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TITLE:	SST System Closure Plan

APPENDIX C

WMA C CLOSURE ACTION PLAN

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LIST OF TERMS

AEA	*Atomic Energy Act of 1954*
ARAR	applicable or relevant and appropriate requirement
BBI	Best Basis Inventory
bgs	below ground surface
C-106	single-shell tank 241-C-106
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
COC	contaminant of concern
CPP	CERCLA Past Practice
CY	calendar year
DOE	U.S. Department of Energy
DQO	data quality objective
DST	double-shell tank
DWS	drinking water standards
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
EPA	U.S. Environmental Protection Agency
Framework Plan	*Framework Plan for Single-Shell Tank System Closure*
FY	fiscal year
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HSRAM	*Hanford Site Risk Assessment Methodology*
HWTOS	*Hanford Tank Waste Operation Simulator*
HWMA	"Hazardous Waste Management Act"
HWIS	Hanford Well Information System database
ILCR	incremental lifetime cancer risk
IP	intrusion prevention
IS	interim stabilized
LCF	latent cancer fatality
MCL	maximum contaminant limit
PI	partial interim isolation
PNNL	Pacific Northwest National Laboratory
PUREX	plutonium-uranium extraction
R	retrieval
RFI	RCRA Facility Investigation
RFI/CMS	RCRA Facility Investigation/Corrective Measures Study
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	*Revised Code of Washington*
ROD	record of decision
RMIS	Hanford Records Management Information System
RPP	RCRA Past Practice
SAC	system assessment capability
SPR	selected phase removal

SST	single-shell tank
TSD	treatment, storage, and disposal
TWINS	Tank Waste Information Network System
UPR	unplanned release
WAC	*Washington Administrative Code*
WIDS	Waste Information Data System
WMA	waste management area

C1.0 INTRODUCTION

The waste management area C (WMA C) is a dangerous waste management unit within the single-shell tank (SST) system. For the purposes of closure, the WMA C components include numerous tanks, pits, transfer piping, diversion boxes, and vaults as well as soil and groundwater contaminated by WMA C operations. The boundary of the WMA C is generally coincident with the 241-C tank farm area (C farm) fenceline. While most WMA C components are physically located within this boundary, some components extend beyond the boundary (e.g., pipelines and groundwater) or are located outside the boundary (e.g., 241-C-154 diversion box). Section 2.0 describes the WMA and its associated components.

U.S. Department of Energy (DOE) will conduct closure activities for single components or groups of components within WMA C. In accordance with Section 173-303-610 of the *Washington Administrative Code* (WAC) "Dangerous Waste Regulations" (WAC 173-303) and the *Hanford Federal Facility Agreement and Consent Order* (HFFACO, Ecology et al. 1989), it is the intent of the DOE to close WMA C after all associated component closure activities have been completed. Closure of WMA C will include disposition of all components including any corrective or remedial actions determined to be necessary to meet performance objectives for soil or groundwater contaminated with dangerous waste or dangerous waste constituents.

This WMA C Closure Action Plan includes both the requirements associated with clean closure of WMA C as a tank system (WAC 173-303-640[8](a)), and closure and postclosure actions associated with landfills (WAC 173-303-640[8](b) and WAC 173-303-665[6]). In accordance with WAC 173-303-640(8)(c), a closure and postclosure plan consistent with landfill requirements is required to be included in a closure plan for a tank system that does not comply with secondary containment (such as the SST system). Landfill closure will only occur if approved by Ecology through modifications to the Site-Wide Permit. These landfill closure and postclosure plans must provide contingent actions should the removal and decontamination activities that are to be performed for WMA C components leave dangerous waste or dangerous waste constituents in excess of those identified in WAC 173-303-610(2)(b). Contingent actions will include design and installation of an engineered surface barrier in compliance with WAC 173-303-665(6)(a) performance standards (described in Sections C4.2.7 and C4.3, herein) and performance of postclosure care requirements in compliance with WAC 173-303-665(6)(b) (described in Section C8.0, herein).

C1.1 WMA C CLOSURE ACTION PLAN RATIONALE

DOE submits this closure action plan to support the following:

- Closure in accordance with WAC 173-303-610 treatment, storage and disposal (TSD) closure and postclosure requirements.
- The concurrent closure activity for the tank 241-C-106 (C-106)

- HFFACO Milestone M-45-06, which directs closure of all WMAs (tank farms) by September 30, 2024
- HFFACO Milestone M-45-06-T03, which directs closure actions to proceed on a WMA (tank farm) basis
- HFFACO Milestone M-24-00, which specifies groundwater monitoring, will occur in relation to the SSTs.

This WMA C Closure Action Plan describes waste characterization, removal, decontamination, treatment, and other such closure activities for the tanks, pits, piping, diversion boxes, vaults, soil and groundwater of the WMA. It also describes actions that will be taken to support closure of the entire WMA such as risk assessment, groundwater monitoring, planning for design of a final cover, and integration of the WMA-wide actions with adjacent and site-wide remediation and closure strategies. The WMA C Closure Action Plan identifies specific activities, schedules, plans, documentation, and integration needs that can be identified at the present time, as well as the information gaps. DOE expects that information gaps will be filled by successive revisions of this closure action plan as component closure activities generate data and reduce the uncertainties. DOE will not propose closure of WMA C until all associated components have been addressed pursuant to component closure activity plans or alternative documentation (such as corrective measures, *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) Action Memoranda or Records of Decision [ROD] upon approval), through incorporation into the Site-Wide Permit.

A relative sequence for completion of component closure activities, including contingent closure activities for landfills, leading to closure of the WMA, as well as contingent postclosure activities for completion is described in Section C4.0.

C1.2 REGULATORY SETTING

A complete discussion of applicable statutes and regulations is presented in the *Framework Plan for Single-Shell Tank System Closure* (Framework Plan). With respect to closure of WMA C, the driving factors are the State of Washington *Hazardous Waste Management Act of 1976* (HWMA, *Revised Code of Washington* [RCW] 70.105) and the HFFACO.

The HFFACO establishes that WMA C and the balance of the SST system will be closed in accordance with WAC 173-303-610, WAC 173-303-645, and the HFFACO Milestone M-45 series.

Closure will be carried out at the WMA level. Thus, the requirements for certification of closure and, potentially, postclosure care, will apply to WMA C and will be addressed in this closure action plan.

As specified in Section 6 of the HFFACO, the *SST System Closure Plan* will address all waste constituents that could potentially affect human health and/or the environment. Where information regarding treatment, management, and disposal of the radioactive source, byproduct

material, and/or special nuclear components of mixed waste (as defined by the *Atomic Energy Act of 1954* [AEA]) has been incorporated into the Site-Wide Permit, it is not incorporated for the purpose of regulating such components under the authority of the Site-Wide Permit and the HWMA. To the extent that *Resource Conservation and Recovery Act of 1976* (RCRA)/HWMA requirements are inconsistent with requirements under the AEA, Section 1006 of RCRA provides that the inconsistent RCRA requirements yield to those of the AEA.

C1.3 THE WMA C CLOSURE ACTION PLAN

DOE is establishing a system for dispositioning individual components and the WMA, as contributory actions in closing the SST system. DOE has developed a tiered structure of documentation to integrate the various component closure activity plans and closure action plans into the Site-Wide Permit, as shown in Figure C1-1. The following sections describe how the WMA C Closure Action Plan (tier 2) relates to each of the tiers.

C1.3.1 Relationship to Framework Plan

The Framework Plan (Tier 1) describes the systemic and sitewide integrated approach for closing the entire SST system through closure of the seven WMAs (A-AX, B-BX-BY, C, S-SX, T, TX-TY, U). The approved Framework Plan will be incorporated into Part V of the Site-Wide Permit. The WMA C Closure Action Plan (Tier 2) is an appendix to the Framework Plan.

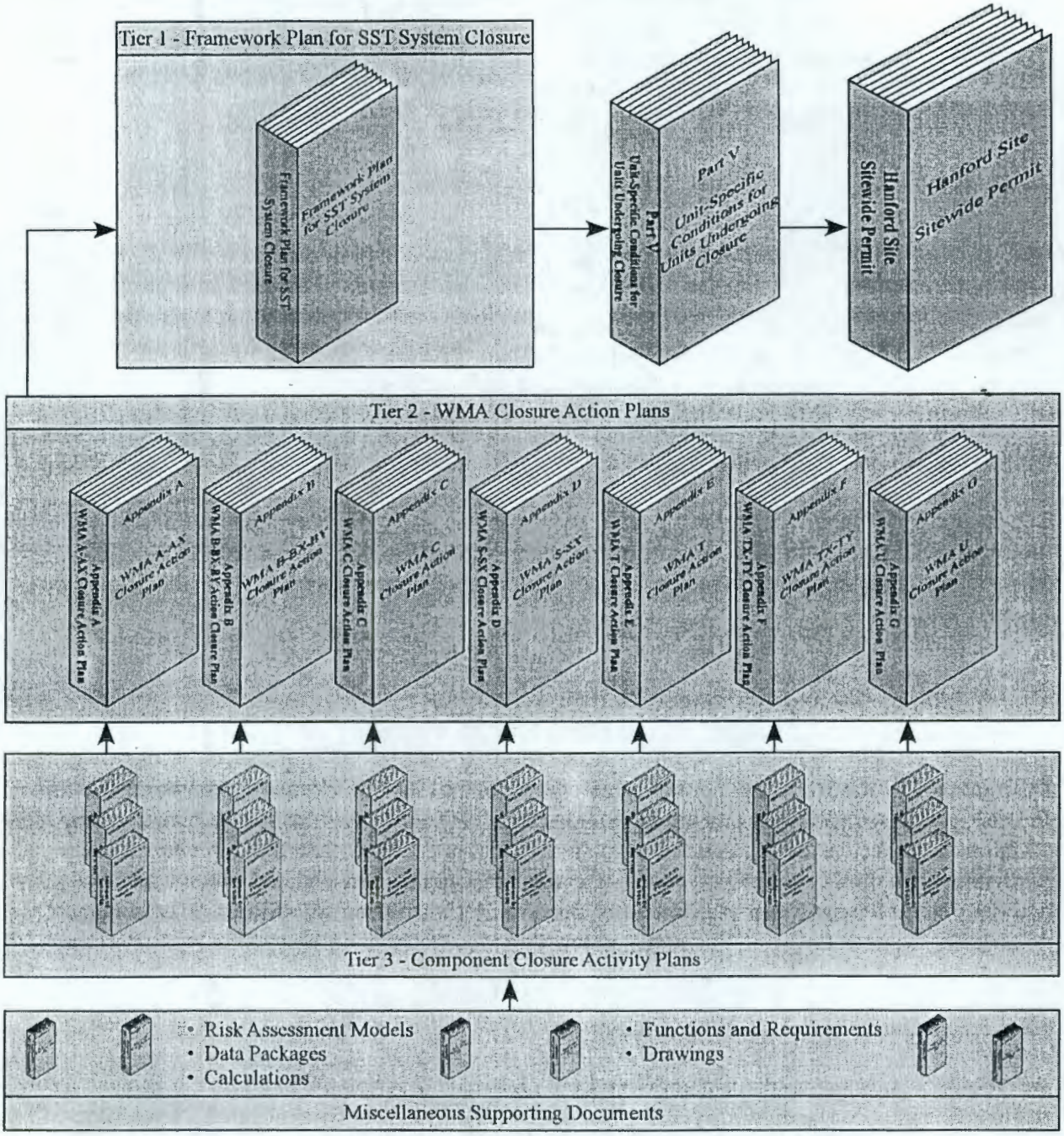
C1.3.2 Relationship to Component Closure Activity Plans

DOE intends to submit component closure activity plans (Tier 3) for the various components of WMA C, such as individual or groups of tanks, ancillary equipment, soil, and groundwater. The component closure activity plans, or equivalent decision documents, will be developed to be consistent with the overall WMA strategy for closure. Each approved component closure activity plan will become an attachment to this WMA C Closure Action Plan. If equivalent documents are used they will be approved through incorporation into the Site-Wide Permit.

C1.3.3 Relationship to Site-Wide Permit

All WMA closure action plans and component closure activity plans, including contingent plans for landfills in accordance with WAC 173-303-640(8)(c), will be incorporated through the permit modification process into Part V, "Unit-Specific Conditions for Units Undergoing Closure," of the Dangerous Waste Portion of the Site-Wide Permit as they are approved. At that time, they will become subject to the terms and conditions of the permit. Should postclosure activities that are consistent with landfill requirements be required for WMA C, the postclosure requirements will be incorporated into Part VI, "Unit-Specific Conditions for Units in Postclosure," of the Site-Wide Permit.

Figure C1-1. *Single-Shell Tank System Closure Plan* Document Structure.



C2.0 WMA C DESCRIPTION

WMA C encompasses the C farm located in the east central portion of the 200 East Area (Figures C2-1 and C2-2) including soil and groundwater contaminated by C farm operations. In general, the WMA C boundary is represented by the fenceline surrounding the C tank farm.

The C farm 100-series tanks are 23 m (75 ft) in diameter, have a 5-m (15 ft) operating depth, and have an operating capacity of 1,892,700 L (530,000 gal) each. The 200-series tanks are 6 m (20 ft) in diameter with a 5-m (17 ft) operating depth and an operating capacity of 208,000 L (55,000 gal) each. Typical tank configuration and dimensions are shown in Figure C2-3. The tanks sit below grade with at least 2 m (7 ft) of soil cover to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the tanks and provide access to the tank, pumps, and monitoring equipment.

The SSTs were constructed in place with carbon steel (ASTM A283 Grade C) lining the bottom and sides of a reinforced concrete shell. The tanks have concave bottoms (center of tanks lower than the perimeter) and a curving intersection of the sides and bottom. The inlet and outlet lines are located near the top of the liners (Figure C2-3). These lines are also referred to as "cascade" lines since they allowed transfer of fluids between tanks using gravity flow. The SSTs in WMA C were used to store waste primarily from the bismuth phosphate, the plutonium-uranium extraction (PUREX), and the uranium extraction processes.

To support the transfer and storage of waste within WMA C SSTs, there is a complex waste transfer system of pipelines (transfer lines), diversion boxes, vaults, valve pits, and other miscellaneous structures. Collectively, these are referred to as ancillary equipment.

The 244-CR vault is located south of the tanks. The vault is a two level, multi-cell, reinforced concrete structure constructed below grade (DOE/RL-92-04), which contains four underground tanks along with overhead piping and equipment. Two tanks have a capacity of 170,343 L (45,000 gal) each. The other two tanks have capacities of 55,494 L (14,700 gal) each. This vault was constructed in 1946 and ceased operating in 1988. It was last used to transfer waste solutions from processing and decontamination operations (DOE/RL-92-04). A schematic of the 244-CR vault is shown in Figure C2-4.

