: hot water was flushed through before a transfer to heat the pipeline to reduce the potential for waste to cool and coagulate and form a plug in the line; water was flushed through the line after a transfer to clean out the line and prevent any residual build up that could plug the line; hot water or acids solutions were flushed through the line to open up a plugged line.

The process of flushing a pipeline requires an access portal to the line to be flushed. Portal access could be through a diversion box or similar structure to which the pipeline is connected directly, or overburden could be removed to expose the pipeline and an access point could be cut directly into the line. A vessel is required to collect the residual waste/flush water. The flushing liquid is injected with sufficient head to move waste, scour interior surfaces and dislodge plugs.

The potential exists that the secondary waste volume could exceed that of the waste being removed in the efforts. For example, during Hanford's retrieval efforts of the C-200 series tanks, transfer line flushes were decreased after trends in operating data showed that the waste was sufficiently diluted to minimize the risk of line plugging. Transfer line flushes accounted for ~1/5 of the water used for waste retrieval (SRNL-STI-2009-00064).

Flushing is only an applicable treatment technology for pipelines whose integrity can be confirmed. Approximately 75% of WMA C pipelines are over 40 years old and many are constructed of carbon steel. The integrity of all pipelines is highly suspect in WMA C. Therefore flushing is not considered an implementable technology and has not been retained for further consideration.

6.6.2 Hydraulically Activated Pipeline Pigging

Pigs are devices that are inserted into and travel throughout the length of a pipeline driven by the product flow. They were originally developed to remove deposits which could obstruct or retard flow through a pipeline (Figure 6-1). Today pigs are used during all phases in the life of a pipeline for many different reasons and can be divided into three categories (Figure 6-2):

- Utility pigs are used to perform functions such as cleaning, separating, or dewatering.
- Inline inspection tools provide information on the condition of the line, as well as the extent and location of any problems.

- Gel pigs are used in conjunction with conventional pigs to optimize pipeline dewatering, cleaning, and drying tasks.

Figure 6-1. Cleaning Pig in a Pipeline

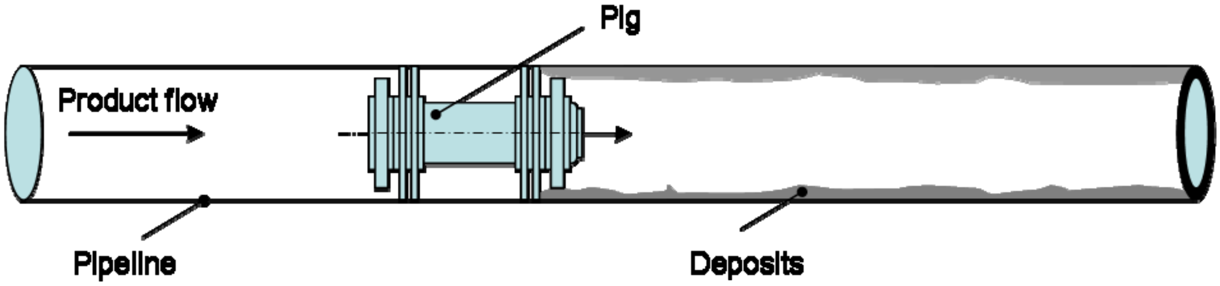
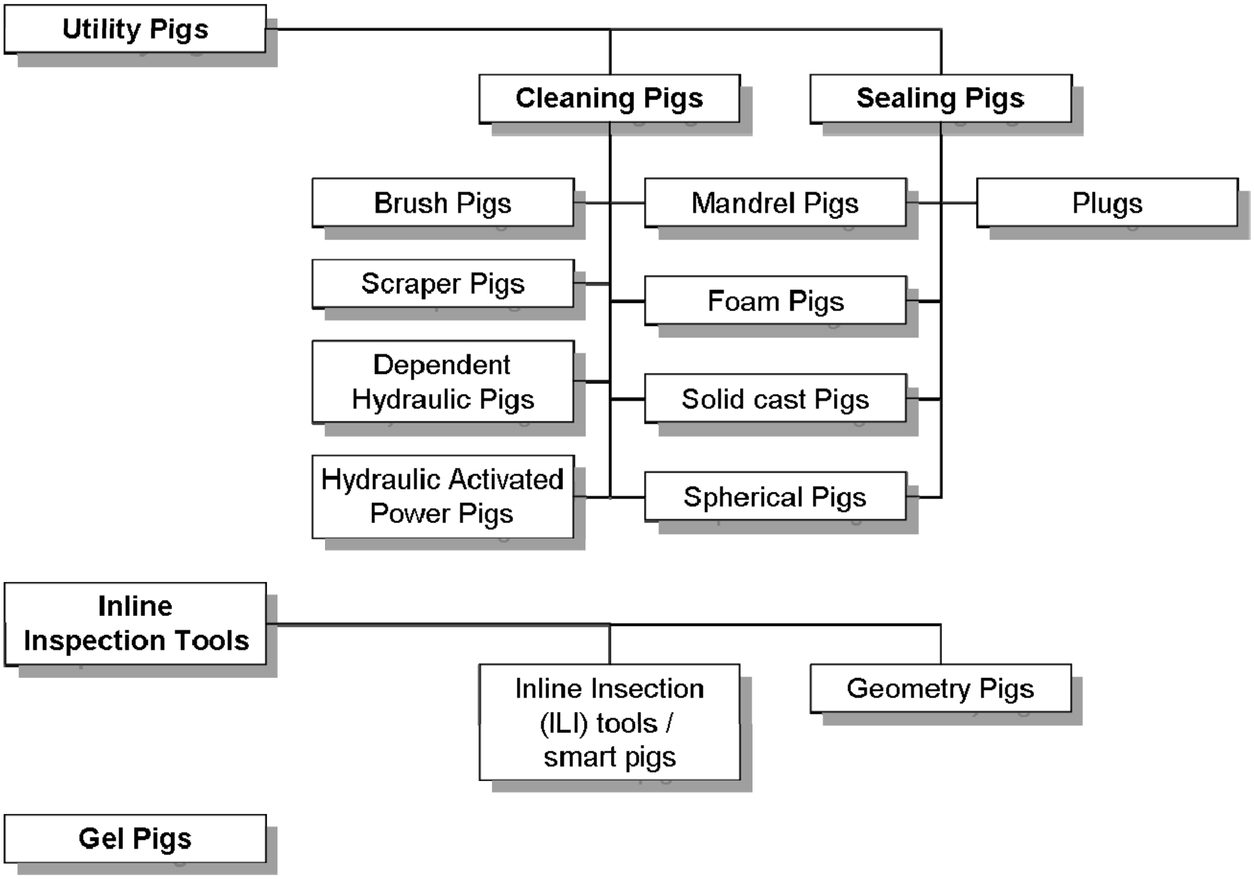


Figure 6-2. Classification of Pipeline Pigs



Hydraulically activated pipeline pigging (HAPP) is a pigging technology applied for pipeline cleaning. This technology transforms kinetic energy of the pipeline fluid into a locally available differential pressure which in this process is used to create cleaning jets. The basic principle is that a pressure drop is created over a by-passable pig held back against a pipeline's fluid flow. The pipeline fluid passing through the pig's cleaning head is accelerated by this pressure drop forming strong cleaning jets. These jets are directed onto the inner wall in front of the pig removing all kinds of deposits.

Generally for cleaning pigs, the cleaning force applied is the mechanical force between the pipe inner wall and the cleaning pig itself. This force is determined by the pig travel speed as well as by the hardness and shape of the cleaning edge: The faster the pig, the higher the cleaning impact on the deposits but at the same time only the surface of debris is scratched away. Therefore multiple pig runs are required to clean a pipeline.

Pigging is not considered a viable technology for WMA C pipeline closure because it requires the introduction of a significant volume of water under pressure to activate and move the pig. The unknown and questionable integrity of the pipelines makes this technology impractical for inspection or characterization.

6.7 RETAINED PIPELINE CLOSURE TECHNOLOGIES

Retained technologies that will be further evaluated in Section 7.0 are as follows:

a. Removal
    i. Conventional excavation equipment
    ii. Vacuum systems
    iii. Remotely-operated excavation equipment

b. Excavation support
    i. Sloping and benching
    ii. Shoring (e.g., soldier pile and lagging)

c. In situ encapsulation by grout (encased pipelines only).

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7.0 FINDINGS AND RECOMMENDATIONS

This section presents the findings and recommendations concerning characterization and supplemental closure actions for pipelines in WMA C.

7.1 SUMMARY OF FINDINGS FROM PROCESS HISTORY REVIEW OF WASTE MANAGEMENT AREA C PIPELINES RELEVANT TO CHARACTERIZATION AND CLOSURE CONSIDERATIONS

For most of the process waste pipeline systems at WMA C, information is available concerning location, construction design, and type of waste received or transferred through the pipelines. Residual waste composition that may exist in the pipes can best be ascertained from the BBI which is considered a reliable indicator of tank waste as well as pipeline residuals. Process history can be effectively used to reconstruct estimated volumes of residuals in the transfer pipelines. In using process knowledge it is important to understand what is known about the volumes and composition of residuals, the uncertainty of this information, the relative long-term impacts associated with the range of estimated residual inventories, and the ability to obtain meaningful data through characterization. Below is a summary of the findings from the process history review of WMA C pipelines presented in this report.

- Three cascade lines have plugged with waste.

- Eleven pipelines have failed.

- Plugged lines were either unplugged through flushing of the line to break the plug or if this was not successful they would be cut, capped and taken out of service with the residual waste plug left in place.

- Failed pipelines were either cut, capped and replaced or cut and capped and taken out of service.

- Pipelines were routinely flushed following a waste transfer and at times prior to a waste transfer in accordance with standard operating procedures.

- All WMA C pipelines were constructed to drain into receiving vessels without leaving significant residuals volumes.

- Collected quantitative data that characterize residual waste in pipelines at Hanford, while limited, do indicate there is significant pitting and corrosion in the pipelines and tend to support the notion that residual waste is minimal with no standing liquids (DOE/RL-2003-11 and WHC-SD-NR-ER-103).

- The estimates for the volume of residual waste remaining in the WMA C pipelines have used inconsistent assumptions in their development. In some case the results have produced highly conservative and unrealistic values. The technical basis estimate of

2,600 L (700 gal) has been developed and still maintains an appropriate degree of conservativism for making closure decisions.

- Prior to implementing intrusive activities, surface geophysical and radiation surveys would be conducted at all sample locations. Because of the highly radiological environment associated with much of the pipelines in WMA C, exposure to the workers would be a major concern with any sampling effort. The length of the section of pipe removed would need to be limited to address ALARA concerns based on field survey results.

- The survey results support the conclusion that if WMA C pipelines have not completely lost their integrity, they are likely in such a poor condition that the ability to obtain representative characterization data is highly unlikely.

- A scoping analysis performed for estimated pipeline residual inventory indicates associated impacts well below performance objectives for inadvertent intrusion and groundwater protection. This scoping analysis evaluated a range of inventories and utilized conservative assumptions.

- The cost and schedule to remove pipeline segments for characterization purposes would be on the order of $24 to 26M and could take up to 48 months following tank retrieval operations. Screening activities (non-pipeline removal) would cost on the order of $10M and could take between 36 and 48 months following tank retrieval operations.

7.2 NEED FOR CHARACTERIZATION TO EVALUATE AND DETERMINE CLOSURE ALTERNATIVES

In determining if there is a need for further characterization of WMA C pipelines to support closure decisions, the following considerations should be addressed:

- Is there a need for characterization in order to evaluate and determine closure alternatives?

- If characterization is required, identify characterization technologies that would be the most effective based on the screening evaluation presented in this report.

- Determine if demonstrations of characterization technologies are needed prior to implementation.

7.2.1 Recommendations for Characterization of Waste Management Area C Pipelines

The findings in this report support the recommendation that sampling of WMA C pipelines is not required to support closure decisions. This is based on the following conclusions:

1. Obtaining representative samples of in-pipeline residuals in a highly radioactive and congested environment such as WMA C would increase potential worker exposure, would be costly, and would result in significant schedule impacts to closure of the WMA.

2. Process knowledge for WMA C provides sufficient information to make closure decisions for pipelines based on long-term impacts (note that other closure actions may be necessary for the purposes of ensuring optimal performance of a landfill cap).

3. A technically sound WMA C pipeline residual inventory has been developed.

4. This inventory does not significantly contribute to potential long-term impacts to human health and the environment based on a scoping analysis using conservative assumptions.

7.2.2 Technology Recommendations if Characterization is Determined to be Required

A range of pipeline characterization technologies have been identified in Section 5.0. Any final decisions regarding selection of pipeline characterization technologies should only be made after conducting a Data Quality Objectives process and developing a sampling and analysis plan for collecting data.

Table 7-1 presents a qualitative screening of these technologies. Some of the technology categories can provide information on both the volume of residual waste and the composition of the waste, while others only can provide data on one of these parameters. In some cases the data provided by the technology is very specific and does not address the full spectrum of information needed. As noted previously, the volume of residual waste that may be present in the WMA C pipelines is a more important data need than residual waste composition.

7.2.2.1 Characterization Technology Screening Findings. The following are the findings from the screening evaluation of pipeline characterization technologies.

1. Pipeline removal and sampling and analysis represents high worker risk potential and high cost and schedule impacts. This technology is considered the most effective at obtaining representative volume and composition data.

2. In-pipe technologies are not readily discernable from one another based on the screening criteria, i.e., any of them could be deployed with similar caveats regarding the difficulties in implementation within WMA C.

Table 7-1. Screening of Pipeline Technologies Potentially Applicable to Waste Management Area C

Characterization Technology	Pre-deployment	Implementability	Effectiveness	Representativeness of Data	Worker Exposure	Cost	Investigation-Derived Waste
Removal of Pipeline Segment or Residual	Extensive pre-deployment required. Average depth of pipelines in WMA C is ~8 ft. Because of the number of samples required for representative sample, there will be numerous interferences and exposure issues. There are limited excavation technologies.	To obtain 10% sample population would require ~420 10-ft segments be removed. Actual characterization potentially could not take place until tank retrievals are completed.	Probably the most effective means to characterize pipelines.	Data on both the volume and composition of residual wastes could be collected, but could require large sample size for representativeness.	High	High	There would be an extensive volume of IDW generated.
Video Camera	Utilization of diversion boxes or pits and boxes on the tanks would potentially eliminate excavation requirements for equipment placement. Accessing boxes and pits will involve extensive pre-deployment planning for mobilization of specialized equipment to access interior of boxes and pits.	To obtain 10% sample population would require ~4,200 ft of random segments of pipeline evaluated. Actual characterization potentially could not take place until tank retrievals are completed.	Marginal in the actual characterization because only visual images are obtained. Questionable if 10% sample could be obtained because of limitation in moving camera through pipes.	Potentially could improve estimate of residual waste volume. Does not collect waste composition information.	High	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Real-time Dosimetry	If in pipe, pre-deployment is similar to that of placement of a video camera. If outside pipe, similar to removal technology.	Same as video camera.	Very limited to localizing radioactive hotspots. Does not provide characterization data on residual waste or pipeline.	Not considered to be representative of residual waste volume or composition or of pipeline contamination.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Spectrometry	If in pipe, pre-deployment is similar to video camera. If outside pipe similar to removal technology.	Same as video camera.	Identification of specific radionuclides. Real-time high-purity germanium (HPGe) spectroscopy can measure "prompt" signature gammas from chemical constituents, which may be correlated to the radiological components.	Provides no data on residual waste volume.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Gamma Logging	If in pipe similar to video camera. If outside pipe similar to removal.	Same as video camera.	Gamma logging to identify hot-spots and potential sampling locations. Very limited to localizing radioactive hotspots. Does not provide characterization data on residual waste or pipeline.	Provides no data on residual waste volume.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Electrometers	If in pipe similar to video camera. If outside pipe similar to removal.	Same as video camera.	Measurement of air ionization from alpha particles from TRU isotopes.	Not considered to be representative of residual waste volume or composition or of pipeline contamination.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Flammable gas sensors	Similar to video camera.	Same as video camera.	In-situ detection of flammable gases within pipelines.	Not considered to be representative of residual waste volume or composition or of pipeline contamination.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Miniature chemical sensors	Similar to video camera.	Same as video camera.	Identification of presence of volatile organic compounds (VOCs), but not quantities, concentrations or locations.	Not considered to be representative of residual waste volume or composition or of pipeline contamination.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.

Table 7-1. Screening of Pipeline Technologies Potentially Applicable to Waste Management Area C

Characterization Technology	Pre-deployment	Implementability	Effectiveness	Representativeness of Data	Worker Exposure	Cost	Investigation-Derived Waste
Portable analytical chemistry systems	Same as removal.	Same as removal. Very impractical to assume samples would be analyzed for 4,200 ft of pipeline in a mobile field laboratory in or adjacent to WMA C.	Minimal effectiveness because of the high potential for error in conducting a large number of field test procedures. Difficult QA/QC.	Not considered to be representative of residual waste volume or pipeline contamination. Composition data may have limited utility based on issues with implementability and effectiveness.	High	High	There would be a significant volume of IDW generated.
Pipe explorer	Same as video camera.	Sampling tool for in-pipe collection of smears.	Smear samples collected using this tool can be characterized in a laboratory setting.	Provides no data on residual waste volume.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Remote in-pipe sample collection	Same as video camera.	Same as Pipe Explorer. May require multiple entries into pipe to obtain samples.	Same as Pipe Explorer.	Provides no data on residual waste volume.	Moderate to high	Moderate to high	None to moderate depending on the volume of material excavated to access pipes.
Tracers	Same as video camera.	Would require random selection of ~20 pipelines (~10% of # pipelines and not 10% of length of pipeline because an entire length can be assessed).	Unproven emerging technology, demonstrated in a laboratory at the proof-of-concept level for detection of chemical or radiological contamination.	Unproven emerging technology. Demonstrated in a laboratory at the proof-of-concept level.	Moderate	Unknown	None to moderate depending on the volume of material excavated to access pipes.

IDW = Investigation-derived waste
QA = Quality assurance
QC = Quality control
TRU = transuranic
WMA = waste management area

3. There are no in-pipe technologies that can be deployed in WMA C in a timely manner that could support full characterization of the pipelines. All in-pipe technologies are developmental to some extent given the unique WMA C environment. Complex access and interference issues with on-going tank waste retrieval activities and the current closure milestone schedule would not be avoided.

4. Deploying any in-pipe technology within the tank farm environment may require further custom adaptation of technologies and deployment platforms. The quality of the characterization data that would result for any technology, including sources of uncertainty, depends on site-specific conditions and characterization objectives, pipeline integrity, in-pipe environment, as well as the operating parameters of a particular tool.

5. Any of the in-pipe technologies would require some level of demonstration post-adaptation to ensure implementability.

6. The time frame in which to demonstrate these limited technologies and then conduct a full deployment in WMA C to collect a representative set of data likely cannot be conducted within the closure time frame for WMA C.

Pipeline characterization using tracers (PCUT) technology utilizes gaseous tracers for detection of chemical or radiological contamination (see Table 5-1). The potential advantage this technology has over other characterization technologies is its ability to address the entire length of pipe without the challenges of placing and moving equipment inside of the pipe. The major disadvantage known at this time is that this is an emerging technology so far only demonstrated at the proof-of-principle level in a laboratory setting. Further development and the demonstration time frame is not conducive to the closure time frame for WMA C.

7.2.2.2 Recommendations for Selecting Characterization Technologies. The findings in this report support the following recommendations concerning the selection of technologies for characterizing WMA C pipelines, if characterization is subsequently determined to be necessary.

1. Pipeline Segment Removal or Residual Removal: The potential for high worker risk, high cost and schedule impacts make pipeline segment removal a non-viable technology for characterization of pipelines within WMA C.

2. In-Pipe Technologies: Even though there are obstacles to deploying in-pipe technologies in WMA C, they represent the best approach to characterization. It must be recognized that in some cases further technology development would be required (this may include miniaturization and demonstration of multiple systems for compatibility). It is recommended that if they are deployed, that a strategy to integrate multiple inspection tools and/or technologies be used.

3. Tracers: PCUT is currently in a demonstration testing phase at Hanford. Further testing is recommended.

7.3 SUMMARY FINDINGS AND RECOMMENDATIONS FOR WASTE MANAGEMENT AREA C PIPELINE CLOSURE ACTIONS

This section makes recommendations on the need for supplemental closure actions for pipelines and, if required, which technologies would be the most effective for support of WMA C final closure. This information will be used to begin a dialogue with the regulatory agencies and stakeholders in order to begin early planning to support WMA C closure. The final closure plans required under the HWMA and DOE Order 435.1 will contain the specific closure actions for WMA C pipelines. The current presumption is that WMA C will be closed as a landfill and an approved barrier will be placed over the entire system. Key considerations in making recommendations for closure actions are as follows:

- Determine if pipeline-specific closure actions are warranted.
- If closure technologies are required, identify those that would be the most effective based on the screening evaluation presented in this report.
- Determine if demonstrations of closure technologies are needed prior to implementation.

7.3.1 Recommendations for the Need for Pipeline Closure Actions

Section 4.3 concluded that WMA C pipeline residuals do not significantly contribute to the overall long-term impacts at WMA C. This report has concluded that there is acceptable uncertainty in the estimates of residual volumes in WMA C pipelines, and that the technical basis estimate for pipeline residual volume does not indicate a need for action. Therefore, this report recommends that no supplemental closure actions are required specifically for WMA C pipelines for purposes of reduction of long-term impacts to human health and the environment.

Although this report concludes that closure actions are not required for the purposes of risk reduction of long-term impacts, actions such as encasement grouting may be required for other closure-related purposes (e.g., reduction of cap size, removal of void spaces for cap integrity).

7.3.2 Recommendations for Closure Technologies, if Deemed Necessary

Waste Management Area C pipeline closure technologies were screened based on implementability in Section 6.0 and the following technologies were retained.

a. Removal Technologies
    i. Conventional excavation equipment
    ii. Vacuum systems
    iii. Remotely-operated excavation equipment

b. Excavation support
    i. Sloping and benching
    ii. Shoring (e.g., soldier pile and lagging)

c. In-situ encapsulation by grout (encased pipelines only).

7.3.2.1 Closure Technology Screening. The findings of the closure technology screening based on the implementability criteria are as follows.

- Removal Technology:
    - Any of the screened removal technologies may be used depending on the site-specific configuration and environment surrounding the pipeline to be removed.
    - Pipeline removal actions will expensive and time consuming.
- Excavation Support Technologies:
    - Excavation support technologies are site-specific.
    - Sloping and benching will create large soil layback areas which may be suitable in fairly open areas outside of WMA C such as at UPR 200-E-115 and possibly UPR 200-E-86.
    - Shoring technologies would likely be required for removal of the majority of WMA C pipelines. The major advantage of shoring is the ability to remove material in confined areas while avoiding utilities or obstructions both overhead and underground. Potential impacts to worker safety with shoring are higher than sloping and benching, however this could be mitigated by use of engineering controls.
    - The implementability of Excavation Support Technologies decreases with depth of excavation, however, the depths of pipelines identified in the appendix are considered conducive to their use.
- In Situ Encapsulation by Grout: The need for grouting pipeline encasements should be revisited as part of design, construction and maintenance of the WMA C surface barrier.

7.3.2.2 Recommendation Based on Findings. Removal and excavation support technologies are well understood and should not require demonstration activities prior to implementation. All screened removal technologies are candidates to be carried forward as possible alternative technologies in a closure plan should supplemental closure actions for pipelines be required.