The routing of liquid waste from the operations buildings to the tank farms was accomplished using underground transfer lines, diversion boxes, and valve pits. The diversion boxes housed the switching facilities where waste could be routed from one transfer line to another. The diversion boxes are below-ground, reinforced concrete boxes that were designed to contain any waste that leaked from the high-level waste transfer line connections. Diversion boxes generally drained by gravity to nearby catch tanks where any spilled waste was stored and then pumped to SSTs (DOE/RL-92-04). Figure C2-5 shows a schematic of a typical diversion box.

Figure C2-1. Location Map of WMA C in the 200 East Area at the DOE Hanford Site.

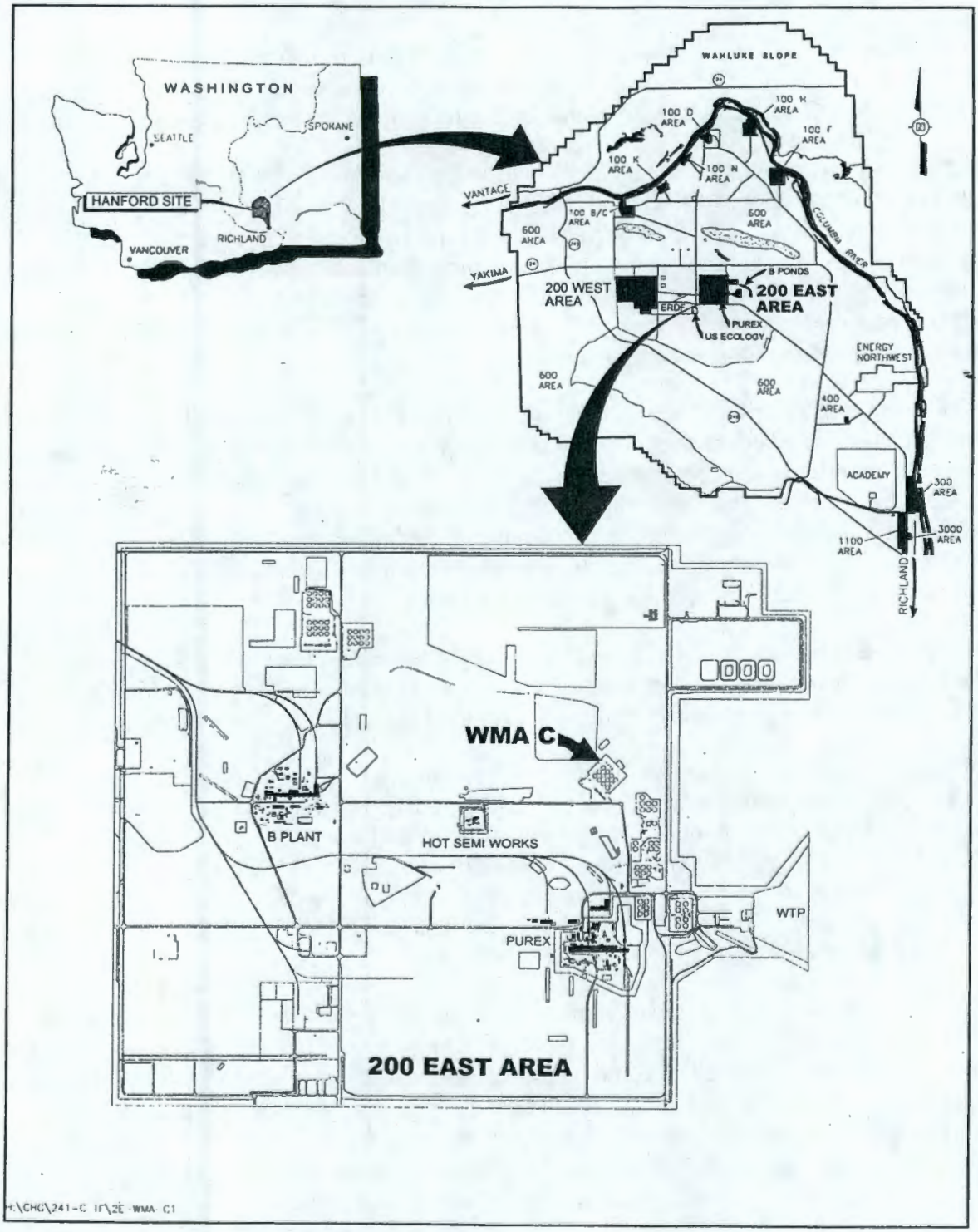


Figure C2-2. Location Map of WMA C and Surrounding Area.

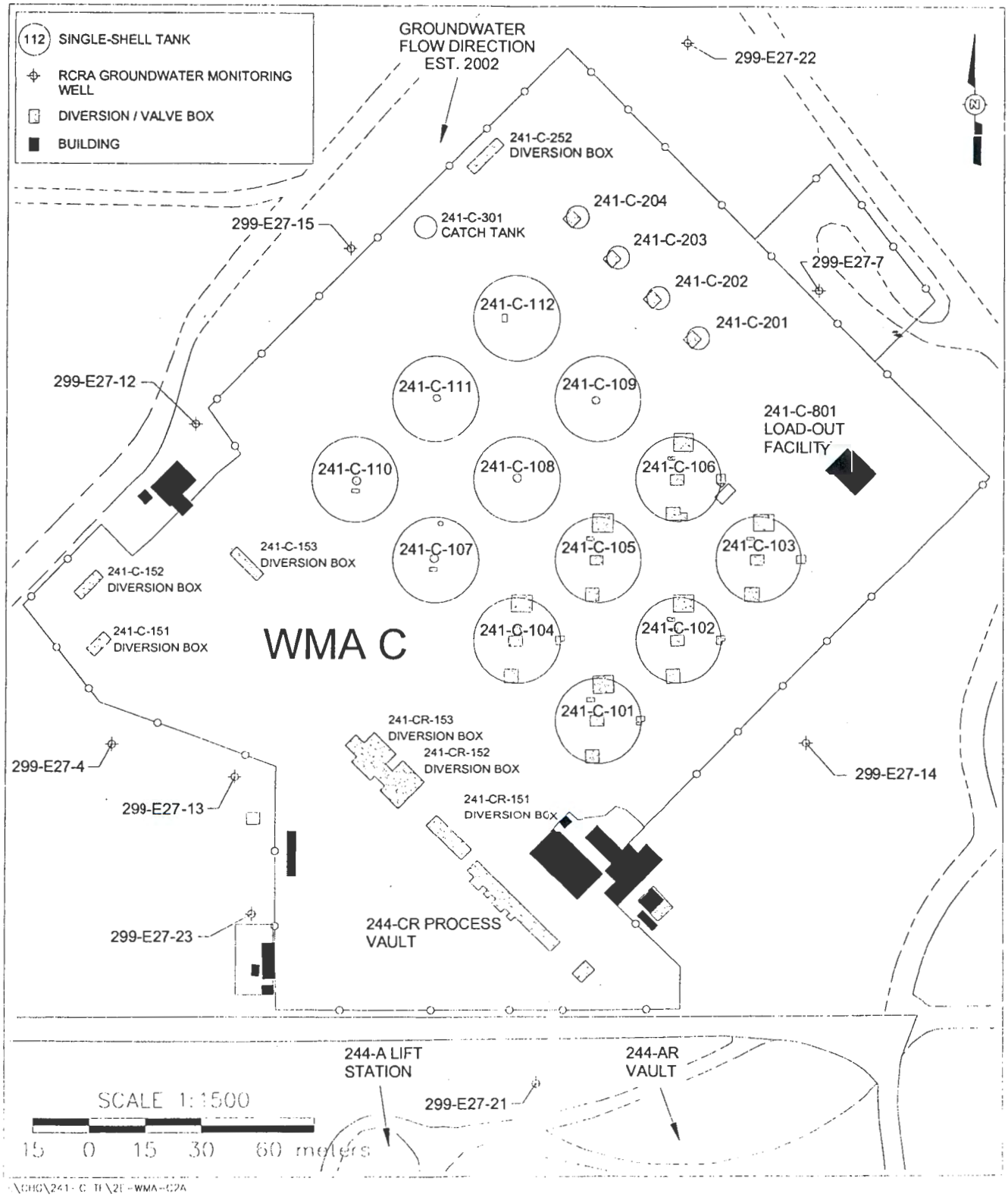


Figure C2-3. Typical Configuration and Dimensions of SSTs in WMA C.

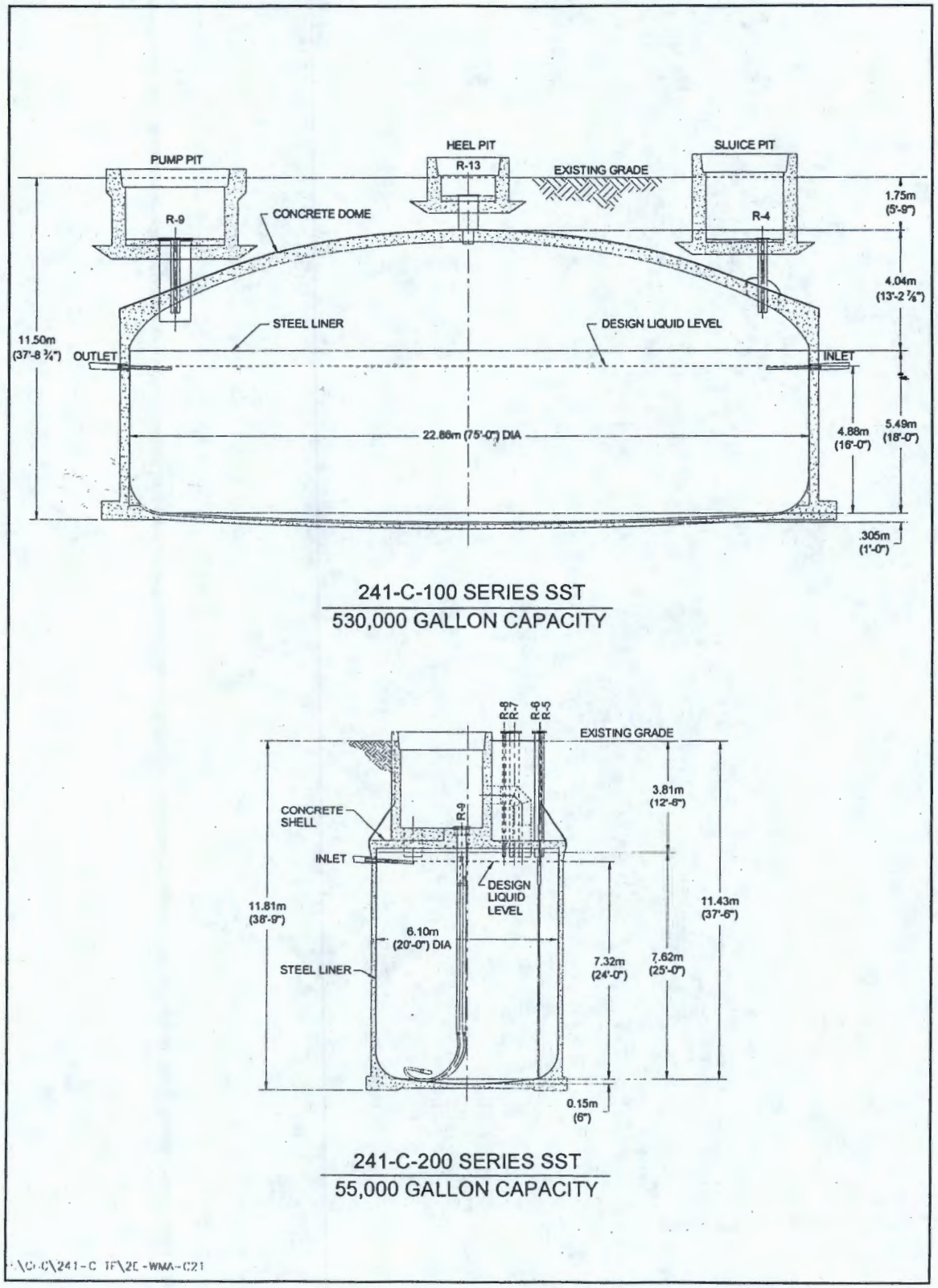


Figure C2-4. Schematic of the 244-CR Vault in WMA C.

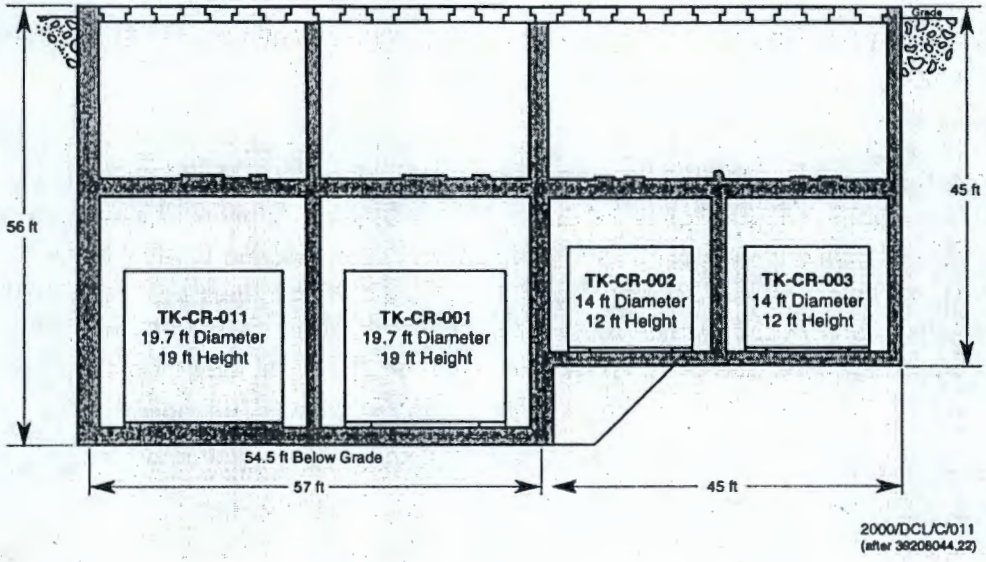
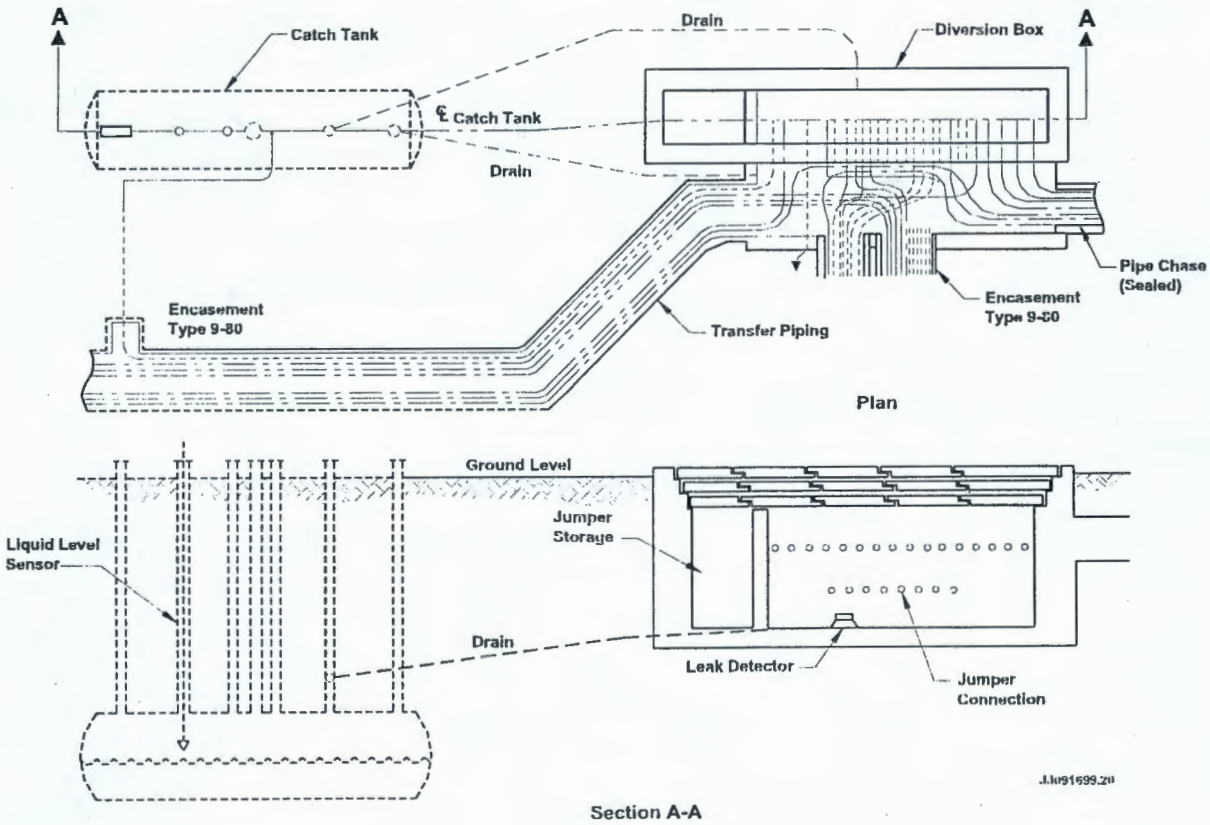


Figure C2-5. Schematic of a Typical Diversion Box Transfer System.



Valve pits are below-ground, reinforced concrete structures that contain valve and jumper assemblies that were used for routing the liquid waste through the transfer lines. Liquid waste was routed to valve pits when several tanks were undergoing simultaneous pumping to a single receiver tank. Each valve pit has a flush line connected to a flush pit or drain line connected to an underground tank.

Waste management practices in WMA C have included efforts to reduce the liquid content in tanks and to perform preliminary isolation of the tank systems. Table C2-1 provides the waste volume and stabilization/isolation status of the SSTs in WMA C. Waste volumes are updated on a quarterly basis. The values included in the table are from the December 2002 Best Basis Inventory (BBI) for tank contents as maintained on the Tank Waste Information Network System (TWINS) website. The risk assessment in Section C5.0 addresses uncertainty in input values. Most of the pumpable liquids have been removed from the SSTs and transferred to double-shell tanks (DST) as part of interim stabilization.

Intrusion prevention (IP) is the administrative designation for the completion of the physical activities required to minimize the addition of liquids into an inactive storage tank. Electrical and other instrumentation devices are not disconnected during intrusion prevention. Partially interim isolated (PI) is an administrative designation reflecting the completion of the physical activities required to minimize the addition of liquids to an inactive storage tank. Isolation of risers and piping that are required for jet pumping or other methods of stabilization are not included in the PI process. Interim stabilized (IS) means that the tank now contains less than 189,250 L (50,000 gal) of drainable interstitial liquid and less than 18,925 L (5,000 gal) of supernatant liquid. Waste volumes are updated on a quarterly basis in the BBI, and will document changes resulting from in-tank physical and chemical processes that may cause settling, condensing, stratification, and segregation of waste components. Retrieval (R) designation is given to tanks scheduled for removal of waste to the maximum extent practical, generally focusing on the removal of solids from the tank (HNF-EP-0182 2003).

Table C2-1. Waste Volume and Stabilization/Isolation Status by Tank as of December 2002. (2 Pages)

Tank 241-	Stabilization/ Isolation Status[a]	Total Waste (L [gal] x 1,000)	Supernatant Liquid (L [gal] x 1,000)	Sludge (L [gal] x 1,000)	Saltcake (L [gal] x 1,000)
C-101	IS/IP	333 [88]	0 [0]	333 [88]	0 [0]
C-102	IS/IP	1,196 [316]	0 [0]	1,196 [316]	0 [0]
C-103	/PI	764 [202]	291[77]	473 [125]	0 [0]
C-104	IS/IP	980 [259]	0 [0]	980 [259]	0 [0]
C-105	IS/PI	500 [132]	0 [0]	500 [132]	0 [0]
C-106	/PI	138 [36][a]	115 [30]	23 [6]	0 [0]
C-107	IS/IP	939 [248]	0 [0]	939 [248]	0 [0]
C-108	IS/IP	250 [66]	0 [0]	250 [66]	0 [0]
C-109	IS/IP	238 [63]	0 [0]	238 [63]	0 [0]
C-110	IS/IP	674 [178]	4 [1]	670 [177]	0 [0]

Table C2-1. Waste Volume and Stabilization/Isolation Status by Tank as of December 2002. (2 Pages)

Tank 241-	Stabilization/ Isolation Status[a]	Total Waste (L [gal] x 1,000)	Supernatant Liquid (L [gal] x 1,000)	Sludge (L [gal] x 1,000)	Saltcake (L [gal] x 1,000)
C-111	IS/IP	216 [57]	0 [0]	216 [57]	0 [0]
C-112	IS/IP	394 [104]	0 [0]	394 [104]	0 [0]
C-201	IS/R	4 [1]	0 [0]	4 [1]	0 [0]
C-202	IS/R	4 [1]	0 [0]	4 [1]	0 [0]
C-203	IS/R	11 [3]	0 [0]	11 [3]	0 [0]
C-204	IS/R	11 [3]	0 [0]	11 [3]	0 [0]

[a] HNF-EP-1082 2003
IP = intrusion prevention
IS = interim stabilized
PI = partially interim isolated
R = retrieval

C2.1 HISTORY OF WMA C

Constructed in the mid 1940s, WMA C was one of two original tank farms to receive bismuth phosphate process waste from B Plant. By the end of 1948, all tanks in the farm were filled with waste from the bismuth phosphate process.

In 1952 and 1953, metal wastes were sluiced from the SSTs in WMA C and sent to U Plant for uranium extraction. All the 100-series tanks in WMA C received the uranium recovery waste from the tributyl phosphate processing. The 200-series tanks received hot semi-works waste generated during PUREX pilot plan studies conducted in the mid 1950s. Tank C-204 received strontium semi-works waste in 1967 from the strontium recovery operations at the hot semi-works plant.

Beginning in May 1955 until December 1957, the 244-CR vault was used to mix ferrocyanide scavenging chemicals with uranium recovery waste to precipitate cesium-137 and strontium-90. Uranium recovery waste already stored in other 200 East Area tank farms was pumped to the vault for processing. The vault was used later as a receiving station, and operations ceased in 1988.

The PUREX process, along with B Plant waste fractionization processes, produced the most complicated combination of wastes at the Hanford Site. Waste types sent to WMA C included cladding wastes, organic wash wastes, and cell drainage.

Several other waste streams were routed to one or more tanks in WMA C. These include S Plant ion-exchange wastes, N Reactor complexed waste, evaporator bottom concentrate from 241-B and 241-BX farms, S Plant supernatant, process development wastes from the Hot Semi-Works (C Plant), low-level and metal waste from 241-B farm, and Hanford laboratory operations waste (DOE/RL-92-04).

Fourteen unplanned releases (UPR) have occurred within or adjacent to WMA C. The following brief descriptions of the UPRs are summarized from the Waste Information Data System (WIDS) General Summary Reports (the access page located at the Hanford intranet web site http://apweb02/cfroot/wids/) and represent the best information available on the nature and extent of releases. There exists substantial uncertainty in the volume and content of UPRs from components within the WMA C. Estimates of contaminant release volumes, inventories and location for some UPRs are included in the WMA C inventory data package associated with the risk assessment presented in Section C5.0. These estimates will be revised as new information becomes available. The UPR sites will be addressed as potentially contributing sources to the soil component and will be part of the soil component investigation and cleanup.

- Unplanned release UN-200-E-16 is a surface spill that resulted from a leak in an overground transfer pipeline between tanks C-105 and C-108. The surface spill associated with this release is located approximately 18 m (60 ft) northeast of tank C-105 and occurred in 1959. The spilled liquid was classified as coating waste from the PUREX process.

- Unplanned release UN-200-E-27 is located just east of the 244-CR vault and extends east beyond the tank farm fenceline. DOE/RL-92-04 indicates the surface contamination was deposited in 1960, but does not identify the source(s) of the contamination. Since the UN-200-E-27 release consisted of airborne particulate contamination, the impact was limited to the ground surface.

- Unplanned release UN-200-E-68 is wind-borne surface contamination spread from the 241-C-151 diversion box. The release occurred in 1985 and was subsequently decontaminated to background radiation levels or covered with clean soil for later decontamination (the source document is inconclusive). Sometime after the release, the 241-C-151 diversion box was opened, flushed, and sprayed with Turco Fabri-Film to physically fix contamination to the structure surface.

- Unplanned release UN-200-E-72 occurred in 1985 and is located south of WMA C near the 216-C-8 crib. The source of the contamination was buried contaminated waste. The waste posed little release potential because the contamination was fixed in place with Turco Fabri-Film. The source of the contamination was determined to be from the burial of previously undocumented contamination material. The area was surrounded with a chain and posted as a Surface Contamination Area; however, the site is no longer marked or posted. No information regarding the buried material was given in the WIDS report, it is assumed that the contamination extends to the depth of the buried material, but the aerial extent and depth are not known. The volume of the contamination was not specified.

- Unplanned release UN-200-E-81 is located northeast of the 244 CR vault, near the 241-CR-151 diversion box. It occurred as a result of a leak in an underground transfer pipeline in October 1969. The waste leaked from the pipeline consisted of PUREX coating waste. The site was covered with 0.5 m (18 inches) of backfill and clean gravel.

- Unplanned release UN-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 241-C-152 diversion box. The liquid release flowed from the vicinity of the 241-C-152 diversion box to the northeast, downgrade, until it pooled into an area, measuring approximately 0.46 m^2 (5 ft^2), outside the WMA C fence. The leak volume is unknown.The contaminated site was covered with clean gravel in 1969. The depth of the clean gravel applied in 1969 was not provided in the WIDS report; however, it states that additional decontamination of the area was done in 1985.

- Unplanned release UN-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 approximately 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 curies of cesium-137. 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 with "shotcrete". The release site is demarcated with concrete AC-540 marker posts and signs indicating "Underground Radioactive Material".

- Unplanned release UN-200-E-91 is located approximately 30 m (100 ft) from the northeast side of the tank farm. It resulted from surface contamination that migrated from WMA C. The date of the occurrence, its areal extent, and the nature of the contamination are not specified. DOE/RL-92-04 states that the contaminated soil was removed, and the area was released from radiological controls.

- Unplanned release UN-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.

- Unplanned release UN-200-E-100 is a surface spill of unknown volume and constituents that occurred in 1986. It is located about 60 m (8 ft) south and east of WMA C and surrounds the 244-A lift station.

- Unplanned release UN-200-E-107 is a surface spill located north of the 244-CR vault, inside WMA C. DOE/RL-92-04 states that a spill occurred on November 26, 1952, when a pump discharged liquid to the ground surface during a pump installation. The spilled waste was tributyl phosphate waste from 221-U building. The volume of the spill and any cleanup measures were not documented.

- Unplanned release UN-200-E-118 is located in the northeast portion of the tank farm and extends north up to about 300 m (1,000 ft) beyond the fenceline. It was the result of an airborne release from tank C-107 that occurred in April 1957. The highest exposure rate was estimated at 50 mrem/hour at the ground surface (DOE/RL-92-04).

- Unplanned release UPR-200-E-136 is a release of 64,345 to 90,840 L (17,000 to 24,000 gal) of waste from tank C-101. Two thousand curies were released between 1946 and 1970 (DOE/RL-92-04).

- Unplanned release UPR-200-E-137 occurred when water entered tank C-203, migrated through the saltcake, and either became entrained in the saltcake or leaked out of the tank. The leak was 1,514 L (400 gal) of PUREX high-level waste.

C2.2 COMPONENTS OF WMA C

The components that will be included in the WMA C closure action are listed in Table C2-2. This list is extracted from Addendum 1 of the *Single-Shell Tank System Closure Plan* (RPP-13774) which incorporates units listed on the RCRA Part A, Form 3, Rev. 8 permit application, in addition to RCRA Past Practice (RPP), *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) Past Practice (CPP), and Miscellaneous Storage Tank units. While most WMA C components are physically located within the C farm fenceline (also the WMA C boundary), some components extend beyond the fenceline (e.g., pipelines and groundwater) or are located outside the fenceline (e.g., 241-C-154 diversion box). Closure actions for components extending outside of the WMA boundary will be addressed through modifications to the Hanford Site-Wide Permit. Section C4.2 describes closure activities for these components.