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APPENDIX A

MASTER WASTE MANAGEMENT AREA C PIPELINE TABLE

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APPENDIX A

MASTER WASTE MANAGEMENT AREA C PIPELINE TABLE

	WIDS Code or Official Title	Type of Structure	Connecting Facilities	Connecting Facilities	Size	Length	Min Depth	Max Depth	Construction Material	References
The Manhattan Project (1943-1945)										
	241-C-151	Diversion Box								
	241-C-152	Diversion Box								
	241-C-153	Diversion Box								
	Cascade Line	Pipeline	241-C-101	241-C-102	3	25	21	21		
	Cascade Line	Pipeline	241-C-102	241-C-103	3	25	21	21		
	Cascade Line	Pipeline	241-C-104	241-C-105	3	25	21	21		
	Cascade Line	Pipeline	241-C-105	241-C-106	3	25	21	22		
	Cascade Line	Pipeline	241-C-108	241-C-107	3	25	21	21		
	Cascade Line	Pipeline	241-C-109	241-C-108	3	25	21	22		
	Cascade Line	Pipeline	241-C-110	241-C-111	3	25	21	21		
	Cascade Line	Pipeline	241-C-111	241-C-112	3	25	21	23		
	Cascade Line Cleanout (2 Pipes)	Pipeline	241-C-104	241-C-105	3	Vertical Pipes				H-2-73338
	Cascade Line Cleanout (2 Pipes)	Pipeline	241-C-105	241-C-106	3	Vertical Pipes				H-2-73338
	Cascade Line Cleanout (2 Pipes)	Pipeline	241-C-101	241-C-102	3	Vertical Pipes				H-2-73338
	Cascade Line Cleanout (2 Pipes)	Pipeline	241-C-102	241-C-103	3	Vertical Pipes				H-2-73338, H-2-2338
	V100	Pipeline	241-C-151-L1	241-C-153-U9	3	170				H-2-44502, sheet 8
	V101	Pipeline	241-C-151-L2	241-C-104-04A-U4	3	406	5	10		H-2-73338, H-2-44502, sheet 8
	V102	Pipeline	241-C-101	241-C-151-L4	3	411	10	21		H-2-73338, H-2-44502, sheet 8
	V103	Pipeline	241-C-105	241-C-151-L3	3	519	10	21		H-2-73338, H-2-44502, sheet 8, H-2-61981
	V104	Pipeline	241-C-101	241-C-151-L5	3	412	10	21		H-2-73338, H-2-44502, sheet 8
	V107	Pipeline	241-C-252-U4	241-C-151-L8	3	634	9	13		H-2-44502, sheet 8
	V112	Pipeline	241-C-151 U-5		3	30	7	8	Stainless steel	W-72183, sheet 4, H-2-44502, sheet 8
	V114	Pipeline	241-C-151	241-C-301	6	537	10	15		H-2-73338
	V118	Pipeline	241-C-152-L4	241-C-153-U6	3	174	6	9		H-2-44502, sheet 8
	V119	Pipeline	241-C-152-L5	241-C-153-U5	3	172	6	9		H-2-44502, sheet 8
	V120	Pipeline	241-C-152-L6	241-C-153-U4	3	170	6	9		H-2-44502, sheet 8
	V130	Pipeline	241-C-152-U4	241-B-154-L8	3	64	6	7		H-2-44502, sheet 8
	V137	Pipeline	241-C-153-L2	241-C-111	3	75	9	23		H-2-73338
	V138	Pipeline	241-C-110	241-C-153-L3	3	90	9	23		H-2-73338
	V139	Pipeline	241-C-110	241-C-153-L4	3	90	9	23		H-2-73338
	V140	Pipeline	241-C-110	241-C-153-L5	3	90	9	23		H-2-73338
	V142	Pipeline	241-C-153-L7	241-C-108	3	99	9	18		H-2-73338
	V143	Pipeline	241-C-107	241-C-153-L8	3	135	9	22		H-2-73338
	V144	Pipeline	241-C-107	241-C-153-L9	3	134	9	22		H-2-73338
	V145	Pipeline	241-C-107	241-C-153-L10	3	133	9	22		H-2-73338

	WIDS Code or Official Title	Type of Structure	Connecting Facilities	Connecting Facilities	Size	Length	Min Depth	Max Depth	Construction Material	References
	V147	Pipeline	241-C-153-L12	None Identified	3	185	9	19		H-2-73338
	V148	Pipeline	241-C-104	241-C-153-L13	3	214	9	22		H-2-73338
	V149	Pipeline	241-C-104	241-C-153-L14	3	213	9	22		H-2-73338
	V150	Pipeline	241-C-104	241-C-153-L15	3	212	9	22		H-2-73338
	V155	Pipeline	241-C-252	241-C-301	6	56	13	14		
	V156	Pipeline	241-C-201	241-C-252-L1	3	236	12	16		H-2-73338, H-2-44502, sheet 8
	V157	Pipeline	241-C-201	241-C-252-L2	3	235	12	16		H-2-73338, H-2-44502, sheet 8
	V158	Pipeline	241-C-202	241-C-252-L3	3	186	12	15		H-2-73338, H-2-44502, sheet 8
	V159	Pipeline	241-C-202	241-C-252-L4	3	185	12	15		H-2-73338, H-2-44502, sheet 8
	V160	Pipeline	241-C-203	241-C-252-L5	3	136	12	16		H-2-73338, H-2-44502, sheet 8
	V161	Pipeline	241-C-203	241-C-252-L6	3	135	12	16		H-2-73338, H-2-44502, sheet 8
	V162	Pipeline	241-C-204	241-C-252-L7	3	86	12	15		H-2-73338, H-2-44502, sheet 8
	V163	Pipeline	241-C-204	241-C-252-L8	3	85	12	15		H-2-73338, H-2-44502, sheet 8
	V210	Pipeline	241-C-151-U4	241-B-154		234	8	9		
Bismuth Phosphate & Uranium Recovery Operations (1946-1957)										
	241-C-252	Diversion Box								
	241-CR-151	Diversion Box								
	241-CR-152	Diversion Box								
	241-CR-153	Diversion Box								
	244-CR Vault	Vault								
	V110/8902	Pipeline	241-C-151-U3	244-CR Vault-U12	3	16	7	8		H-2-44502, sheet 8
	V136	Pipeline	241-C-153	None Identified	3	26	8	9		H-2-44502, sheet 8
	V141	Pipeline	241-C-153-L6	C-110	3	99	-1	9		H-2-44502, sheet 8
	V172	Pipeline	241-C-252-U1	241-C-109/241-C-112	3 connected to 2	274	9	11	Stainless steel	H-2-73338, H-2-36835, H-2-2338, H-2-2909, H-2-44502, sheet 8
	V175	Pipeline	241-C-252-U5	201-C Diversion Box (Hot Semi-Works)	3	595	9	13		H-2-72182, H-2-44502, sheet 8
	V244 (PAS-244)	Pipeline	241-ER-152-2	244-CR-TK-003-U13	3	190	6	8		H-2-36646
	V843	Pipeline	241-C-102	241-CR-151	3	319	4	13	Carbon steel	H-2-73338, H-2-44502 sheet 6, H-2-33087
	V844	Pipeline	241-C-102 and 241-CR-152	241-CR-151 L8	3	176	2	13	Carbon steel	H-2-73338, H-2-33087
	V1001	Pipeline	241-CR-152-U4A	241-CR-153-U3A		53	4	4		
	V1002	Pipeline	241-CR-152-U6A	241-CR-153-U1A	3	45	4	4		H-2-36646
	Wall drain	Pipeline	241-CR-152	241-CR-01C						
	812 (V108)	Pipeline	241-AR Vault	241-C-151	3	465	7	9	Stainless steel	H-2-43037
	SW Main	Pipeline	C Valve Box (between 241-C-111 and 241-C-112)	C Valve Box (between 241-C-110 and 241-C -111)	2	210	2	3	M5	H-2-73862, H-2-73877, H-2-73973
	SW104	Pipeline	SW Main	241-C-104	2	74	3	5	M5	H-2-73862, H-2-73877, H-2-73973
	SW107	Pipeline	SW Main	241-C-107	2	20			M5	H-2-73862, H-2-73877, H-2-73973
	SW108	Pipeline	C Valve Box (between 241-C-111 and 241-C-112)	241-C-108	2	64	-1	2	M5	H-2-73862, H-2-73877, H-2-73973
	SW109	Pipeline	C Valve Box (between 241-C-111 and 241-C-112)	241-C-109	2	103	3	7	M5	H-2-73862, H-2-73877, H-2-73973

	WIDS Code or Official Title	Type of Structure	Connecting Facilities	Connecting Facilities	Size	Length	Min Depth	Max Depth	Construction Material	References
	SW110	Pipeline	SW Main	241-C-110		79	5	6		
	SW111	Pipeline	C Valve Box (between 241-C-111 and 241-C-112)	241-C-111	2	84	-1	2	M5	H-2-73862, H-2-73877, H-2-73973
	SW112	Pipeline	C Valve Box (between 241-C-111 and 241-C-112)	241-C-112	2	44	-1	2	M5	H-2-73862, H-2-73877, H-2-73973
	Drain-301		241-C-106-06C-U8	To Process Building Floor Drain						
	Drain-302		241-C-106-06C-U9	To Metal Filter Drain						
	Drain line		241-C Valve Pit	241-C-103	3				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-103-03B-U1	241-C-Valve Pit	2				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-105-05B-U2	Line 8210	2				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-104-04B-U3	241-C-Valve Pit-L2	2				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-105-05B-U3	Capped	2				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-110-U1	241-C-Valve Pit-L4	2				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-107-07C-U1	241-C-Valve Pit-L3	2				M5	H-2-73862, H-2-73877, H-2-73973
	No identifier		241-C-112	241-C-Valve Pit-L5	2				M5	H-2-73862, H-2-73877, H-2-73973
	V050	Pipeline	241-C-104	241-A-152-L7	3	497	7	13	Schedule 40 Stainless Steel	H-2-44502, H-2-33087
	V051	Pipeline	241-C-104	241-A-152-L8	3	496	7	13	Schedule 40 Stainless Steel	H-2-44502, H-2-33087
	V050 capped	Pipeline	241-CR-151	Extend SW	3	40	12	13		
	V0511 capped	Pipeline	241-CR-151	Extends SW	3	68	12	15		
	V0512 capped		241-CR-151	Extends SW	3	52	12	14		
	8636 / V105	Encased Pipeline	241-CR-151-U1	241-C-151-L6	3	177	8	11		H-2-44502, sheet 8, H-2-43037, H-2-43038, H-2-41413, H-2-41539
	V121	Pipeline	241-C-152	None Identified (241-C-109)	3	227	8	9		H-2-44502, sheet 8, H-2-2021, sheet 2
	2805-E1	Pipeline	north of BY-109 to cribs	241-C Valve Pit		282	2	5		H-2-44502, sheet 8
	2805-E2	Pipeline	north of BY-109 to cribs	241-C Valve Pit		282	2	5		H-2-44502, sheet 8
	8002	Encased Pipeline	241-C-103-03A-U1	241-CR-152-L13	6	462	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8006	Encased Pipeline	241-C-102-02A-U1	241-CR-152-L12	6	362	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8010	Encased Pipeline	241-C-101-01A	241-CR-152-L11	6	228	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8012	Encased Pipeline	241-CR-152-U9, U11, U12	241-CR-151-U4	6	50	9	11	P93-CS-SCH. 80	H-2-2338, H-2-44502, sheet 7
	8014	Encased Pipeline	241-C-103-03C-U1	241-CR-152-L10	6	442	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8017	Encased Pipeline	241-C-102-02C-U1	241-CR-152-L7	6	317	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8020	Encased Pipeline	241-C-101-01C-U1	241-CR-152-L9	6	212	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8025	Encased Pipeline	241-CR-151	241-CR-152	3	52	9	11	P93-CS-Sch. 80	H-2-44502, sheet 7
	8031	Encased Pipeline	241-CR-152	241-C-101-C01A	6	240	4	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8032	Encased Pipeline	241-C-103-03A-U2	241-CR-152-U6	6	465	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8035	Encased Pipeline	241-CR-152	241-C-103-C03A	6	447	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8037	Encased Pipeline	241-C-102-02A-U3	241-CR-152-L15	6	368	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8038	Encased Pipeline	241-C-102-02A-U2	241-CR-152-U4	6	365	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8041	Encased Pipeline	241-C-102-02C-U2	241-CR-152-U3	6	323	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8044	Encased Pipeline	241-C-101-01A-U2	241-CR-152-U2	6	237	4	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8047	Encased Pipeline	241-C-101-01C-U2	241-CR-152-U1	6	220	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
Not In Meiers	8052	Pipeline	251-CR-152	Unknown						