Table C2-2. WMA C Components. (7 Pages)

Single-Shell Tanks			
Tank 241-	**Constructed**	**Removed From Service**	**Constructed Operating Capacity L (gal)**
C-101	1943 – 1944	1970	2,000,000 (530,000)
C-102	1943 – 1944	1976	2,000,000 (530,000)
C-103	1943 – 1944	1979	2,000,000 (530,000)
C-104	1943 – 1944	1980	2,000,000 (530,000)
C-105	1943 – 1944	1979	2,000,000 (530,000)
C-106	1943 – 1944	1979	2,000,000 (530,000)
C-107	1943 – 1944	1978	2,000,000 (530,000)
C-108	1943 – 1944	1976	2,000,000 (530,000)
C-109	1943 – 1944	1976	2,000,000 (530,000)
C-110	1943 – 1944	1976	2,000,000 (530,000)
C-111	1943 – 1944	1978	2,000,000 (530,000)
C-112	1943 – 1944	1976	2,000,000 (530,000)
C-201	1943 – 1944	1977	210,000 (55,000)
C-202	1943 – 1944	1977	210,000 (55,000)
C-203	1943 – 1944	1977	210,000 (55,000)
C-204	1943 – 1944	1977	210,000 (55,000)

Table C2-2. WMA C Components. (7 Pages)

Diversion boxes			
Unit 241-	**Constructed**	**Removed From Service**	**Description**
C-151	1946	1985	Interconnected 241-C-152, -153, and CR-151 diversion boxes
C-152	1946	1985	Interconnected 241-B-154 and -153 and C farm, associated with 241-C-301 catch tank
C-153	1946	1985	Interconnected 241-C-151 and -152 diversion boxes
C-154	1946	1985	Interconnected B-Plant to Hot-Semi Works. Box located at Hot-Semi Works
C-252	1946	1985	Interconnected 241-C-151 diversion box and C farm
CR-151	1952	1985	Interconnected 241-C-151 and C farm
CR-152	1946	1985	Interconnected 241-C-151 diversion box and C farm
CR-153	1946	1985	Interconnected 241-CR-152 diversion box and C farm
244-CR-Vault (contains four tanks)			
Tank 244-	**Constructed**	**Removed From Service**	**Description**
CR-011	1946	1988	Transfer of waste solutions from processes and decontamination operations.
CR-001	1946	1988	
CR-002	1946	1988	
CR-003	1946	1988	
Miscellaneous Tanks			
Facility Number		**Description**	
241-C-301 (aka 241-C-301C) (RPP)		Catch tank	
CR-003-TK/SMP		Tank/sump	
Miscellaneous Structures			
Facility Number		**Description**	
241-C-801 (RPP)		Cesium loadout facility	
Valve Pits			
Facility Number		**Description**	
241-C		Valve pit	
Tank Pits			
Facility Number		**Description**	
241-C-01A		Pump Pit	
241-C-01B		Heel Pit	
241-C-01C		Sluice Pit	
241-C-02A		Pump Pit	

Table C2-2. WMA C Components. (7 Pages)

Tank Pits (continued)	
Facility Number	**Description**
241-C-02C	Sluice Pit
241-C-03A	Pump Pit
241-C-03C	Sluice Pit
241-C-05A	Pump Pit
241-C-05B	Heel Pit
241-C-05C	Sluice Pit
241-C-07	No pit, covered saltwell caisson
241-C-08	No pit, covered saltwell caisson
241-C-09	No pit, covered saltwell caisson
241-C-110	No pit, covered saltwell caisson
241-C-111	No pit, covered saltwell caisson
241-C-112	No pit, covered saltwell caisson
241-C-02C	Sluice Pit
241-C-03A	Pump Pit
241-C-03C	Sluice Pit
241-C-05A	Pump Pit
241-C-05B	Heel Pit
241-C-05C	Sluice Pit
241-C-07	No pit, covered saltwell caisson
241-C-08	No pit, covered saltwell caisson
241-C-09	No pit, covered saltwell caisson
241-C-110	No pit, covered saltwell caisson
241-C-111	No pit, covered saltwell caisson
241-C-112	No pit, covered saltwell caisson

Transfer Lines		
Line Number	**Connecting Facilities**	
4012	241-CR-153	241-AX-151-D-Cell
4013	241-AX-151-D-Cell	241-CR-152-U3A
8002	241-C-103-03A-U1	241-CR-152-L13
8006	241-C-102-02A-U1	241-CR-152-L12
8010	241-C-101-01A-U1	241-CR-152-L11
8012	241-CR-152-U9,-U11,-U12	241-CR-151-U4
8014	241-C-103-03C-U1	241-CR-152-L10
8017	241-C-102-02C-U1	241-CR-152-L7
8020	241-C-101-01C-U1	241-CR-152-L9
8031	241-C-101-01A-U3	241-CR-152-L14

Table C2-2. WMA C Components. (7 Pages)

Transfer Lines (continued)		
Line Number	**Connecting Facilities**	
8032	241-C-103-03A-U2	241-CR-152-U6
8035	241-C-103-03C-U2	241-CR-152-U5
8037	241-C-102-02A-U3	241-CR-152-L15
8038	241-C-102-02A-U2	241-CR-152-U4
8041	241-C-102-02C-U2	241-CR-152-U3
8044	241-C-101-01A-U2	241-CR-152-U2
8047	241-C-101-01C-U2	241-CR-152-U1
8107	241-CR-152-L8	V844/241-CR-151-L8
8202	241-C-106-06A-U1	241-CR-153-L13
8206	241-C-105-05A-U1	241-CR-153-L12
8210	241-C-104-04A-U1	241-CR-153-L11
8214	241-C-106-06C-U1	241-CR-153-L10
8217	241-C-105-05C-U1	241-CR-153-L7
8220	241-C-104-04C-U1	241-CR-153-L9
8225	241-CR-153-U10	241-CR-151-U10
8231	241-C-104-04A-U3	241-CR-153-L14
8232	241-C-106-06A-U2	241-CR-153-U6
8235	241-C-106-06C-U2	241-CR-153-U5
8237	241-C-105-05A-U3	241-CR-153-L15
8238	241-C-105-05A-U2	241-CR-153-U4
8241	241-C-105-05C-U2	241-CR-153-U3
8244	241-C-104-04A-U2	241-CR-153-U2
8247	241-C-104-04C-U2	241-CR-153-U1
8552	241-C-201,-202,-203,-204-U2	241-CR-151-U2
8555	241-CR-151-U5	241-C-201,-202,-203,-204-U2
8601	241-CR-151-L1	244-CR-Tank-001
8616	241-CR-151-L5	244-CR-Tank-011-U1
8624	241-CR-152-U8	241-CR-151-U7
8625	241-CR-153-U8	241-CR-151-U6
8630	241-CR-152-L1,-2,-3,-4,-5,-6	241-CR-151-U9
8631	241-CR-153- L1,-2,-3,-4,-5,-6	241-CR-151-U8
8644	241-CR-151-U12,-U13,-U15	241-CR-151-U12,-U13,-U15
8647	241-CR-151-L4	244-CR-Tank-003-U1
8648	241-CR-151-L6	244-CR-Tank-002-U1
8656	241-AX-151	244-CR-DCRT-Tank-003
8900	201-C-Valve Box	244-CR-Tank-003-U10

Table C2-2. WMA C Components. (7 Pages)

Transfer Lines (continued)		
Line Number	**Connecting Facilities**	
108/837/8649/8901	221-B	244-CR-DCRT
8636/V105	241-CR-151-U1	241-C-151-L6
8653/8618	241-ER-151-L9	241-CR-151-U14
A4013	241-CR-152-3A	241-AX-151-Washdown
Drain Line	241-C-102-02B-U3	241-C-Valve Pit-L1
Drain Line	241-C-103	241-C-Valve Pit
Drain Line	241-C-104-04C	241-CR-153
Drain Line	241-C-104-04B-U3	241-C-Valve Pit-L2
Drain Line	241-C-107-U1	241-C-Valve Pit-L3
Drain Line	241-C-252	Unknown Catch Tank
Drain Line	241-C-153 & 241-C-151	Unknown Catch Tank
Drain Line	244-CR-Tank-002	241-CR-151
Drain-301	241-C-106-06C-U8	Metal Filter Drain
Drain-302	241-C-106-06C-U9	Process Building Floor Drain
Flush Line	241-SX-A-R6,R17	241-SX-B-Flush Pit
SN244	244-CR-Vault	241-ER-153
SN275	241-C-VP-U1,-U2,-U3,-U4,-U5,-U6	244-CR-U15
Unknown	241-C-101	241-C-102
Unknown	241-C-102	241-C-103
Unknown	241-C-101-01B-U1	8010
Unknown	241-C-102-02B-U2	Line 8006
Unknown	241-C-103-03B-U1	241-C-Valve Pit-L6
Unknown	241-C-103-03B-U2	Line 8002
Unknown	241-C-104-04B-U2	Line 8210
Unknown	241-C-104-04B-U3	241-C-Valve Pit-L2
Unknown	241-C-10505B-U3	Capped
Unknown	241-C-105-05B-U2	Line 8206
Unknown	241-C-106-06B-U2	Line 8202
Unknown	241-C-108	241-C-107
Unknown	241-C-109	241-C-108
Unknown	241-C-110-U1	241-C-Valve Pit-L3
Unknown	241-C-111	241-C-110
Unknown	241-C-112	241-C-111
Unknown	241-C-112	241-C-Valve Pit-L5
V050	241-A-152-L7	241-C-104
V051	241-A-152-L8	241-C-104

Table C2-2. WMA C Components. (7 Pages)

Transfer Lines (continued)		
Line Number	**Connecting Facilities**	
V100	241-C-151-L1	241-C-153-U9
V1000	241-CR-152	244-CR Vault-U14
V1001	241-CR-152-U4A	241-CR-153-U3A
V1002	241-CR-152-U6A	241-CR-153-U1A
V101	241-C-153	Capped
V101	241-C-151-L2	241-C-104-04A-U4
V102	241-C-101	241-C-151-L4
V103	241-C-105	241-C-151-L3
V104	241-C-101	241-C-151-L5
V105/8636	241-C-151-L6	241-CR-151-U1
V107	241-C-252-U4	241-C-151-L8
V108/812	241-C-151-U1	244-AR-Tank-002-T9
V109	241-C-151-U2	241-A-101
V110	241-C-151-U3	244-CR Vault-U12
V113	241-C-151	241-AX-101-01A
V113	241-C-151	241-AX-103-03A-1
V115	241-C-105-05A-U8	241-C-152-L1
V118	241-C-152-L4	241-C-153-U6
V119	241-C-152-L5	241-C-153-U5
V120	241-C-152-L6	241-C-153-U4
V121	241-C-152	Capped
V122	241-C-105-05A-U4	241-C-152-L8
V130	241-B-154-L8	241-C-152-U4
V136	241-C-153-L1	None Identified
V137	241-C-153-L2	241-C-110
V138	241-C-110	241-C-153-L3
V139	241-C-110	241-C-153-L4
V140	241-C-110	241-C-153-L5
V141	241-C-153-L6	Capped
V142	241-C-153-L7	Capped
V143	241-C-107	241-C-153-L8
V144	241-C-107	241-C-153-L9
V145	241-C-107	241-C-153-L10
V147	241-C-153-L1,-L2	None Identified
V148	241-C-104	241-C-153-L13
V149	241-C-104	241-C-153-L14

Table C2-2. WMA C Components. (7 Pages)

Transfer Lines (continued)		
Line Number	**Connecting Facilities**	
V150	241-C-104	241-C-153-L15
V156	241-C-201	241-C-252-L1
V157	241-C-201	241-C-252-L2
V158	241-C-202	241-C-252-L3
V159	241-C-202	241-C-252-L4
V160	241-C-203	241-C-252-L5
V161	241-C-203	241-C-252-L6
V162	241-C-204	241-C-252-L7
V163	241-C-204	241-C-252-L8
V172	241-C-252-U1	241-C-109/241-C-112
V175	241-C-252-U5	201-C-Hot-Semi Works
V210/V111	241-B-154-L10	241-C-151-U4
V228	241-CR-153-U6A	241-ER-153-7

C3.0 GROUNDWATER MONITORING

In accordance with closure requirements outlined in WAC 173-303-610(3)(a)(vi) and the HFFACO, this section describes groundwater monitoring requirements and activities associated with WMA C. To provide context to the groundwater monitoring discussion, the description includes:

- The regulatory basis for groundwater monitoring at WMA C
- A summary of the hydrogeologic conditions in the vicinity of WMA C
- The extent of known contamination in the vadose zone beneath WMA C and plans for future vadose zone characterization
- Current monitoring network configuration and management
- Groundwater sampling results
- Plans for modifications to the groundwater monitoring network.

C3.1 REGULATORY BASIS FOR GROUNDWATER MONITORING ACTIVITIES

DOE monitors groundwater at the Hanford Site pursuant to the HFFACO and to fulfill a variety of state and federal regulations, including the AEA, RCRA, CERCLA, and WAC regulations. DOE manages groundwater monitoring activities through the Hanford groundwater monitoring project.

U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), and DOE agreed to implement a RCRA groundwater monitoring system in accordance with the HFFACO Milestone M-24 and M-45 series. The primary objectives of RCRA groundwater monitoring are to comply with regulatory requirements and agreements, assess the potential impact of facilities on groundwater quality, and identify near-term corrective measures, if feasible, for the protection of human health and the environment. In conformance with interim-status standards contained in 40 *Code of Federal Regulations* (CFR) 265 Subpart F (which was incorporated by reference into WAC 173-303-400), RCRA projects are monitored according to three levels of effort:

- Background monitoring
- Indicator evaluation
- Groundwater quality assessment.

As shown on Figure C2-2, nine RCRA groundwater monitoring wells are located outside the WMA C fenceline. The wells are intended to monitor groundwater contamination attributable to the entire WMA rather than individual components. The initial background-monitoring program for WMA C is complete and monitoring is currently conducted under an interim status indicator evaluation program (PNNL-13024 , PNNL-13024-ICN-1). Monitoring under the indicator evaluation program will continue until the entire WMA is closed or at such time there is a shift to assessment monitoring as a result of statistically significant changes in indicator parameter concentrations in groundwater. Changes in the monitoring program status will be documented in modifications to the WMA C RCRA groundwater monitoring plan (PNNL-13024, PNNL-13024 ICN-1).

Prior to closure of WMA C, a postclosure groundwater-monitoring plan will be developed. Postclosure groundwater monitoring, in compliance with WAC 173-303-645, will be integrated with the Central Plateau regional groundwater monitoring system. At that time, a description of the planned groundwater monitoring activities, frequencies at which they will be performed, and reporting requirements as required by WAC 173-303-645 and -665 will be included. The plan must be approved by Ecology and modified through the WAC 173-303-830 process.

C3.2 HYDROGEOLOGIC CONDITIONS IN THE VICINITY OF WMA C

The site stratigraphy, aquifer characteristics, and vadose zone characteristics described in this section are based on information presented in the *RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C at the Hanford Site* (PNNL-13024) and the corresponding interim change notice (PNNL-13024-ICN-1). Characterization information in these references was compiled principally using wells outside the WMA C fenceline. Geologic and hydrologic data obtained from these wells are used for inferring generalized stratigraphy and groundwater conditions below WMA C, but do not provide site-specific detail regarding hydrogeologic conditions that affect potential distribution and movement of contaminants directly below the individual components of WMA facilities. Elevation values contained in Section C3.2.1 are based on the North American vertical datum of 1988.

C3.2.1 Site-Specific Stratigraphy

The geology beneath WMA C was first described in ARH-LD-132 and later in WHC-SD-EN-AP-012, WHC-SD-EN-TA-004, and HNF-2603. WMA C geology was recently updated based on examination of gross gamma-ray and neutron moisture logs, archived drill cuttings, and analysis of laboratory moisture and particle size distribution data (PNNL-13024, PNNL-13024-ICN-1).