	WIDS Code or Official Title	Type of Structure	Connecting Facilities	Connecting Facilities	Size	Length	Min Depth	Max Depth	Construction Material	References
	8053	Encased Pipeline	241-C-101-01C	241-CR-152	3	220	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8056	Encased Pipeline	241-C-103-03B-U2	Line 8002?	3	47	2	5	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8063	Encased Pipeline	241-C-102-02B-U2	Line 8006?	3	56	2	4	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8070	Encased Pipeline	241-C-101-01B-U1	8010?	3	38	2	4	P93-CS-SCH. 80	H-2-41413, H-2-41385
	8202	Encased Pipeline	241-C-106-06A-U1	241-CR-153-L13	6	456	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8206	Encased Pipeline	241-C-105-05A-U1	241-CR-153-L12	6	352	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8210	Encased Pipeline	241-C-104	241-CR-153	6	228	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8212	Encased Pipeline	241-CR-151	241-CR-153	6	193	9	11	P93-CS-SCH. 80	H-2-41413, H-2-41539
	8214	Encased Pipeline	241-C-106-06C-U1	241-CR-153-L10	6	435	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8217	Pipeline	241-C-105-05C-U1	241-CR-153-L7	6	311	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8220	Pipeline	241-C-104-04C-U1	241-CR-153-L9	6	206	6	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8225	Encased Pipeline	241-CR-153-U10	241-CR-151-U10	3	92	9	11	P93-CS-SCH. 80	H-2-44502, sheet 7
	8231	Encased Pipeline	241-C-104-04A-U3	241-CR-153-L14	6	234	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8232	Encased Pipeline	241-C-106-06A-U2	241-CR-153-U6	6	459	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8235	Encased Pipeline	241-C-106-06C-U2	241-CR-153-U5	6	440	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8237	Encased Pipeline	241-C-105-05A-U3	241-CR-153-L15	6	359	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8238	Encased Pipeline	241-C-105-05A-U2	241-CR-153-U4	6	355	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8241	Encased Pipeline	241-C-105-05C-U2	241-CR-153-U3	6	316	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8244	Encased Pipeline	241-C-104-04A-U2	241-CR-153-U2	6	231	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8247	Encased Pipeline	241-C-104-04C-U2	241-CR-153-U1	6	213	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8253	Encased Pipeline	241-C-104	241-CR-153 (grouted)	3	214	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8256	Pipeline	241-C-106-06B-U2	Line 8202	3	47	2	4	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8263 (not in Part A)	Pipeline	241-CR-05B-U2	Line 8206	3	56	2	4	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8270/8210	Pipeline	241-C-104-04A-U10	241-CR-153-L11 and Line 8210	3	228	5	10	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8270	Pipeline	241-C-104	Line 8210	3	38	2	5	P93-CS-SCH. 80	H-2-41413, H-2-41386
	8400	Encased Pipeline	8402	8408	6	165	3	4	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8402	Encased Pipeline	241-C-201	8400	6	35	3	5	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8404	Encased Pipeline	241-C-202	8400	6	38	3	5	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8406	Encased Pipeline	241-C-203	8400	6	38	4	5	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8408	Encased Pipeline	241-C-204	8400	6	35	4	5	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8410	Encased Pipeline	8411	8423	6	165	4	4	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8411	Encased Pipeline	241-C-201	8410	6	35	4	7	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8415	Encased Pipeline	241-C-202	8410	6	37	4	6	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8419	Encased Pipeline	241-C-203	8410	6	37	4	7	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8423	Encased Pipeline	241-C-204	8410	6	35	4	6	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8552	Encased Pipeline	8400	241-CR-151-U2	6	638	3	14	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8555	Encased Pipeline	241-C-104 (capped)	8410	6	632	4	14	P93-CS-SCH. 80	H-2-41389, H-2-44502, sheet 8
	8555-2	Pipeline	241-CR-151	241-C-105	6	270	4	14	P93-CS-SCH. 80	H-2-44502, sheet 6
	8601	Pipeline	241-CR-151-L1	244-CR-Tank-001	3	63	15	25	P93-CS-SCH. 80	H-2-44502, sheet 6
	8603	Pipeline	244-CR-TK-003	244-CR-TK-001	3	60	18	25	P90-SS-SCH. 40	H-2-44502, sheet 6
	8604	Pipeline	244-CR-001	241-CR-002	3	43	18	25	P93-CS-SCH. 80	H-2-44502, sheet 6

	WIDS Code or Official Title	Type of Structure	Connecting Facilities	Connecting Facilities	Size	Length	Min Depth	Max Depth	Construction Material	References
	8609	Pipeline	244-CR-011	244-CR-003Q	3	84	18	25	P93-CS-SCH. 80	H-2-44502, sheet 6
	8616	Pipeline	241-CR-151-L5	244-CR-Tank-011	3	37	14	15	P93-CS-SCH. 80	H-2-44502, sheet 6
	8618	Encased Pipeline	241-ER-151	241-CR-151-U14	3.5	202	9	11	P91-SS-SCH. 10	H-2-41413, H-2-41539
	8622	Pipeline	241-CR-151	241-CR-001-TK	6	75	15	19	P93-CS-SCH. 80	H-2-44502, sheet 6
	8624	Encased Pipeline	241-CR-152-U8	241-CR-151-U7	6	50	9	11	P93-CS-SCH. 80	H-2-44502, sheet 6
	8625	Encased Pipeline	241-CR-153-U8	241-CR-151-U11	6	121	9	11	P93-CS-SCH. 80	H-2-41413, H-2-41539, H-2-44502, sheet 6
	8630	Encased Pipeline	241-CR-152-L1,2,3,4,5,6	241-CR-151-U9	3	50	9	11	P93-CS-SCH. 80	H-2-44502, sheet 6
	8631	Encased Pipeline	241-CR-153-L (1-6)	241-CR-151-U8	3	90	9	11	P93-CS-SCH. 80	H-2-44502, sheet 6, H-2-41413
	8644	Pipeline	241-CR-151-U12, 13,15	241-CR-151-U12,U13,U15	3				P90-SS-SCH. 40	H-2-41414
	8647	Pipeline	241-CR-151-L4	244-CR-Tank-003-U1	3	113	15	18	P93-CS-SCH. 80	H-2-44502, sheet 6
	8648	Pipeline	241-CR-151-L6	244-CR-Tank-002-U1	3	88	15	18	P93-CS-SCH. 80	H-2-44502, sheet 6
	8653	Encased Pipeline	241-ER-151	244-CR-TK 004	3.5	227	6	9	P91-SS-SCH. 10	H-2-41413, H-2-41414
	8653/8901	Pipeline	241-ER-151	244-CR-TK-003	3	831	6	13	P90-SS-SCH. 40	H-2-44502, sheet 6
	8670	Pipeline	Unknown	244-CR-Vault	3	90	14	22	P90	H-2-41414
	8712	Pipeline				611	1	6		
	8679	Pipeline	244-CR-TK-003	Blanked off	3				P90-SS-Sch 40	H-2-44502, sheet 6
	8755	Pipeline	244-CR-TK-003	Blanked off	3				P91-SS-Sch 10	H-2-44502, sheet 6
	8764/8675	Pipeline	241-CR-151	244-CR Vault Sump	3				P90-SS-Sch 40	H-2-44502, sheet 6
	8765				3				P90	H-2-41414
	8808	Pipeline	244-CR Vault	V051/ Capped	3	110	7	18	P90	H-2-41414
Waste Fractionization Operations (1961 – 1978)										
	V101-old	Pipeline	241-C-153	Capped		83	6	8		
	V113	Pipeline	241-C-151-U6	241-AX-101 or 103	3	1043	7	13	Carbon Steel	H-2-44502, sheet 8, H-2-58610
	V115	Pipeline	241-C-105-05A-U5	241-C-152-L1	3	553	2	9	Stainless Steel	H-2-73339, H-2-44502, sheet 8
	V122	Pipeline	241-CR-05A	241-C-152-L8	3	494	5	9		H-2-73339, H-2-44502, sheet 8
	8107/V844	Pipeline	241-C-102	241-CR-151	3	282	5	9	Carbon Steel	H-2-33087, H-2-33087
	M-21, Process Waste Feed Line	Pipeline	241-C-103 and 241-C-102	241-C-801	3		5	9	M21-P	H-2-4574, sheet 3
	2904-E-1 aka 2904-CR-1, Drainline	Pipeline	241--C-103 Pump Pit 241-CR-03A	2904-E1 CMP to B Pond	30	397	4	10	M5	H-2-44502, sheet 7, H-2-4566
	241-C-801 drain line 1	Pipeline	241-C-801	216-CR-1 dry well	3	104	2	7	Stainless Steel	H-2-44502, sheet 7, H-2-4566
	241-C-801 drain line 2	Pipeline	241-C-801	216-CR-1 dry well	2	122	0	7	Stainless Steel	H-2-44502, sheet 7, H-2-4566
	241-C-801 drain line 2	Pipeline	241-C-801	216-CR-1 dry well	1	13	4	5	M2-C	H-2-4574, sheet 3
	V111/8902	Pipeline	241-C-151-U4	241-B-154-L10	3	27	7	8		H-2-44502, sheet 8
	V228	Pipeline	241-ER-151-U-10	241-CR-153-U6A	3	318	4	10		H-2-36646
	4012	Pipeline	241-CR-153-U4A	241-ER-153	3	315	4	10		H-2-36646
	4013	Pipeline	241-CR-152-U3A	241-ER-153	3	280	4	10		H-2-36646
	V1000	Pipeline	241-CR-152	244-CR Vault	3	373	4	6		H-2-36646
	8900	Pipeline	244-CR-TK-003-U-10	201-C Valve Box	2	210	8	8	SS	H-2-44502, sheet 6
	8656	Pipeline	244-CR-TK-003	241-AX-151 G Cell	3				P91-SS-Sch 10	H-2-44502, sheet 6
	V108	Pipeline	200-ER-151	241-C-151	3	766	7	9		
	V109	Pipeline	241-C-151-U2	241-A-101-01A	3	764	7	7		H-2-44502, sheet 8

	WIDS Code or Official Title	Type of Structure	Connecting Facilities	Connecting Facilities	Size	Length	Min Depth	Max Depth	Construction Material	References
Interim Stabilization and Isolation (1975 – 2001)										
	SN251	Pipeline	241-C Valve Pit	241-C-112	2	316	3	8	M25	H-2-73862, H-2-73877, H-2-73973
	SN252	Pipeline	241-C Valve Pit	241-C-110	2	430	2	8	M25	H-2-73862, H-2-73877, H-2-73973
	SN253	Pipeline	241-C Valve Pit	241-C-107	2	409	2	8	M25	H-2-73862, H-2-73877, H-2-73973
	SN254	Pipeline	241-C Valve Pit	241-C-104	2	237	2	8	M25	H-2-73862, H-2-73877, H-2-73973
	SN255	Pipeline	241-C Valve Pit	241-C-102	2	86	2	8	M25	H-2-73862, H-2-73877, H-2-73973
	SN275	Pipeline	241-C-Valve Pit	244-CR Vault	2	491	5	5	M25	H-2-73862, H-2-73877, H-2-73973
	SN200	Pipeline	241-C-106	241-AY-102	2	270	2	5	M5	H-2-73862, H-2-73877, H-2-73973
	SN200 Encasement Drain	Pipeline	241-C-06A-U7	SN200 Encasement	2				M5	H-2-73862, H-2-73877, H-2-73973
	Process line M21-P	Pipeline	241-C-102	241-C-103 Pit/241-C-801	3/1 1/2					H-2-4574
	Process line M21-P	Pipeline	241-C-103 Pit	241-C-801	1 1/2					H-2-4574

Note: Data for these fields could not be located.

WIDS = Waste Information Data System

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APPENDIX B

SCOPING ANALYSIS OF THE POTENTIAL LONG-TERM IMPACTS FROM WASTE RESIDUALS IN PIPELINES IN WASTE MANAGEMENT AREA C

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INTERA, Inc.

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ABBREVIATIONS AND ACRONYMS

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BBI	Best Basis Inventory
MCL	maximum contaminant level
WMA	waste management area

APPENDIX B

SCOPING ANALYSIS OF THE POTENTIAL LONG-TERM IMPACTS FROM WASTE RESIDUALS IN PIPELINES IN WASTE MANAGEMENT AREA C

B.1 INTRODUCTION

This appendix describes an initial scoping analysis of the potential long-term impacts of estimated waste residual left in pipelines in Waste Management Area (WMA) C. The analysis is intended to put initial bounds on the potential impacts, but should not be regarded as a definitive study. This analysis recognizes that few data or observations exist that define the amount of waste residuals within pipelines at WMA C, and, as a result, the analysis considers a range of possible inventories and the assumptions about the exposure pathways and scenarios. As such, this analysis is not intended to represent a final WMA C risk assessment from residual wastes in pipelines needed to support closure.

B.2 BASIS FOR THE ANALYSIS

Potential impacts from waste residuals left in pipelines within this scoping analysis were based on evaluating impacts from two exposure scenarios. The scenarios evaluated included:
(1) exposure to waste residuals through an inadvertent drilling intrusion at WMA C, and
(2) exposure of a member of the public to water pumped from a well completed immediately downgradient from WMA C.

For the purposes of this scoping analysis, estimates of the waste residual inventory left in pipelines were developed. A number of estimates have been made for the amount of residual waste in pipelines that reflect different levels of conservatism, and depend to some extent on where one draws the boundary of the area under study. In this analysis, a range of estimates were applied based on an assumption that the total volume of residual waste left in each mile of pipeline is ~87.5 gal (0.3 m^3). This is based on an assumption that waste residual left in all pipes within the system make up ~5% of the total pipe volume. This assumption is believed to be conservative, based on process knowledge of the way the pipelines were flushed in the past. With this assumption, the total volume of waste in the pipelines is a function of the estimated length of pipeline containing residual wastes. In this analysis, this total pipeline length was assumed to vary in length from 4 to 8 miles.

The type of residual waste in pipelines may be estimated by recognizing that pipelines were routinely flushed after operational use, so that any material left in the pipelines would remain as sludges. In the absence of other information, average concentrations for WMA C sludges have been calculated across all tanks from concentrations estimated in the Best Basis Inventory (BBI) [Tank Waste Information Network System (TWINS), Queried 2010, [*Sample Analysis, Best Basis Inventory*], http://twins.pnl.gov//twins.htm] concentrations. The BBI has assumed that material is left in and potentially contaminates the pipelines. Using the average BBI volumetric concentrations, and multiplying by the total assumed volume of contamination, provides an estimate of the inventory in the pipelines. These values are shown in Table B-1 for selected radiological constituents and in Table B-2 for selected non-radiological constituents.

Table B-1. Inventories of Selected Radiological Constituents for Several Volume Estimates of Waste Residuals Left in Pipelines at Waste Management Area C (2 sheets)

Analyte	Total Pipeline Inventory (µCi) for 150 gal (based on assumed 4 miles of pipelines)	Total Pipeline Inventory (µCi)for 530 gal (based on assumed 6 miles of pipelines)	Total Pipeline Inventory (µCi) for 620 gal (based on assumed 7 miles of pipelines)	Total Pipeline Inventory (µCi)for 700 gal (based on assumed 8 miles of pipelines)
^{106}Ru	1.78E-02	6.28E-02	7.34E-02	8.29E-02
^{113m}Cd	7.31E+03	2.58E+04	3.02E+04	3.41E+04
^{125}Sb	5.56E+03	1.97E+04	2.30E+04	2.60E+04
^{126}Sn	3.01E+03	1.06E+04	1.25E+04	1.41E+04
^{129}I	1.66E+02	5.86E+02	6.86E+02	7.74E+02
^{134}Cs	1.10E+01	3.90E+01	4.57E+01	5.15E+01
^{137}Cs	7.44E+07	2.63E+08	3.08E+08	3.47E+08
^{137m}Ba	7.02E+07	2.48E+08	2.90E+08	3.28E+08
^{14}C	1.18E+03	4.17E+03	4.88E+03	5.50E+03
^{151}Sm	5.30E+07	1.87E+08	2.19E+08	2.47E+08
^{152}Eu	1.36E+04	4.79E+04	5.60E+04	6.33E+04
^{154}Eu	2.48E+05	8.77E+05	1.03E+06	1.16E+06
^{155}Eu	1.35E+05	4.78E+05	5.59E+05	6.31E+05
^{226}Ra	9.12E-01	3.22E+00	3.77E+00	4.26E+00
^{227}Ac	6.05E+02	2.14E+03	2.50E+03	2.83E+03
^{228}Ra	5.17E+02	1.83E+03	2.14E+03	2.41E+03
^{229}Th	1.91E+02	6.74E+02	7.88E+02	8.90E+02
^{231}Pa	6.00E+01	2.12E+02	2.48E+02	2.80E+02
^{232}Th	5.17E+02	1.83E+03	2.14E+03	2.41E+03
^{232}U	9.98E+02	3.52E+03	4.12E+03	4.66E+03
^{233}U	5.87E+04	2.07E+05	2.42E+05	2.74E+05
^{234}U	7.62E+03	2.69E+04	3.15E+04	3.56E+04
^{235}U	2.95E+02	1.04E+03	1.22E+03	1.38E+03
^{236}U	1.42E+02	5.01E+02	5.86E+02	6.62E+02
^{237}Np	6.34E+02	2.24E+03	2.62E+03	2.96E+03

Table B-1. Inventories of Selected Radiological Constituents for Several Volume Estimates of Waste Residuals Left in Pipelines at Waste Management Area C (2 sheets)

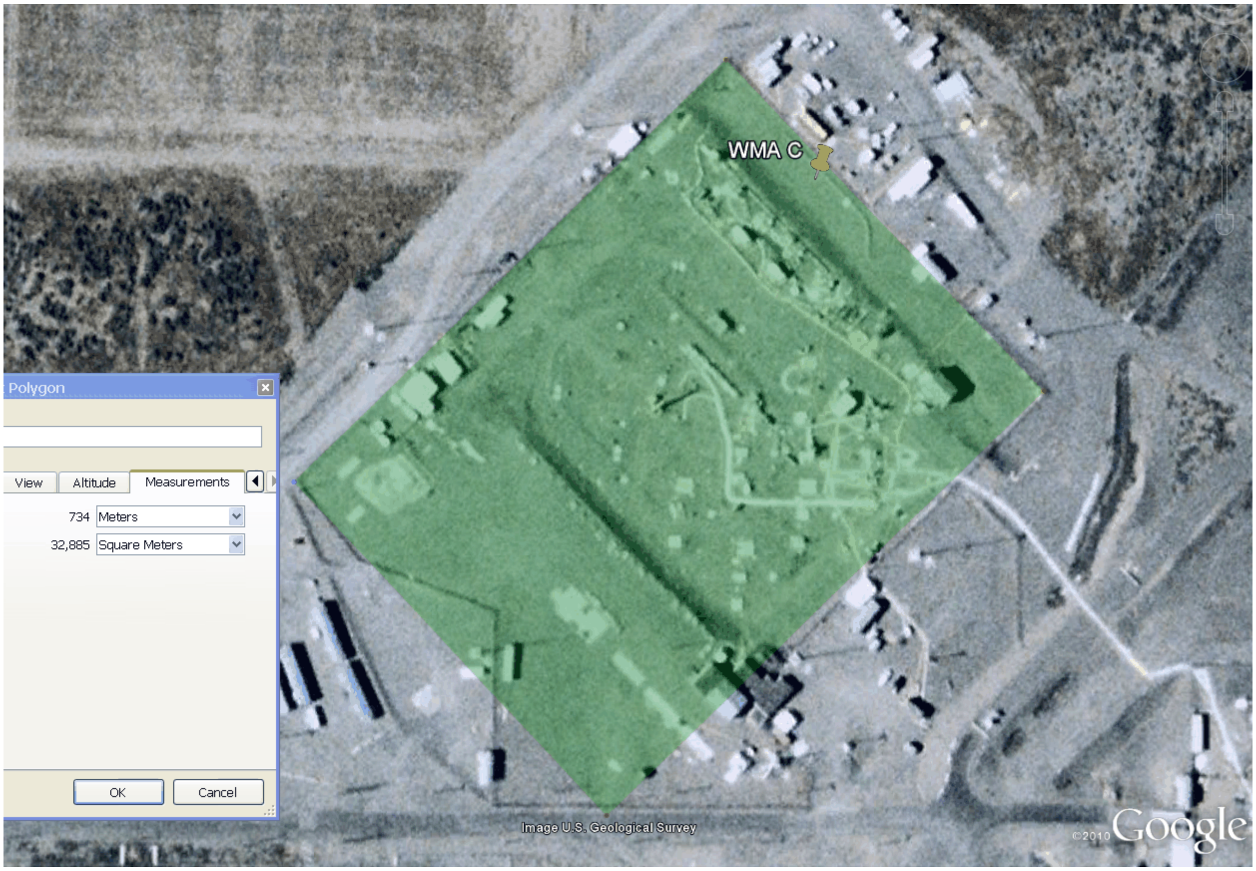
Analyte	Total Pipeline Inventory (µCi) for 150 gal (based on assumed 4 miles of pipelines)	Total Pipeline Inventory (µCi)for 530 gal (based on assumed 6 miles of pipelines)	Total Pipeline Inventory (µCi) for 620 gal (based on assumed 7 miles of pipelines)	Total Pipeline Inventory (µCi)for 700 gal (based on assumed 8 miles of pipelines)
^{238}Pu	6.69E+04	2.36E+05	2.76E+05	3.12E+05
^{238}U	6.73E+03	2.38E+04	2.78E+04	3.14E+04
^{239}Pu	8.05E+05	2.84E+06	3.33E+06	3.76E+06
^{240}Pu	1.94E+05	6.87E+05	8.04E+05	9.07E+05
^{241}Am	1.17E+06	4.12E+06	4.82E+06	5.44E+06
^{241}Pu	1.58E+06	5.59E+06	6.54E+06	7.38E+06
^{242}Cm	6.87E+02	2.43E+03	2.84E+03	3.20E+03
^{242}Pu	1.84E+01	6.49E+01	7.59E+01	8.57E+01
^{243}Am	2.87E+02	1.01E+03	1.19E+03	1.34E+03
^{243}Cm	1.59E+02	5.60E+02	6.55E+02	7.40E+02
^{244}Cm	2.72E+03	9.62E+03	1.13E+04	1.27E+04
^{3}H	1.95E+04	6.89E+04	8.06E+04	9.10E+04
^{59}Ni	2.15E+04	7.59E+04	8.88E+04	1.00E+05
^{60}Co	4.03E+04	1.43E+05	1.67E+05	1.88E+05
^{63}Ni	4.74E+05	1.67E+06	1.96E+06	2.21E+06
^{79}Se	6.76E+02	2.39E+03	2.79E+03	3.16E+03
^{90}Sr	6.53E+08	2.31E+09	2.70E+09	3.05E+09
^{90}Y	6.53E+08	2.31E+09	2.70E+09	3.05E+09
^{93m}Nb	1.75E+04	6.19E+04	7.24E+04	8.18E+04
^{93}Zr	1.85E+04	6.54E+04	7.65E+04	8.64E+04
^{99}Tc	2.83E+04	9.99E+04	1.17E+05	1.32E+05

This initial scoping analysis is focused on impacts for radiological constituents. In this analysis, the estimated radionuclide inventory was assumed to be uniformly distributed in the pipelines, which in turn are assumed to be uniformly distributed across WMA C. The dimensions of WMA C have been estimated to be a square 200 m × 160 m (~33,000 m^2), calculated from measurements made using Google Earth, as shown in Figure B-1. The pipes themselves are thought to be predominantly carbon steel, which are assumed to corrode relatively quickly over performance assessment time scales. Once the pipes have corroded, this analysis assumes that the waste residuals left in pipelines can be represented as a uniform layer of contaminated soil distributed uniformly across WMA C, with a thickness of 3 in. (7.6 cm), equivalent to the diameter of the pipes. This means the waste comprises 2,500 m^3 of material spread in a layer assumed to be located 5 to 7 m below the final ground surface, depending on the design of the final closure cover.