The geology beneath WMA C consists of basalt basement overlain by five sedimentary sequences distinguished by texture or particle size and stratigraphic position. These sequences are (oldest to youngest):

- Hanford formation lower gravel sequence

- Hanford formation sand sequence
- Hanford formation upper gravel sequence
- Holocene eolian surficial deposits
- Backfill material

Table C3-1 summarizes the stratigraphic information for selected wells associated with WMA C. Much of the information used in Table C3-1 was taken directly from Table 2.4 in the WMA C groundwater monitoring plan (PNNL-13024). Top of basalt elevations and elevations of units beneath drywells 30-04-12 (aka 299-E27-65) and 30-06-02 (aka 299-E27-72) were interpolated from geologic surface maps and geologic cross sections (PNNL-12261, PNNL-13024). These interpolated data should only be used as estimates until refined through possible future characterization activities.

Table C3-1. Stratigraphic Data.

Well ID	Total depth[b] m (ft)	Elevations[a]						
		Surface[c] m (ft)	Top of eolian surficial deposits[d] m (ft)	Top of backfill material[d] m (ft)	Top of Hanford formation upper gravel sequence[b] m (ft)	Top of Hanford formation sand sequence[b,e] m (ft)	Top of Hanford formation lower gravel sequence[b,e] m (ft)	Top of basalt[f] m (ft)
299-E27-7	86 (281)	194 (636)	NE	NE	194 (636)	182 (596)	130 (426)	107 (351)
299-E27-12	83 (270)	202 (661)	NE	NE	202 (661)	191 (626)	133 (436)	105 (345)
299-E27-13	85 (280)	204 (669)	NE	NE	204 (669)	192 (629)	131 (431)	104 (342)
299-E27-14	81 (267)	201 (658)	201 (658)	NE	198 (650)	187 (613)	131 (428)	105 (344)
299-E27-15	80 (263)	199 (653)	199 (653)	NE	197 (645)	193 (633)	129 (423)	107 (351)
30-04-12 (299-E27-65)	41 (135)	199 (651)	NE	199 (651)	NE	186 (609)	131 (428)	105 (344)
30-06-02 (299-E27-72)	38 (125)	198 (648)	NE	198 (648)	NE	186 (609)	130 (427)	107 (350)

[a] Elevations rounded to nearest whole number – North American vertical datum of 1988 surveyed in 1994.

[b] From Table 2.4 of PNNL-13024.

[c] Surface elevations based on brass marker elevations minus a 0.2 m (0.5-ft) correction factor for approximate thickness of concrete pad. For wells 299-E27-65 and 299-E27-72 surface elevation based on top of casing survey.

[d] Interpreted from geologists logs in Appendix C of PNNL-13024.

[e] For wells 299-E27-65 and -72 geologic contacts interpolated from geologic cross sections (Plates 1-3) in PNNL-13024. Assumes 12 m (40 ft) of backfill material inside tank farm boundary.

[f] Interpolated from top of basalt map (Plate 4) in PNNL-12261 .

NE = Unit not encountered during drilling of borehole.

The Elephant Mountain Member of the Saddle Mountains Basalt Formation forms the bedrock base below WMA C. Drywells associated with the WMA C are not deep enough to encounter the Elephant Mountain Member basalt. A 200 East Area basalt surface map published in PNNL-12261 depicts the top basalt below WMA C at approximately 104.3 to 107.0 m (342 to 351 ft) elevation. The apparent dip of the basalt surface is south-southwest.

Directly overlying the basalt beneath WMA C is a sedimentary sequence characterized as cobble to pebble gravels, sandy gravels, and gravelly sands with lesser amounts of silty sandy gravel, and sand with occasional silt lenses. The gravels are subangular to well rounded and generally uncemented, although some local calcium carbonate consolidation is present. The age and stratigraphic nomenclature associated with this lower gravel sequence are variably described by WHC-SD-EN-AP-012, HNF-2603, and PNNL-12261. However, for this closure plan, the sequence is referred to as the Hanford formation lower gravel sequence, which is consistent with nomenclature used in the WMA C groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1). The elevation of the top of the Hanford formation lower- gravel sequence ranges from 129.0 to 132.9 m (423 to 436 ft). Below the tank farm proper, the depth to the unit is approximately 67.7 m (222) or 56.4 m (185 ft) below the bottom of the SSTs. The estimated thickness of this undifferentiated sequence ranges from 22.0 to 27.7 m (72 to 91 ft) with an apparent thinning toward the basalt high.

The Hanford formation sand sequence overlies the Hanford formation lower gravel sequence beneath WMA C. This sequence is the thickest sedimentary unit underlying WMA C. The sequence is characterized as variably bedded silty sand, sand, and slightly gravelly to gravelly sand. The sandy beds exhibit a "salt and pepper" coloration due to the basaltic and felsic-mineral composition. The sequence is not cemented but does contain zones with calcium carbonate as small concretions and as coatings on sediment grains. The elevation of the top of the Hanford formation sand sequence ranges from 181.7 to 193.0 m (596 to 633 ft). Below the tank farm proper, the sequence occurs at approximately 12.2 m (40 ft) bgs or about 0.9 m (3 ft) below the bottom of the SSTs. The estimated thickness of the sequence ranges from 51.8 to 64.0 m (170 to 210 ft).

The Hanford formation upper gravel sequence overlies the sand sequence. The Hanford formation upper gravel sequence is described on borehole logs of cuttings as consisting of interbedded sandy gravels, gravelly sands, and sands. The upper gravel sequence consists of the gravel-dominated facies and was deposited by high-energy, glacial flood waters.

The elevation of the top of the Hanford formation upper gravel sequence ranges from 193.9 to 204.0 m (636 to 669 ft). The sequence varies from 3.7 to 12.2 m (12 to 40 ft) thick in the WMA C vicinity. This unit was removed from most, if not all, of the tank farm proper during construction and replaced as backfill after construction was complete. Outside WMA C, the sequence occurs at ground surface except at wells 299-E27-14 and 299-E27-15 where approximately 2.4 m (8 ft) of Holocene eolian sands cap the surface.

Within WMA C, the uppermost 12.2 m (40 ft) of material is backfill consisting of mixed gravel, sand and silt excavated from the Hanford formation during construction of the tank farm (WHC-SD-EN-TA-004). Excavated soils were used as backfill around the tanks.

C3.2.2 Aquifer Identification and Hydrogeologic Description

Depth-to-groundwater measurements collected from the five of the WMA C groundwater monitoring wells on June 25, 2002, indicate that the elevation of the uppermost aquifer beneath WMA C occurs at 122.3 m (401 ft) (PNNL HydroDat Database 2002). Details on the nature of the unconfined, uppermost aquifer are provided in PNNL-13024 and PNNL-13024-ICN-1.

In general, aquifer materials beneath WMA C are comprised of sandy gravel or silty sandy gravel. Although there is some consolidation of sediments within the unconfined aquifer, there is little evidence of compaction or cementing. Consequently, permeability is high and relatively homogeneous within the aquifer (PNNL-13024, PNNL-13024-ICN-1).

The base of the uppermost unconfined aquifer is defined by the top of the basalt. The thickness of the uppermost unconfined aquifer in the vicinity of WMA ranges from approximately 14 to 20 m (45 to 50 ft).

Groundwater flow direction and gradient in the vicinity of WMA C historically has been influenced by the substantial groundwater mound beneath B pond, located east of the WMA. The B pond mound, when at its peak, caused groundwater to assume a west to northwest flow direction. Following discontinuation of discharges to B pond, the mound has dissipated. As a result, the groundwater flow direction beneath WMA C has begun to return to what is expected to be its natural flow direction (which is generally southeast toward the Columbia River).

The hydraulic gradient below WMA C is nearly flat making it difficult to determine groundwater flow direction from water-level elevations. In fiscal year (FY) 2001, Pacific Northwest National Laboratory (PNNL) integrated the use of colloidal borescope surveys and gyroscopically corrected water-level data to estimate groundwater flow beneath WMA C (PNNL-13788). This survey concluded that the general flow direction is southwest at approximately 214 degrees azimuth (PNNL-13024-ICN-1).

The flow direction is expected to continue to change until it ultimately assumes a southeast direction. The actual time required for return to a "normal" flow pattern beneath WMA C will be driven by the decay of the B-pond mound and potentially by continuing discharges to the Treated Effluent Discharge Facility located to the east of the 200 East Area.

The RCRA standard wells at WMA C constructed prior to 2003 have open intervals within the aquifer ranging from 2.4 to 3.4 m (7.9 to 10.6 ft) in length. Well 299-E27-7, which is a pre-RCRA well, has a 14.3 m (46.9 ft) open interval in the aquifer. The rate of water table decline beneath WMA C has increased from 9.1 cm (0.3 ft) per year in June 1997 to approximately 30.5 cm (1 ft) per year in March 1999. If this current rate continues, downgradient well 299-E27-13, with less than 3 m (10 ft) of water, may become unusable in six or seven years.

The groundwater flow rate beneath WMA C is estimated to be between 0.7 and 1.4 m (2.4 and 4.8 ft) per day, or 267 to 534 m (876 to 1,752 ft) per year (PNNL-13024, PNNL-13024-ICN-1). These estimates were derived using the groundwater gradient across WMA C from June 2000

data, estimated porosity of the saturated sediments (PNNL-12086), and various published values for hydraulic conductivities in the 200 East Area (WHC-SD-EN-TI-147, WHC-SD-WN-TI-019).

C3.2.3 Vadose Zone Description

The vadose zone beneath WMA C is approximately 71.7 to 81.7 m (235 to 268 ft) thick in the vicinity of WMA C based on June 2002 groundwater data. The vadose zone is contained within the following strata (listed oldest to youngest). A brief description of each of these strata is found in Section C3.2.1.

- Hanford formation lower gravel sequence
- Hanford formation sand sequence
- Hanford formation upper gravel sequence
- Backfill material.

Texturally, the vadose zone is largely comprised of coarse sands with some gravels and silts. Clastic dikes (see Section C3.3) also were observed in C farm during construction, but were not mapped (ARH-LD-132).

C3.3 CONCEPTUAL MODEL FOR CONTAMINANT MIGRATION

The conceptual model for WMA C is an overview that summarizes the physical characteristics and mechanisms that potentially could lead to generation and transport of contamination to the groundwater. A detailed assessment of the conceptual model for WMA C including contaminant sources, source constituents, contaminant drivers, and migration pathways is provided in the WMA C groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1) and also elaborated in the WMA C risk assessment which includes numerical modeling (Section 5.0 and Addendum C1). The conceptual model is based upon hydrogeologic and contaminant distribution data collected to date and will be modified subsequent to further field investigations in support of the RFI/CMS process and/or closure activities.

The primary potential sources of contamination in the WMA C are:

- SSTs
- Diversion boxes, vaults, and catch tanks
- Valve pits
- Piping
- Surface spills

- Existing soil contamination.

As discussed earlier, the vadose zone beneath WMA C is approximately 71.7 to 81.7 m (235 to 268 ft) thick in the vicinity of WMA C. Consequently, contamination from a near-surface source must migrate vertically through a substantial thickness of unsaturated soils before reaching the groundwater. Because of the nature of the depositional environment associated with the Hanford formation (that is, moderate to high-energy flood deposits), a large variability exists in heterogeneity and anisotropy over vertical and horizontal scales on the order of tens of feet. Delineating a migration pathway through this thick sequence of unconsolidated sediments beneath WMA C can be complex.

The stratigraphy in the vicinity of WMA C lacks the distinct, laterally continuous, silt-rich units and paleosols (such as caliche layers) found in the suprabasalt sediments in the 200 West Area and some parts of the 200 East Area (such as B, BX, BY farms) (PNNL-13024, PNNL-13024-ICN-1). These generally low-permeability units result in perching and lateral spreading of vertically-migrating liquids, in some cases for long distances. Below WMA C, thin intercalated, silt-rich units and paleosols are present, although these thin layers are not common and generally are not laterally continuous. Consequently, vadose-zone sediments below WMA C are not expected to have much effect on retarding downward migration of fluids or cause extensive lateral spreading. Therefore, potential impacts to the groundwater from contaminant sources would likely occur near the source.

Potential preferential pathways for vertical contaminant migration are identified for the WMA C. These potential pathways include clastic dikes, poorly sealed well casings, and the tank sidewalls. In addition, leaking water and other water sources, such as stormwater runoff, may accelerate transport of contaminants.

Clastic dikes are sedimentary features that crosscut existing horizontal bedding and may provide preferential pathways for contaminants to move through the vadose zone to groundwater. The maximum vertical extent of a clastic dike is about 45.7 m (150 ft) into the subsurface. Clastic dikes have been documented in boreholes at WMA C (ARH-LD-132, BHI-01103), although the effects of clastic dikes on contaminant transport are not established.

The annular space on the outside of unsealed well casings or wells with poorly constructed annular seals potentially provides a vertical preferential pathway. WMA C has several drywells that are used for secondary leak detection and have no annular seals or are poorly sealed. These drywells extend from 15.2 to 47.2 m (50 to 155 ft) bgs.

The sidewalls of the SSTs provide a large surface for preferential contaminant migration in the upper 15.2 m (50 ft) of the soil column. As discussed in Section C3.4.1, much of the cesium-137 contamination associated with the soil column in WMA C is attributed to possible surface or near surface sources that migrated along the sidewalls of the tank structures.

Section C3.4.3 discusses the planned characterization activities for WMA C that are intended to provide understanding of migration pathways through both the vadose zone and the sediments in the unconfined aquifer. Influences from various moisture driving forces also may become better understood. This conceptual model will be revised as necessary to reflect these new findings.

C3.4 EXTENT OF VADOSE ZONE CONTAMINATION

This section describes the known extent of vadose zone contamination in the vicinity of WMA C to supplement the lack of groundwater data inside the tank farm boundary. Vadose monitoring efforts provide data from drywells located around the various waste management facilities (particularly the SSTs) within WMA C.

C3.4.1 Vadose Zone Monitoring – WMA C Drywells

Figure C3-1 shows the existing vadose zone monitoring network associated with WMA C. There are 70 vadose zone monitoring wells (drywells) associated with WMA C. The distribution of these wells is targeted primarily around the twelve 2,000,000-L (530,000-gal) SSTs. There are few drywells around the four 210,000-L (55,000-gal) SSTs (C-201, C-202, C-203, and C-204) and some of the vaults and diversion boxes.

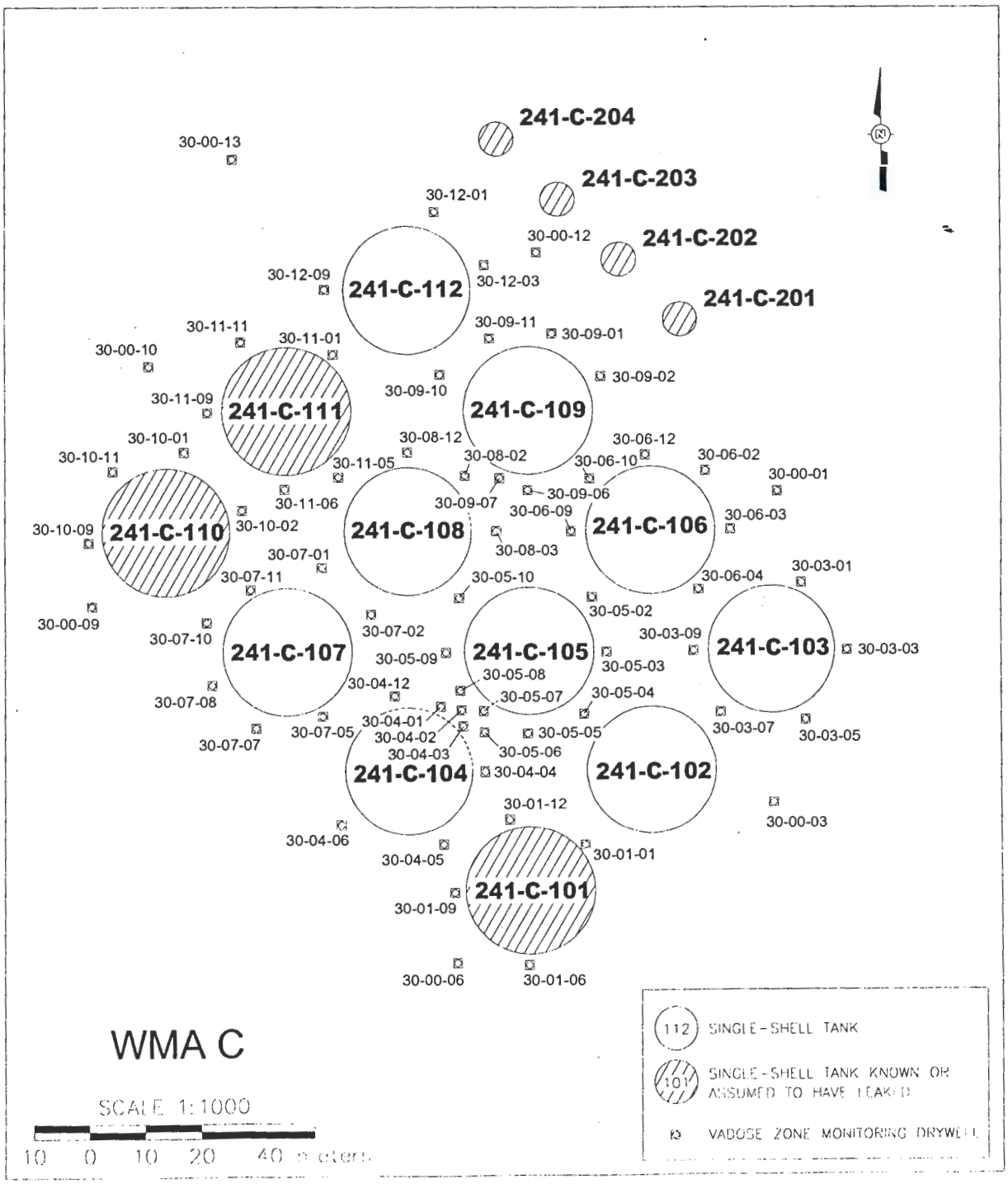
The current vadose zone monitoring program implemented at WMA C as well as other tank farms on the Hanford Site is described in *Hanford 200 Areas Spectral Gamma Baseline Characterization Project – Baseline Characterization Plan* (GJO-HGLP-1.7.1). Under this monitoring plan, drywells are monitored (logged) on a quarterly, annual, or a 5-year frequency. The order and frequency of monitoring is based on a priority score, which is calculated using tank and plume-related factors developed from the baseline characterization. The frequency of routine monitoring currently established for the wells within WMA C is documented in Appendix A of the *Hanford Tank Farms Vadose Zone Monitoring Project Baseline Monitoring Plan* (MAC-HGLP 1.8.1).

In 1997, these drywells were logged using a high resolution spectral gamma logging system. This effort was part of the baseline characterization for WMA C. The purpose of the baseline characterization was to acquire a baseline of the distribution of individual man-made gamma-emitting radioisotopes (originating from mixed-waste sources) within the vadose zone. Results of the baseline characterization for WMA C are documented in the *Vadose Zone Characterization Project at the Hanford Tank Farms C Tank Farm Report* (GJPO-HAN-18 1998) and associated addendum (GJO-HAN-18 2000) and are summarized in Section C3.4.2. Results of the radionuclide concentration logs for individual drywells were compiled and presented in 12 individual tank summary data reports (GJ-HAN-82, -83, -84, -85, -86, -87, -88, -90, -91, -92, -93, -94).

The baseline characterization and follow-up logging provided a better understanding of where gamma-emitting contamination occurs in the upper part of the vadose zone within WMA C. The major gamma-emitting contaminants associated with WMA C are cesium-137 and cobalt-60 with lesser amounts of europium-154. These contaminants are located mostly in and around areas of known or suspected tank and pipeline leaks. Logging results indicated that the contaminated zones are isolated occurrences and most probably resulted from surface spills and pipeline leaks. Although most of the drywells are deeper than the surrounding contamination, some zones of contamination extend deeper than nearby drywells. Consequently, the maximum depth of vadose zone contamination is not known in some areas of WMA C. GJO-HGLP-1.7.1

describes the tasks and organizational requirements associated with routine vadose zone monitoring operations in the SST farms. Included in the plan are the methods and procedures associated with data evaluation, selection, and prioritization of individual borehole intervals to be logged, scheduling, data acquisition procedures, and reporting.

Figure C3-1. Vadose Zone Monitoring Network for WMA C.



C3.4.2 Vadose Zone Monitoring Results

Estimates for volumes of the contaminated formation and total radioactivity for cesium-137, cobalt-60, and europium-154 were determined for WMA C using data from the 1997 baseline spectral gamma characterization system. Total activity for major gamma emitters (cesium-137, cobalt-60, and europium-154) in the vadose zone is approximately 42 curies in 26,400 m^3 (34,500 yd^3) of soil (soil volume estimate based on extent of cesium-137 contamination). Evaluation of repeat logging data indicates that cobalt-60 movement through the vadose zone has occurred in the past and appears to be continuing (GJO-HAN-18 2000).

Limitations of estimates on the extent of contamination include the following:

- No data are available from directly under the tanks.
- No data are available below the bottoms of drywells. The deepest drywell in WMA C is 47.3 m (155 ft) bgs (well 30-00-03), and the maximum logged depth is 43.6 m (143 ft) bgs in well 30-04-08.

Additional information on the derivation of these estimates is included in GJPO-HAN-18 (1998). Additional information on man-made radionuclide distribution and movement will be discussed in the field investigation report resulting from the WMA C Phase I field investigation.

C3.4.3 Planned Vadose Zone Characterization

The *Site-Specific Single-Shell Tank Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan Addendum for Waste Management Areas C, A-AX, and U* (RPP-16608) describes planned vadose zone characterization for WMA C. Additional vadose zone characterization activities are proposed for WMA C between FY 2003 and FY 2005.

Additional vadose zone characterization information obtained subsequent to preparation of this closure action plan will be documented in a RCRA Facility Investigation (RFI) report pursuant to HFFACO M-45-55. This includes data collected during the drilling and installation of the new groundwater monitoring wells discussed in Section C3.5.5. New data will be incorporated in risk assessment modeling as described in Section C4.2.5.

C3.5 INTERIM STATUS GROUNDWATER MONITORING

At WMA C, RCRA groundwater monitoring is performed according to an interim status groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1). The current groundwater monitoring network was designed in accordance with RCRA, as presented in 40 CFR 265, Subpart F.

C3.5.1 Groundwater Monitoring Well Network

The groundwater monitoring network is shown in Figure C2-2. The original groundwater-monitoring network (wells 299-E27-7, -12, -13, -14, and –15) was designed for a flow direction from east to west (WHC-SD-EN-AP-012). Changes in groundwater flow direction necessitated the installation of four additional wells to improve upgradient and downgradient coverage of WMA C. Details of the existing groundwater monitoring network, including well construction information and monitoring efficiencies, are discussed in the WMA C groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1). Ecology has expressed concern regarding the model parameters used to evaluate the groundwater monitoring network efficiency [Ecology Letter, October 13, 2002 D. Goswami, Ecology to K.M. Thompson DOE-RL *Monitoring Efficiency Model (MEMO) as Applied to Single-Shell Tank (SST) Farm Waste Management Areas (WMAs)*].

Table C3-2 gives well-by-well information on the position of each well with respect to flow direction, sampling objective, and sampling frequency. The cross gradient, upgradient, and downgradient designations refer to the location of the wells with respect to the southwesterly groundwater flow direction refined based on colloidal borescope measurements (PNNL-13024, PNNL-13024-ICN-1).

Table C3-2. Network Monitoring Wells.

Well Name (299-)	Completion Date	Upgradient Downgradient*	Sampling Objective and Frequency
E27-7	1982	Up	C, SA
			WL, Q
E27-12	1989	Cross	C, SA
			WL, Q
E27-13	1989	Down	C, SA
			WL, Q
E27-14	1989	Cross	C, SA
			WL, Q
E27-15	1989	Marginally up	C, SA
			WL, Q
E27-22	2003	Up	C, SA
			WL, Q
E27-4	2003	Down	C, SA
			WL, Q
E27-21	2003	Marginally Down	C, SA
			WL, Q
E27-23	2003	Down	C, SA
			WL, Q

Source: PNNL-13024, PNNL-13024-ICN-1

* Upgradient/downgradient determintations based on an average groundwater flow direction as defined in PNNL-13024-ICN-1 (2002)

C = chemistry monitoring

Q = quarterly

SA= semi-annual

WL =water level measurement

C3.5.2 Groundwater Sampling and Analysis Plan Overview

The WMA C groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1) includes a sampling and analysis plan for the current interim-status groundwater monitoring plan. This sampling and analysis plan describes the quality assurance project plan and the field sampling plan for groundwater monitoring. Procedures for groundwater sampling, sample documentation and preservation, shipment, and chain-of-custody requirements are described in ES-SSPM-001 (1998) and in the quality assurance project plan (PNNL 1998).

C3.5.3 Groundwater Quality Monitoring Results

Results of the groundwater detection indicator evaluation program for WMA C are published annually. The contaminant indicator parameters and the statistical evaluation methodology for the groundwater indicator evaluation program are described in the WMA C groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1).

The WMA C groundwater monitoring plan provides historic information on the results of RCRA groundwater monitoring at WMA C since the initiation of routine detection monitoring at that site in 1992. Information on recent and past contaminant issues is provided. There have been recent (1994-1999) small increases in contaminant levels across the WMA. However, the concentrations are generally low. Without a better understanding of local flow direction, it is too early to suggest sources for these small increases in contamination. The critical mean values for the indicator parameters (pH, electrical conductivity, total organic carbon, and total organic halides) have not been exceeded during this time.

Technetium-99 activity has been rising gradually in all the network wells. In well 299-E27-14, it has been increasing since 1994 or earlier (Figure C3-3). The maximum value of 709 pCi/L for this well was reached in December 1999. This concentration is below the drinking water standard (DWS) of 900 pCi/L. Increases in various anion and cation concentrations correspond to the rising technetium-99 trend (Figures C3-3 through C3-7). Until June 1999, nitrate and sodium trends correlated with the technetium-99 activity (Figure C3-8). After September 1999, the nitrate and sodium values ceased to track the technetium-99 upward trend actually decreasing in concentration. As of 2001, the nitrate concentration in this well is about 16,000 μg/L (May 2000), which is well below the DWS of 45,000 μg/L. The calcium chloride and sulfate concentrations continue to track the rising technetium-99 activity (Figures C3-5, C3-6, and C3-7). Maximum sulfate values are about 82,000 μg/L while the calcium value is about 40,000 μg/L. This change in co-contaminant chemistry may be due to chemical heterogeneities within a larger, regional plume.

Figure C3-2. Trend Plot of Technetium-99 at WMA C.

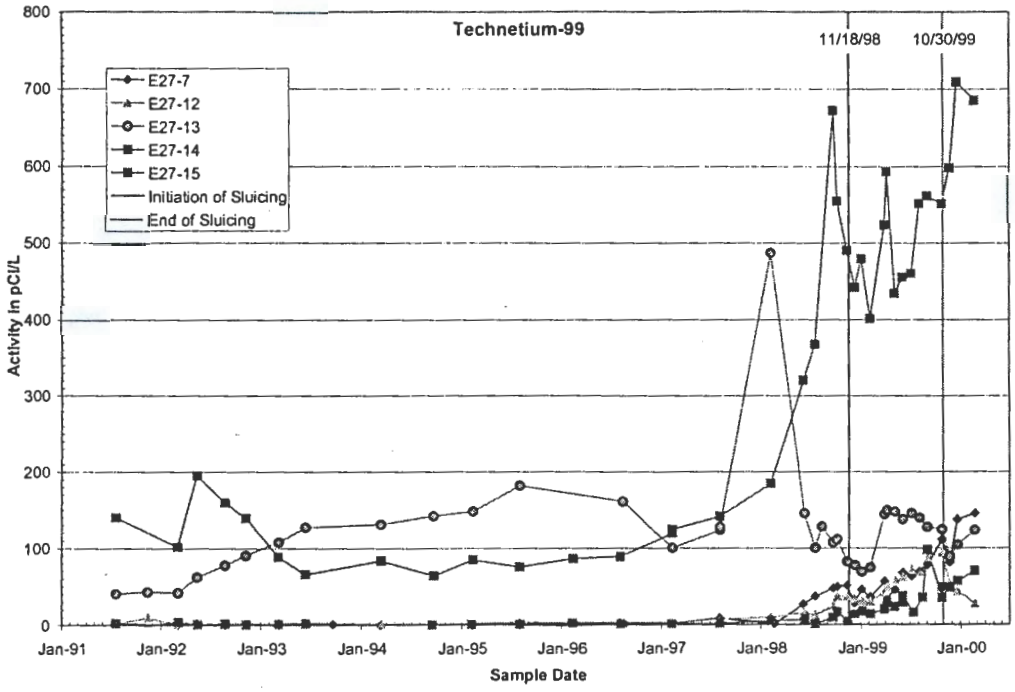


Figure C3-3. Trend Plot of Nitrate at WMA C.