Table B-2. Inventory of Selected Non-Radiological Constituents for Several Volume Estimates of Waste Residuals Left in Pipelines at Waste Management Area C

Analyte	Total Pipeline Inventory (kg) for 150 gal (based on assumed 4 miles of pipelines)	Total Pipeline Inventory (kg) for 530 gal (based on assumed 6 miles of pipelines)	Total Pipeline Inventory (kg) for 620 gal (based on assumed 7 miles of pipelines)	Total Pipeline Inventory (kg) for 700 gal (based on assumed 8 miles pipelines)
Al	6.10E+01	2.16E+02	2.52E+02	2.85E+02
Bi	2.59E+00	9.16E+00	1.07E+01	1.21E+01
Ca	5.08E+00	1.79E+01	2.10E+01	2.37E+01
Cl	6.94E-01	2.45E+00	2.87E+00	3.24E+00
Cr	4.02E-01	1.42E+00	1.66E+00	1.88E+00
F	5.59E+00	1.98E+01	2.31E+01	2.61E+01
Fe	2.03E+01	7.16E+01	8.38E+01	9.46E+01
Hg	6.94E-02	2.45E-01	2.87E-01	3.24E-01
K	5.75E-01	2.03E+00	2.38E+00	2.68E+00
La	7.54E-02	2.66E-01	3.11E-01	3.52E-01
Mn	2.20E+00	7.77E+00	9.09E+00	1.03E+01
Na	6.91E+01	2.44E+02	2.85E+02	3.22E+02
Ni	4.02E+00	1.42E+01	1.66E+01	1.88E+01
NO_2	1.74E+01	6.15E+01	7.19E+01	8.12E+01
NO_3	4.40E+01	1.56E+02	1.82E+02	2.06E+02
Oxalate	1.64E+00	5.79E+00	6.77E+00	7.64E+00
Pb	1.91E+00	6.75E+00	7.90E+00	8.92E+00
PO_4	3.38E+01	1.19E+02	1.40E+02	1.58E+02
Si	6.97E+00	2.46E+01	2.88E+01	3.25E+01
SO_4	7.07E+00	2.50E+01	2.92E+01	3.30E+01
Sr	1.71E-01	6.05E-01	7.08E-01	7.99E-01
TIC as CO_3	1.59E+01	5.62E+01	6.58E+01	7.43E+01
TOC	2.74E+00	9.70E+00	1.13E+01	1.28E+01
UTOTAL	2.02E+01	7.12E+01	8.33E+01	9.41E+01
Zr	7.10E+00	2.51E+01	2.93E+01	3.31E+01

Figure B-1. Estimate of the Area of Waste Management Area C from a Google Earth™ Image



734 Meters

32,885 Square Meters

Google Earth™ is a registered trademark of Google Inc., Mountain View, California.

B.3 EXPOSURE SCENARIOS AND CONCEPTUAL MODEL

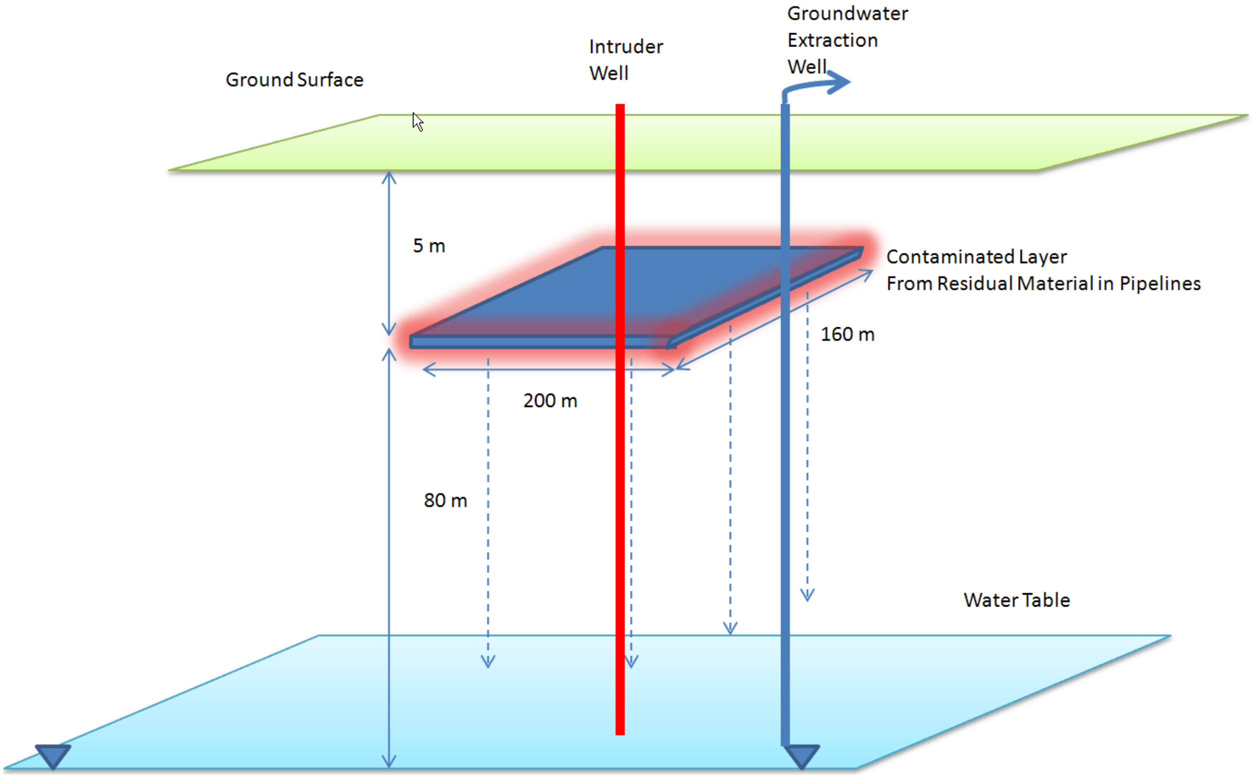
Two exposure scenarios are considered in this scoping analysis. These scenarios are (1) exposure to waste residuals through an inadvertent drilling intrusion at WMA C, and (2) exposure of a member of the public to water pumped from a well completed immediately downgradient from WMA C. Considerations associated with each of these scenarios are discussed in the following sections.

The general configuration of these two scenarios relative to the assumed zone of contamination is shown pictorially in Figure B-2. The dimensions of importance in evaluating the two scenarios are also included in the figure.

B.3.1 Inadvertent Human Intrusion

A number of scenarios for inadvertent human intrusion are often considered when evaluating near-surface disposal facilities. However, in this scoping analysis of post-closure conditions for WMA C, we have assumed that the depth of waste residual left in the pipelines is 5 to 7 m below the ground surface. As a result, the assumed depth of residual wastes is below the normal depth of construction intrusion, and the main credible intrusion scenario is the potential for a driller to drill through the waste.

Figure B-2. Schematic Depiction of the Exposure Scenarios and the Assumed Zone of Contamination Used in Scoping Analysis



For these scoping analyses, it is assumed that a zone of contaminated soils that contains the waste residual inventory is drilled through using a 216-mm (8.5-in.) casing. The volume of contaminated soil containing the residual inventory and penetrated by the drilling process is assumed to be equal to the cross-sectional area of the cased borehole multiplied by the vertical dimension of the zone of contaminated soil. For the assumed 3-in. zone of contamination, the resulting soil volume works out to be 170 in^3 (2.8E-3 m^3).

This exhumed contaminated soil is assumed to be diluted at the surface by drilling mud and surrounding soils. The amount of dilution that may occur with other media is clearly speculative, but was calculated as follows. As the contaminated soil is exhumed, it is assumed to mix with clean borehole material above it, and exposures to the driller would come from the resulting pile of extracted clean and contaminated material. Clean material below the contaminated soil was neglected in the analysis for the sake of conservatism.

Assuming a fully penetrating borehole, concentrations of waste in this exhumed material are given by

$$C_{core} = C_{waste} D_{waste} / (D_{waste} + D_{cov\,er}) = dil_{core} C_{waste}, \tag{1}$$

where C_{waste} is the concentration in contaminated soil contacted by the drill (Ci/kg), C_{core} is the concentration as it is exhumed (Ci/kg), D_{waste} is the vertical dimension of the waste region, D_{cover} is the depth of overburden of clean material over the waste (m), and dil_{core} is a dilution factor applied to exposure to core materials. For 5 m of overburden and a 3-in. (0.076-m) contaminated soil zone, the dilution factor is 0.015, leading to a volume of contaminated soil plus cover material of 0.19 m^3.

The total exposure to a driller is the sum of the exposures by ingestion, inhalation, and external exposure.

$$\text{Total Dose} = D_{ing} + D_{ext} + D_{inh} \tag{2}$$

where

$$D_{ext} = C_{core}(t) F_{ext} f_{onsite} DF_{ext.}. \tag{3}$$

Here, D_{ext} is the dose due to external exposure (mrem y^{-1}),[7] $C_{core}(t)$ is the activity concentration of waste at the time of intrusion (Ci kg^{-1}), DF_{ext} is the external dose rate factor for exposure to contaminated soil (mrem kg Ci^{-1} y^{-1}), F_{ext} is a correction factor applied to the dose factors for infinite extent of contamination, to account for the limited area of contamination from small contamination areas (-), and f_{onsite} is the fraction of the year that the driller spends onsite (-).

ANL/EAD/TM-84, *External Exposure Model Used in the RESRAD Code for Various Geometries of Contaminated Soil* described described an approach to deriving the effect of area on external dose, F_{ext}, in which the area factor depends on the energy and depth of the radiation, and which needed to be derived using a full point-kernel analysis. This approach is judged to be excessively complicated for an analysis of the area effect on intrusion doses. Instead, the earlier analysis of NUREG/CR-3620 (PNL-4054), *Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program* is adopted. ANL/EAD/TM-84 showed that NUREG/CR-3620 (PNL-4054)'s approach provides a good approximation for the reduction factor, except for low-energy radiations. Since those are the

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[7] It is straightforward to demonstrate that doses associated with immersion in air with suspended contaminated particulates are negligible compared to doses associated with external exposure to contaminated soil, so immersion in contaminated soil has been neglected.

least important from a consequence perspective in performance assessment, it is concluded that the approach of NUREG/CR-3620 (PNL-4054) is satisfactory for the current purpose. In this approach, the external dose factor is multiplied by a factor given by

$$F_{ext} = \begin{array}{ccc} 0.016A & for & 0 < A < 25m^2 \\ 0.35 + 0.002A & for & 25 < A < 100m^2 \\ 0.48 + 0.00065A & for & 100 < A < 500m^2 \\ 0.67 + 0.00027 & for & 500 < A < 1222m^2 \\ 1 & for & A > 1222m^2 \end{array} \qquad (4)$$

Assuming the excavated contaminated soil is distributed to a depth of 15 cm, the area contaminated by 0.19 m^3 of excavated material is 1.2 m^2, and the factor F_{ext} is 0.02.

Ingestion doses are associated with inadvertent soil ingestion, associated with secondary transfer of dirt from the driller's hands. The dose by this pathway is calculated from

$$D_{ing} = C_{core}(t)f_{onsite}I_{ing}DF_{ing}, \qquad (5)$$

where I_{ing} is the secondary ingestion rate associated with transfer of soil from hands to mouth (kg/yr).

Furthermore, the inhalation pathway dose is given by

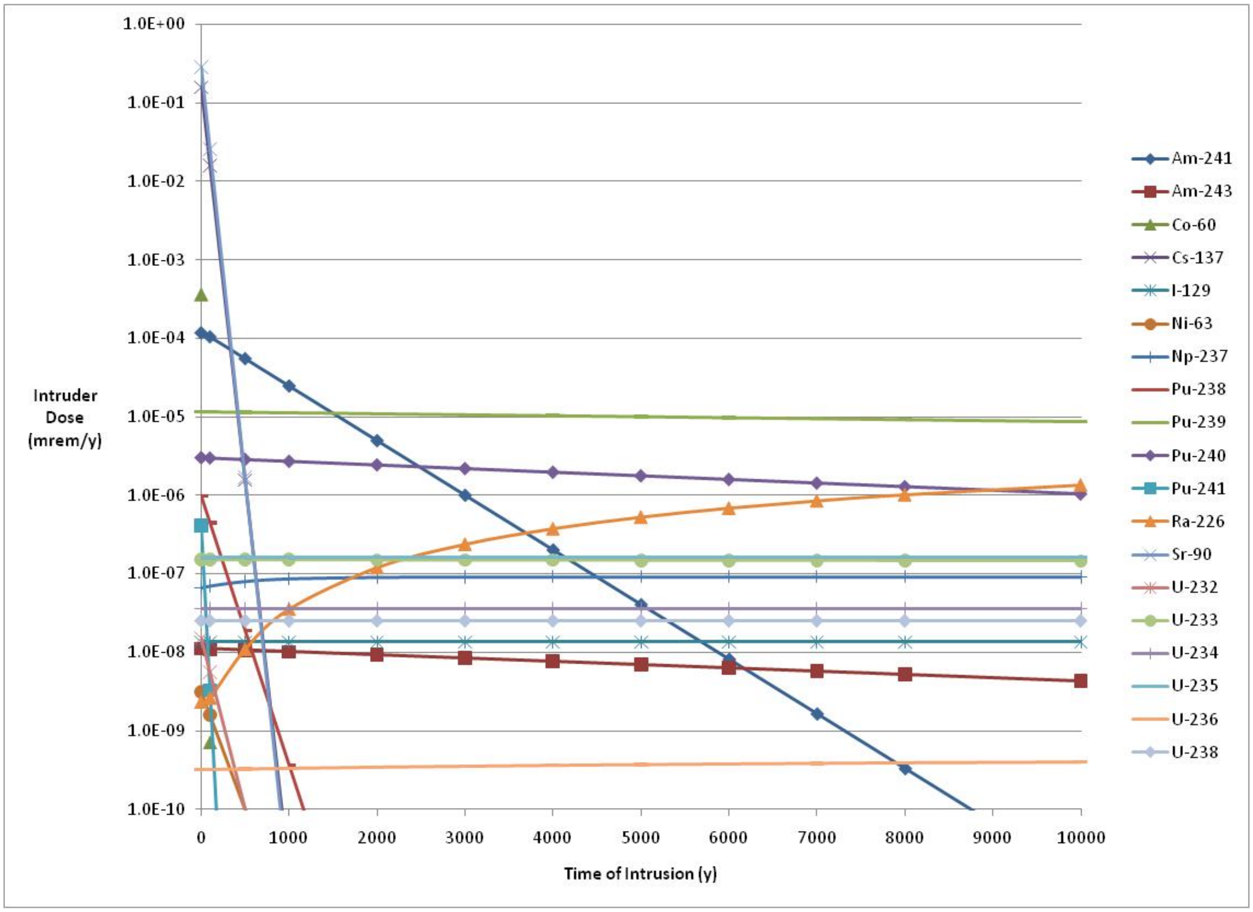
$$D_{inh} = C_{core}(t)C_{dust}If_{drill}DF_{inh} \qquad (6)$$

where D_{inh} is the dose due to inhalation (mrem y^{-1}), C_{dust} is the dust level (kg m^{-3}), I is the worker's inhalation rate (m^3 y^{-1}), and f_{drill} is the fraction of the year that the drill bit is in contact with the waste (-). This value is used for the inhalation exposure because resuspended dust will only contribute to dose during the time in which waste is actively exhumed.

Dose results from the inadvertent drilling intrusion are presented in Figure B-3. The radionuclides and inventories considered for these results were based on an assumed waste residual volume of 700 gal. At time zero, ^{137}Cs and ^{90}Sr dominate the dose to the driller. Over the first 1,000 years, the results show a steep decline in doses from ^{137}Cs, ^{90}Sr, and ^{60}Co, and a slower decline in doses from ^{241}Am. At long times, results show doses from ^{226}Ra increase, but do not become excessive even at 10,000 years. This increase occurs because the model conservatively neglects migration of contaminants into the deep subsurface through this time; the inventory remains in place in the contaminated zone throughout.

A comparison of doses to the inadvertent drilling intruder from inventories based on several assumed volumes of waste residual left in the pipelines is shown in Figure B-4. The results for the upper three estimates of waste residual volumes are very close, with the results for 150 gal of contamination proportionally lower.

Figure B-3. Dose to the Intruder Versus Time of Intrusion Assuming 700 Gallons of Pipeline Contamination

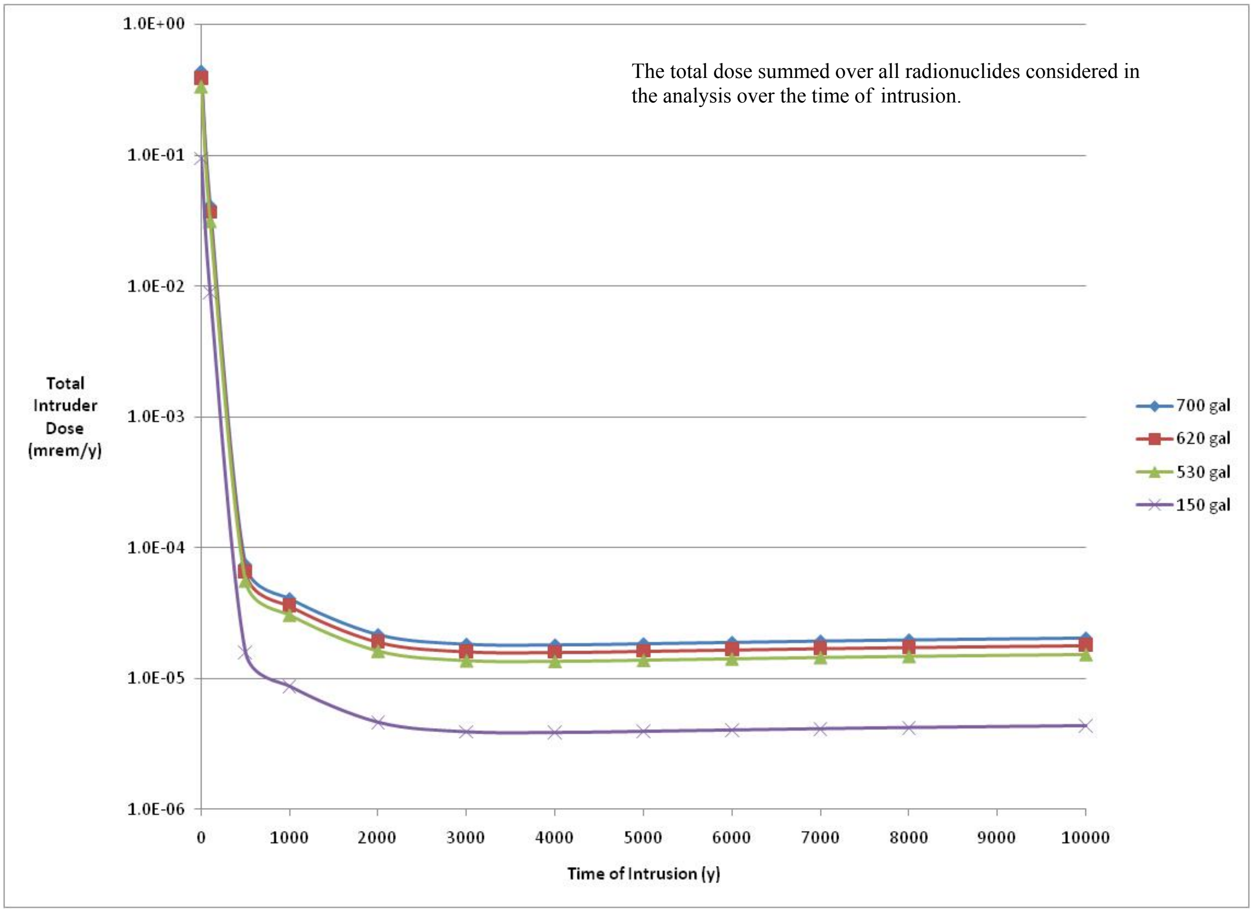


It is important to emphasize that the dose values presented here are for illustrative purposes, since a number of the parameters used in the analysis have been assigned generic values rather than ensuring that they represent typical site-specific values assumed for the Hanford Site analyses. Nevertheless, the general behavior of the intrusion scenario would be similar to an assumed Hanford Site-specific analysis, with the doses shifted somewhat up or down depending on the assumed parameter values.

B.3.2 Release to a Groundwater Well

For purposes of this scoping analysis, a simplified abstraction of releases from the zone of contamination to a groundwater well is as follows. Release from the waste residuals assumed to be left in the pipelines is represented using the same general conceptual model of contaminant release from tank residual wastes proposed in Section 5.5 of RPP-RPT-44042, *Recharge and Waste Release within Engineered System in Waste Management Area C* and presentation PNNL-SA-69753, "Contaminant Release from Residual Waste in Single Shell Tanks at the Hanford Site, Washington, USA" (Cantrell et al. 2009) made at the WMA PA C working session held on January 26 to 28, 2010. In this general contaminant release, experimental results suggest that contaminants are released for residual wastes in two release phases: 1) an initial rapid release of a small fraction of contaminants in the waste, followed by 2) a slow, gradual release of the majority of the contaminants in the waste. Specific information is not yet available to fully parameterize the release rates, so, for purposes of this scoping analysis, some initial nominal assumptions are made, with the understanding that these fractions and rates need to be revisited and made consistent with available leaching data for residual waste.

Figure B-4. Comparison of Drilling Intruder Doses for Several Assumed Volumes of Waste Residual Left in Pipelines



To approximate constituent release from the residual waste, it was assumed that 1% of the waste is released in the first 10 years after failure of the pipelines, with the remainder of the waste being released over 5,000 years. The release rate from the pipelines can therefore be expressed as the sum of two band-release expressions

$$Q_r = I_0\left[\frac{f_r}{T_r}\right], \qquad t \le T_r \text{ and } Q_r = 0 \text{ thereafter} \tag{7}$$

$$Q_s = I_0\frac{1-f_r}{T_s}, \qquad t \le T_s \text{ and } Q_s = 0 \text{ thereafter} \tag{8}$$

where I_0 is the initial inventory, f_r is the fraction of the inventory assumed to be rapidly released (0.01), T_r is the time over which the rapid release occurs (10 years), and T_s is the time period for the slow release. It should be noted that Equations 7 and 8 conserve mass only for contaminants that decay slowly compared to time scales of the assessment. This assumption would be appropriate for the major contaminants of concern considered in this analysis.

In this analysis, transport to the groundwater was assumed to be one dimensional and vertical without taking any credit for dispersion and other dilution phenomena. As a result, the unsaturated zone acts only as a time delay between the release from the waste residuals from pipelines and arrival at the water table. Uranium has been assigned a K_d value of 0.2 mL/g, radium a value of 0.1 mL/g, and thorium, protactinium, and actinium a value of 6 mL/g, while all other radionuclides are assigned a K_d of zero. For the estimated depth to water of 80 m, an assumed infiltration rate 3.5 mm/yr, and a moisture content of 0.09 characteristic of H2 sand at that infiltration rate under a unit gradient, the unretarded travel time to the aquifer is estimated to be 2,060 years.

A pumping well used in this exposure scenario is assumed to be ideally located to capture the plume as it enters the water table. For the sake of conservatism in this initial analysis, this well is assumed to capture all constituents of interest leaving the unsaturated zone. The concentration in pumped water from the well is calculated from the release rate, in Ci/yr, for each constituent of interest entering the saturated zone from the vadose zone divided by the well pumping rate (m^3/yr):

$$C_{borehole,i} = N_{UZ,i} / P_{borehole}, \tag{9}$$

where $C_{borehole,i}$ is the concentration for the i’th radionuclide in the well, $N_{uz,i}$ is the rate of release of the i’th contaminant from the unsaturated zone to the saturated zone (Ci/yr), and $P_{borehole}$ is the pumping rate of the well (m^3/yr). Concentrations calculated using Eq. (7) are conservative in that it neglects the contribution of the saturated zone in diluting the mass release from the vadose before contaminated water is extracted by the pumping well.