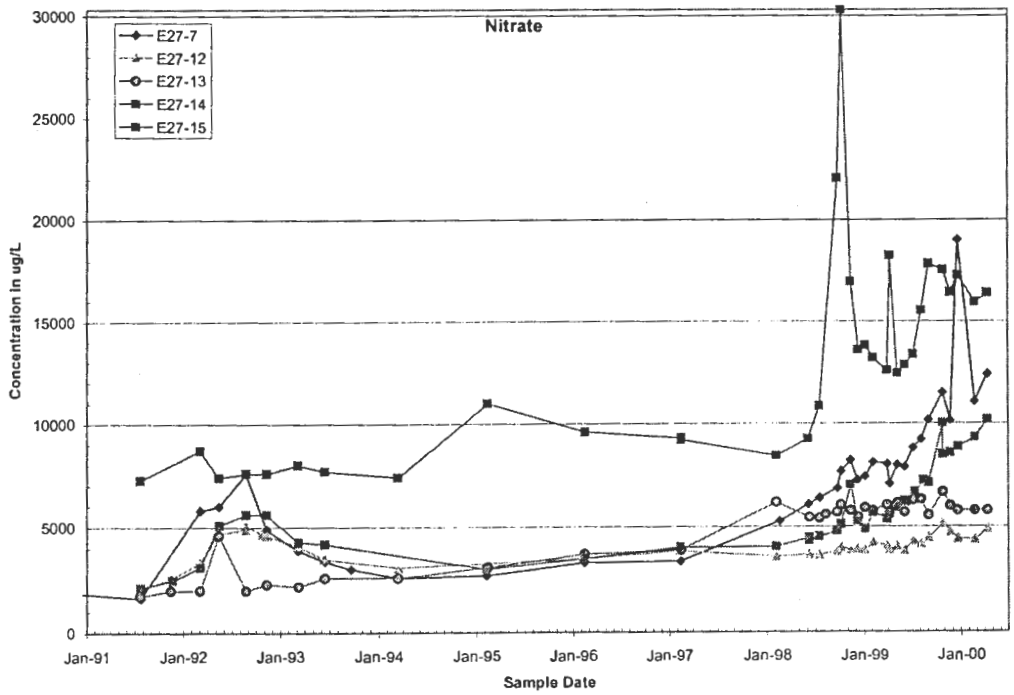


Figure C3-4. Trend Plot of Sodium at WMA C.

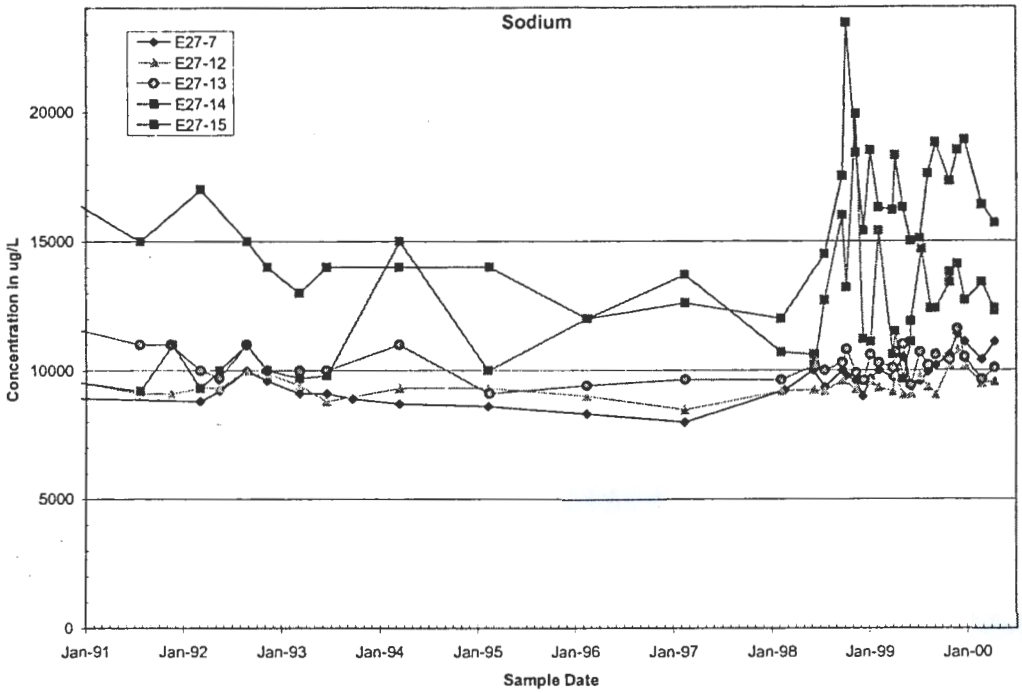


Figure C3-5. Trend Plot of Sulfate at WMA C.

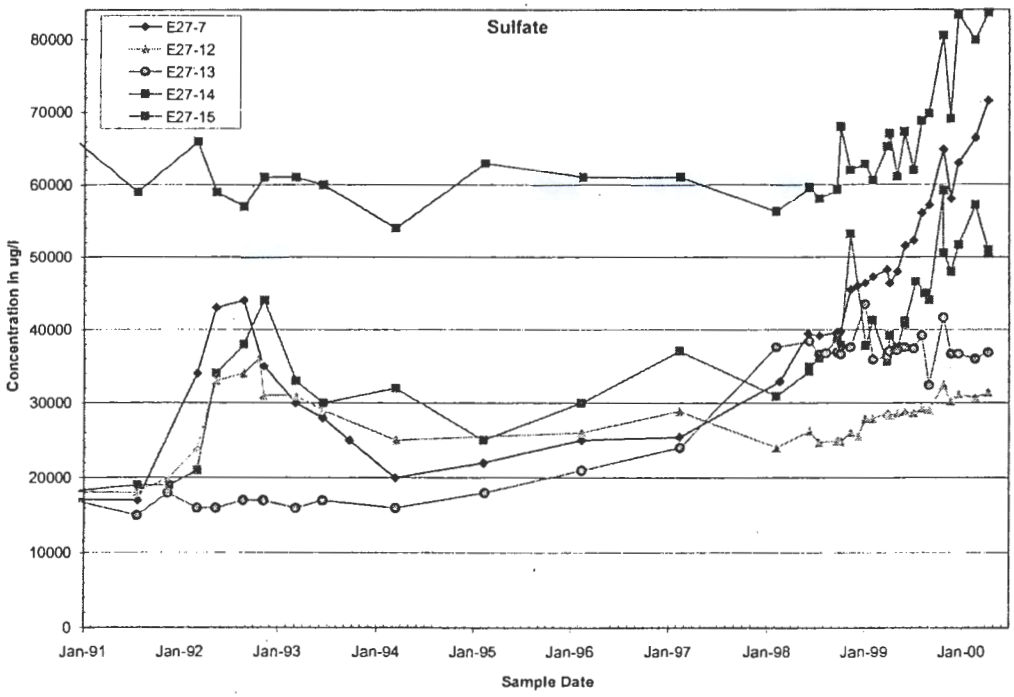


Figure C3-6. Trend Plot of Chloride at WMA C.

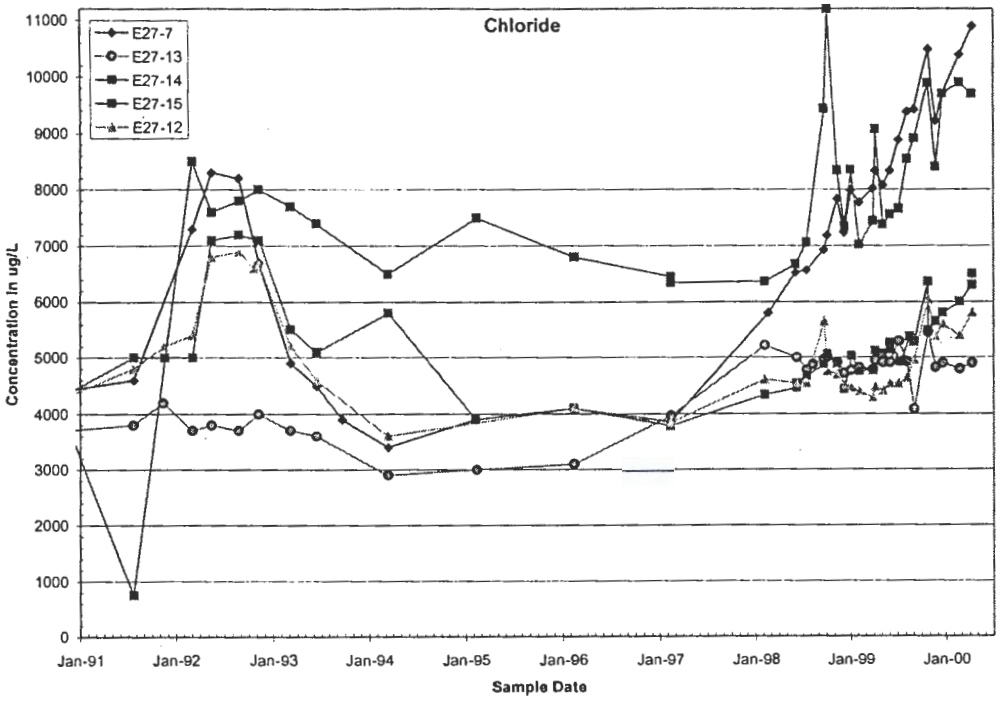


Figure C3-7. Trend Plot of Calcium at WMA C.

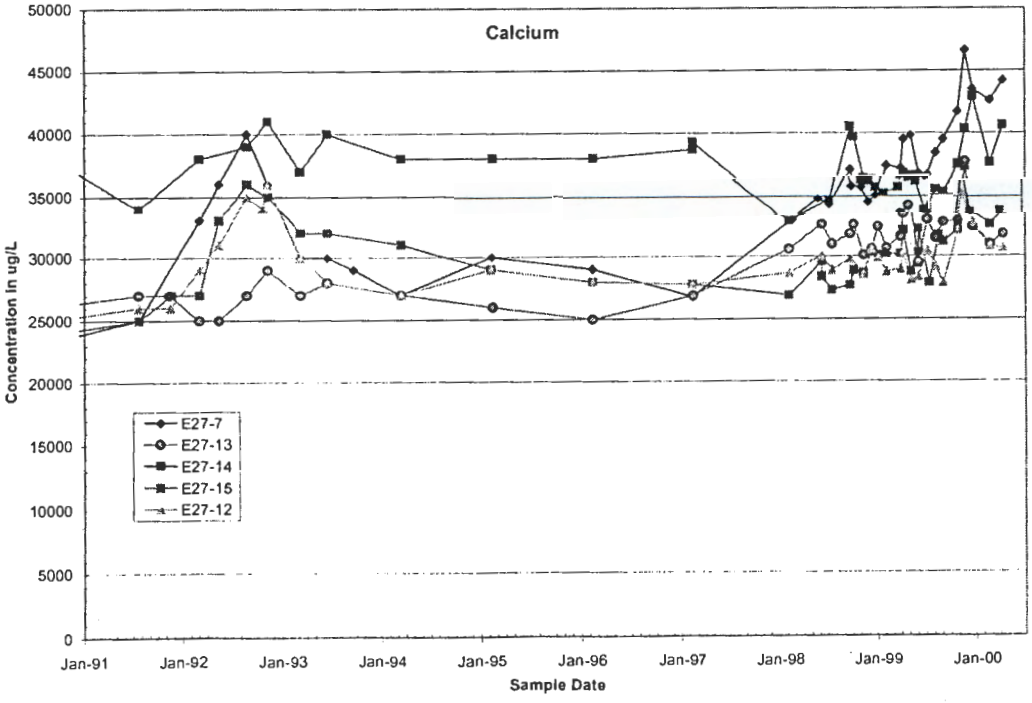
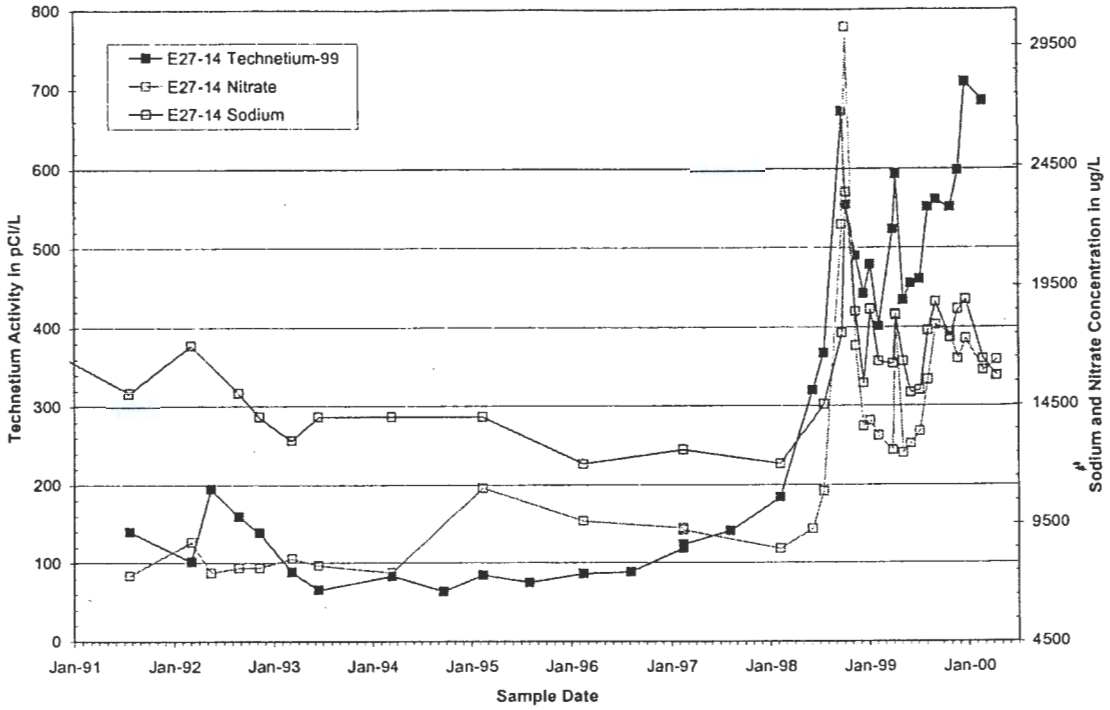


Figure 3-8. Trend Plots for Well 299-E27-14 Comparing Technetium-99 to Nitrate and Sodium.



From November 1998 to October 1999, sluicing operations were performed in C-106. The WMA was temporarily monitored monthly and then bi-monthly to provide additional coverage before, during, and after the recent in-tank sluicing event to increase the ability to detect a leak related to sluicing operations. The period of sluicing is marked in Figure 3-2 by the two vertical lines. As can be seen, the groundwater plume currently impacting the groundwater under the C Farm entered the area several years before sluicing operations began. Thus, the rising contamination in well 299-E27-14 is unlikely to be associated with active sluicing of tank 106.

Just prior to the increases in contamination observed at well 299-E27-14, a single pulse (487 pCi/L) of technetium-99 was observed at well 299-E27-13 in February 1998 (Figure 3-2). Small increases were also observed in nitrate, sulfate, chloride, and calcium at this well. In May 1998, technetium-99 activity returned to historical values of about 150 to 120 pCi/L. It is important to note there were no exceedances of indicator parameters, DWSs, or maximum contaminant levels (MCL) associated with this well. As of 2001, this well has the lowest levels of anions around the WMA except for well 299-E27-12. This elevated technetium-99, seen in 1998, may be associated with the increased contamination currently observed in all the wells around WMA C.