The pumping rate for a well serving a family of four can be estimated as 289 to 477 m^3/yr using EPA/600/P-95/002F, *Exposure Factors Handbook Volume III – Activity Factors*, Table 17-14. This range represents a pumping well serving the individual needs of four people for drinking, showering, cooking, and miscellaneous household uses (i.e., all indoor uses). The arithmetic average of this range is 380 m^3/yr. This value does not take account of additional water to support other typical water uses, such as irrigation or lawn care, which likely makes these values rather conservative. For instance, the California Homebuilding Association (Water Use in the California Residential Home [CHA 2010]) estimates that a new 3-bedroom home, with a 4-person family in residence, uses 174,000 gal/yr (660 m^3/yr), with much of the water used for landscaping. Another way to view the pumping rate of the well is to note that drinking water maximum contaminant levels (MCLs) were explicitly established to apply to public drinking water supplies serving an average of at least 25 people year round (65 FR 76708, “National Primary Drinking Water Regulations; Radionuclides; Final Rule”). A well providing only the indoor needs of an average public drinking water supply for 25 people would pump 2,375 m^3/yr (range 1,800 to 2,981 m^3/yr), based on the values from EPA/600/P-95/002F. Given the intended application of the model for comparison to MCLs, the pumping rate for the well is chosen to be 2,375 m^3/yr, which is the most conservative value for comparison with MCLs.

The simplified model and related assumptions that were developed to evaluate the groundwater use exposure scenario in this analysis were approximated and implemented in the Ecolego software[8] ("Ecolego – A toolbox for radioecological risk assessment" [Avila et al., 2000], *Further AMBER and Ecolego Intercomparisons* [Maul et al. 2003], *AMBER and Ecolego Intercomparisons using Calculations from SR 97* [Maul et al. 2004]).

Initial analyses of doses from this scenario examined the inventory of all radiological constituents to ensure that the most important radionuclides were evaluated. Subsequent analyses considered a reduced set of only the most important radiological constituents. Resulting doses from the drinking water scenario for this reduced set of radionuclides are presented in Figure B-5. This case is based on the selected radionuclide inventories for the upper end case of 700 gal of waste residual left in the pipelines. Results of this case show that, despite the conservatism of the analysis, the peak doses for this drinking water scenario are below 0.1 mrem/yr for all radionuclides.

Total dose results for this same drinking water scenario that considered the inventories of all radionuclides, provided in Table B-2 for different estimates for pipeline residual wastes, is shown in Figure B-6. The upper estimates (500 to 700 gal) give very similar results. In all cases the total dose from all radionuclides is below 0.1 mrem/yr.

For the key nonradiological contaminants at WMA C, the concentrations of nitrate and chromium using the same drinking water scenario are:

- Nitrate – 27.9 µg/L
- Chromium – 0.26 µg/L.

As a check to this analysis, the following simple analytical model was evaluated and compared with the results of the model based on Ecolego. For a non-decaying, non-retarded contaminant, with the peak concentration dominated by the slow release fraction, the preceding expressions given in Equations 7 through 9, can be combined to give an estimate of the well concentration as provided in Equation 10:

$$C_w = \frac{I_0}{P_{borehole}} \frac{1-f_r}{T_s}, \quad T_u < t \leq T_s + T_u \text{ and } C_w = 0 \text{ thereafter.} \qquad (10)$$

In Eq. (10), T_u is the delay time in the unsaturated zone. A comparison between results calculated using this approach and the results from Ecolego for 700 gal contamination are shown in Table B-3.

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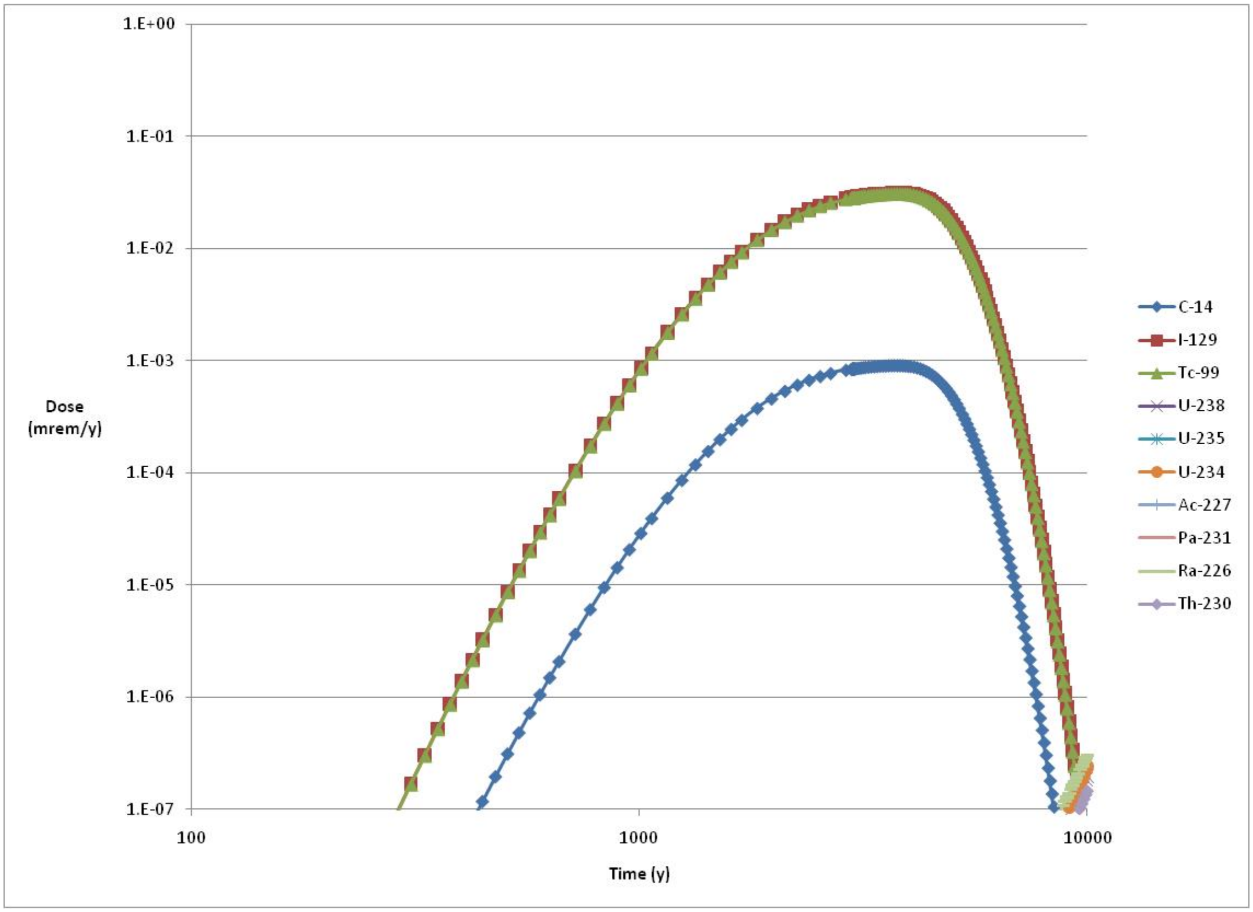
[8] Development of the Ecolego software system was sponsored by the Radiation Protection Authorities of Sweden and Norway.

Figure B-5. Drinking Water Doses for a Selected Set of Key Radionuclides Assuming 700 Gallons of Waste Residuals Left in Pipelines at Waste Management Area C



Examination of Eq. (10) shows the key phenomena involved in producing peak well concentrations in this model:

- Inventory, which in turn is based on conservative assumptions about the volume of contamination in the pipelines,
- Release rate from the solid, which has been set to a rapid rate compared to existing information, and
- Dilution and dispersion in the surroundings, which has been conservatively set to a minimum.

The combination of these conservatisms leads to concentrations and doses that are believed to be very conservative. Doses from these analyses should therefore be used with caution when comparing with doses from tank residuals or past leaks (unplanned releases). A less conservative model would take account of more gradual releases, resulting from the chemical behavior of the inventory constituents, and would take account of a more likely exposure scenario, including higher dilution rates, a more distant receptor, and longer periods of institutional control.

Figure B-6. Total Dose Summed Over All Radionuclides for Several Estimates of Pipeline Contamination Volumes

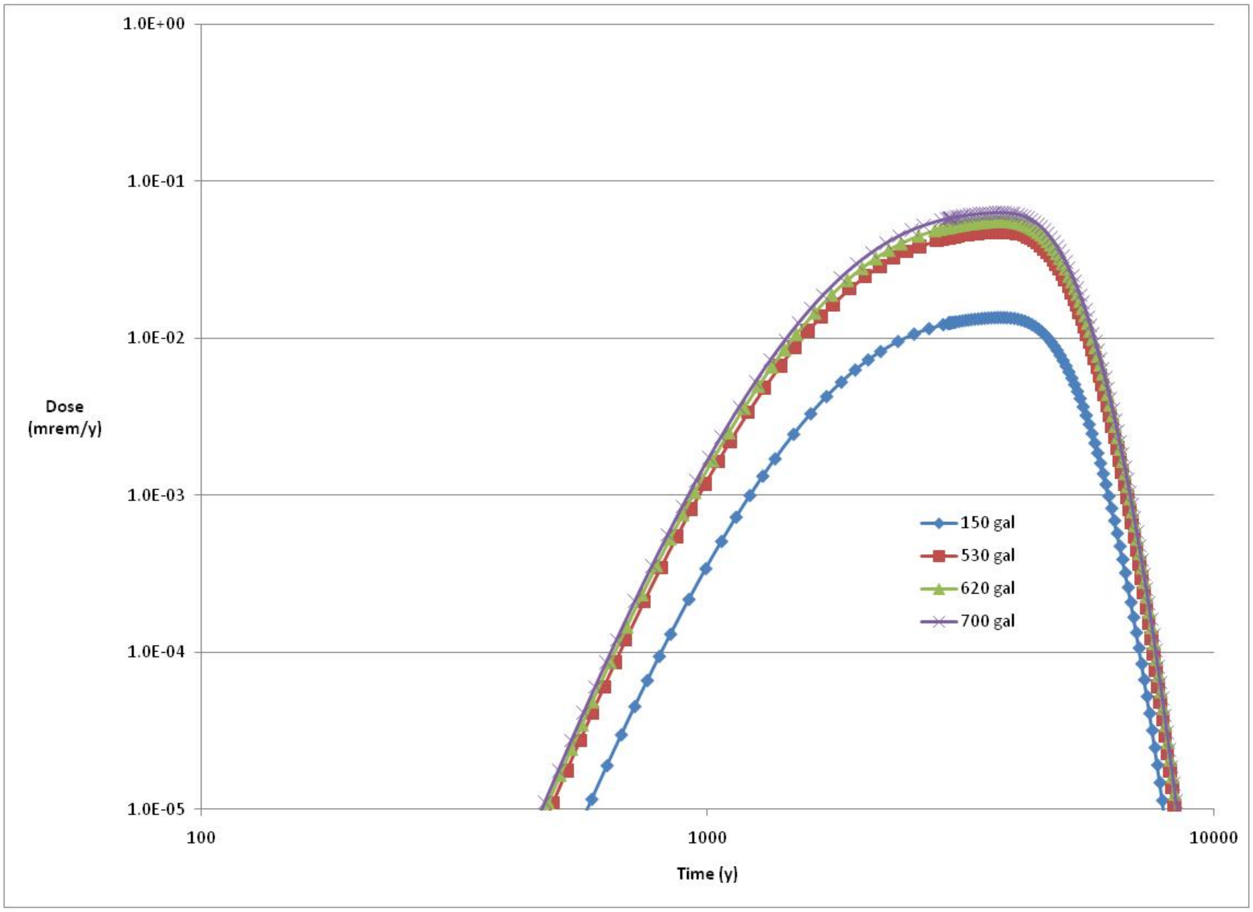


Table B-3. Comparison of Peak Concentrations of Nonretarded Contaminants from Ecolego Model to the Simplified Analytical Expression

Contaminant	Concentration (mol/m^3) from Ecolego Model	Concentration (mol/m^3) from Analytical Expression
Nitrate	4.51E-4	4.61E-04
Chromate	4.91E-6	5.01E-06
I-129	4.62E-9	4.72E-09
Tc-99	1.059E-8	1.09E-08

B.4 REFERENCES

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