For example, technetium-99 values are rising in 299-E27-7, 299-E27-15, and 299-E27-12; however, activities are below 200 pCi/L. Associated with this overall increase in technetium-99, are sharp increases in sulfate, calcium, and chloride. Although there is some increase in nitrate (Figure 3-3), sulfate, calcium, and chloride are the dominant anions for this event. Since early 1999, the chloride concentration at 10,900 μG/L and the calcium concentration at 46,600 μG/L have risen higher in well 299-E27-7 than in any other network well. Located north of the WMA,

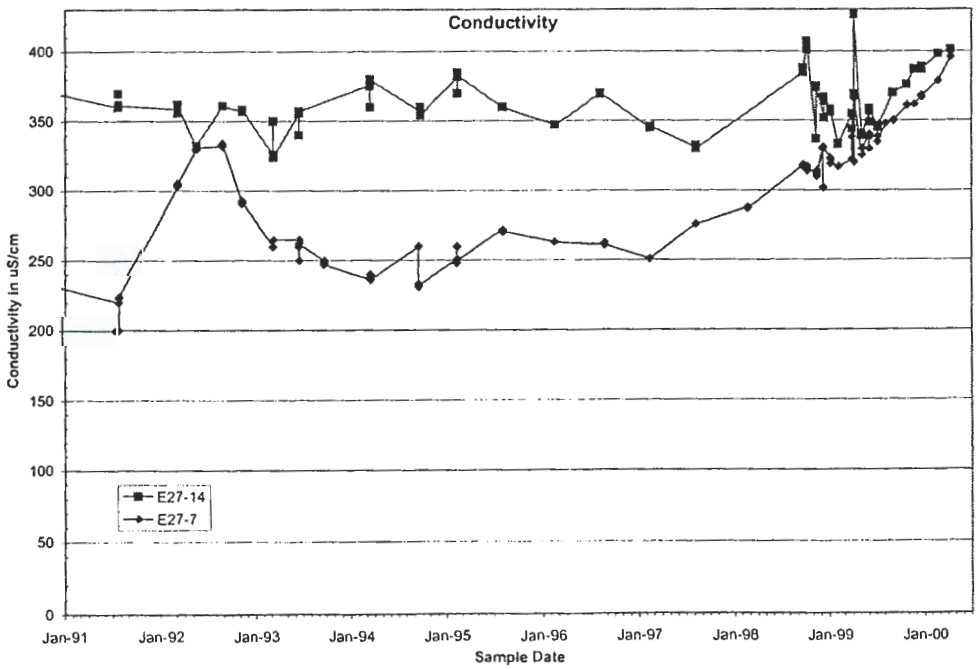
well 299-E27-15 has concentrations also rising sharply. Although sodium has shown increased levels in wells 299-E27-14 and 299-E27-15, it is not clear that sodium is rising with the technetium-99, calcium, sulfate, and chloride seen in the groundwater at the other wells. Typically, sodium is the main cation observed in groundwater contamination associated with processing waste.

Well 299-E27-7 has also recently begun to show low levels of cyanide at 15 µG/L. Cyanide has not been seen in network wells prior to this recent occurrence nor has cobalt-60 been detected in any of the wells. Tanks at WMA C were used for in-tank scavenging with ferrocyanide. The general increase in ionic chemistry is elevating conductivity values up to 400 µS/cm in wells 299-E27-7 and 299-E27-14 (Figure 3-9). Well 299-E27-7 is still considered an upgradient well while it is unclear if well 299-E27-14 is upgradient or crossgradient. It may be necessary to recalculate the critical mean for this site, which is currently 553.5 µS/cm.

Rising sulfate, calcium, and chloride have recently been observed elsewhere in the northern part of the 200 East Area. However, these wells to the north of WMA C are not sampled for technetium-99, although the dominant sulfur and calcium character is similar. Thus, there may be some regional source moving into the area from a northwesterly direction.

There does not appear to be other tank-related wastes in the groundwater. Tritium levels are low, generally less than 1,500 pCi/L, except at well 299-E27-7 where values rose from about 600 pCi/L to 2,500 pCi/L during the late 1990s. As of 2001, the trend is not increasing and remains level at 2,480 pCi/L.

Figure C3-9. Trend Plots of Conductivity for Wells 299-E27-7 and 299-E27-14.



The following summarizes WMA C water chemistry information presented in the FY2001 annual report (PNNL-13788):

- Critical mean values were not exceeded in groundwater for the indicator parameters pH, total organic carbon, and total organic halides in FY2001.

- The critical mean for specific conductance was exceeded in well 299-E27-14 at the end of FY2001. The increase is due primarily to rising concentrations of sulfate and calcium along with nitrate and chloride. Nitric acid was extensively used in chemical processing.

- Low concentrations of cyanide were noted in well 299-E27-7 in FY1999 and FY2000. Concentrations of cyanide decreased in FY2001, and currently are not detected in well 299-E27-7 or any other network monitoring well.

- For information purposes, the following radionuclide information pursuant to AEA authority is summarized.

  - Technetium-99 concentrations continue to increase in all wells at WMA C. Elevated levels of technetium-99 first appeared in well 299-E27-14 in 1997. The greatest increase in FY2001 was measured in well 299-E27-7.

  - Low tritium levels have been observed in groundwater at WMA C. Tritium concentrations in well 299-E27-7 spiked in 1990 but have since stabilized.

The sources for the contamination detected in the groundwater beneath WMA C are not defined (PNNL-13024, PNNL-13024-ICN-1).

C3.5.4 Inspection and Maintenance of Wells

Routine well inspection and maintenance is performed on groundwater monitoring wells to ensure compliance with WAC 173-160, *Minimum Standards for Construction and Maintenance of Wells*. The *Hanford Well Maintenance and Inspection Plan* (BHI-01265) describes the procedures for well maintenance and inspection on the Hanford Site. Routine well maintenance and inspections are performed at least every five years, based on the drilling completion date and the date of the last routine maintenance, whichever is the most recent. Routine well maintenance consists of 1) checking the well pump function, 2) removing the pump, 3) performing a video camera survey, 4) brushing/cleaning the screen or perforations, 5) redeveloping the well, 6) removing fill material and debris from the well bore, and 7) reinstalling the pump.

In addition to the scheduled routine maintenance activities, the well maintenance program addresses nonroutine well maintenance which is performed to keep the well operational (i.e., allow water sampling). Nonroutine well maintenance may consist of replacing sampling pumps, repairing or replacing well tubing, and removing foreign objects from wells. Problems requiring nonroutine maintenance are typically identified during well sampling activities.

Routine and non-routine well maintenance and inspection activities are documented on forms specified in the *Hanford Site Well Management Plan* (DOE/RL-2003-13). Completed forms are entered into the Hanford Records Management Information System (RMIS) and also into the Hanford Well Information System (HWIS) database.

If a monitoring well becomes unsuitable for use, the monitoring program will be reevaluated to determine if a new well should be constructed or if an existing well should be substituted.

C3.5.5 Plans for Monitoring Network Modification and Additional Groundwater Characterization

A data quality objective (DQO) scoping process is underway for the 200 East Area to assess CERCLA remediation performance monitoring, site-wide surveillance monitoring to meet the requirements of the AEA, and detection/assessment monitoring to meet the requirements of RCRA. At the completion of the scoping process, a DQO summary report for the 200 East Area will be issued. This DQO summary report will provide the number, location, and schedule for installing additional groundwater monitoring wells at WMA C. Schedules for installation of new monitoring wells will be developed and detailed per HFFACO Milestone M-24 or the Site-Wide Permit. Four additional groundwater monitoring wells were recently installed and will provide supplementary data for characterizing groundwater flow direction, stratigraphy, vadose zone properties, and groundwater chemistry in the vicinity of WMA C. Additional vadose zone and/or groundwater characterization information will be collected in accordance with the M-45-55 Milestone.

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C4.0 CLOSURE ACTIVITIES

The closure action for WMA C involves conducting closure activities on individual components of the WMA. The WMA C is comprised of four primary types of components: 1) SSTs (including 100 and 200 series), 2) ancillary equipment (piping, diversion boxes, pump pits), 3) soil, and 4) groundwater. Component closure activity plans, or alternate decision documentation such as corrective measures studies or CERCLA RODs upon approval through incorporation into the Site-Wide Permit, will be developed to describe how the components or groups of components will be characterized, disconnected, dismantled, decontaminated, removed, and/or stabilized.

This section describes these component closure activities and presents a relative timeline for the completion of the WMA C closure action, including contingent closure actions for closure as a landfill pursuant to WAC 173-303-640(8)(c). Additionally, the section lists the component closure activities that will contribute to meeting the closure performance standards of WAC 173-303-610(2), -640(8), and -645(3) and HFFACO Milestone M-45.

C4.1 WMA C COMPONENT CLOSURE ACTIVITY RELATIVE TIMELINE

Figure C4-1 presents a relative timeline for the major closure activities necessary to complete the WMA C closure, contingent landfill closure, and contingent postclosure actions. The timeline depicts the relative sequence of the major component activities and the anticipated duration of these activities. Key closure dates have been developed and are described in HFFACO Milestone M-45. The first three columns (left to right) presented in the timeline represent intervals during which closure activities associated with each tier of the *SST System Closure Plan* strategy occur. The fourth column represents Hanford's long-term stewardship program. A general summary of each of the four columns follows. A more detailed discussion of the closure activities is presented in Section C4.2.

1. Column One: Performance of the major component closure activities is presented in column one. Initiation of these activities is currently underway with the retrieval of tank C-106. The relative starting points for the ancillary equipment, soil, and groundwater component closure activities are staggered to depict the most logical order for conducting these activities. The dotted vertical line on the right side of the column denotes that a final activity (such as implementation of the surface barrier as a contingent final remediation method) may be necessary to complete one or all of the component closure activities. Groundwater component closure activities extend beyond the dotted line because completion of this component activity is largely determined by programs outside the SST RCRA closure program (such as CERCLA Operable Unit corrective actions and the Central Plateau closure strategies) and can likely be implemented without impacting ongoing WMA C-specific closure actions.

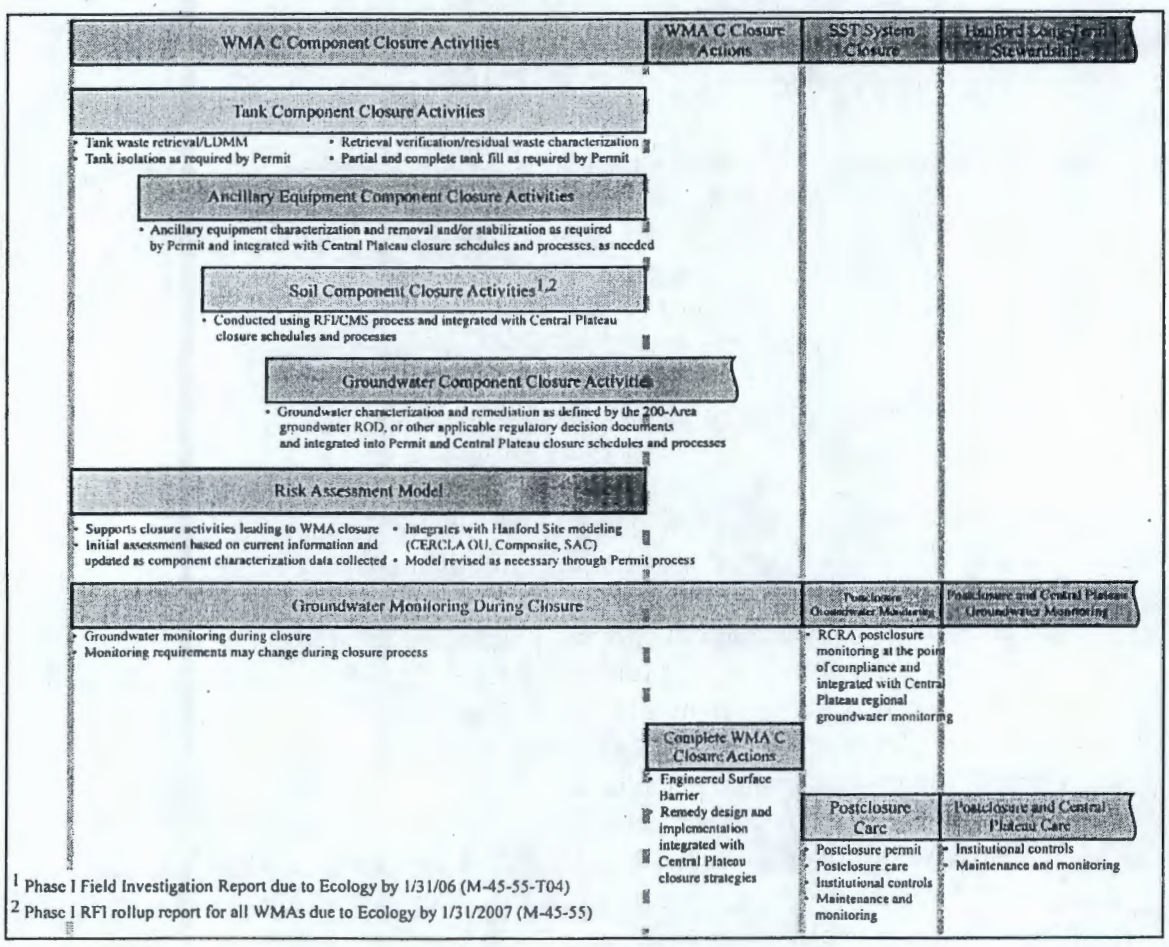
2. Column Two: The second column represents the period during which all WMA C closure activities are completed. This period begins when all of the SSTs within a WMA have

been retrieved, isolated, and filled, and the ancillary equipment and soils have been characterized and appropriately dispositioned. Completion of the WMA closure action occurs when the final remedy (such as the contingent landfill closure engineered surface barrier) for the WMA has been implemented.

3. Column Three: The third column represents the period when the final WMA remedy has been implemented and the contingent WMA postclosure activities, if required, are initiated. A contingent postclosure plan will be developed to define these activities. During this period, other WMA closure actions within the SST system will be ongoing. The period ends when the final WMA closure action is completed.

4. Column Four: The fourth column depicts the integration of any SST postclosure activities with the Hanford long-term stewardship program. Since the SST WMAs are located in the 200 Areas, the postclosure activities will be integrated as specified in the Site-Wide Permit with the Central Plateau closure strategies currently under development by Ecology, EPA, and DOE.

Figure C4-1. Relative Timeline of Major Activities for Closure of WMA C.



C4.2 COMPONENT CLOSURE ACTIVITY DESCRIPTIONS

The following section describes the component closure activities associated with the WMA C closure and postclosure actions. Future characterization activities within WMA C will produce new information. Information pertinent to making closure decisions will be provided as necessary in accordance with the WAC 173-303-830 permit modification process.

C4.2.1 Tank Component Closure Activities

The tank components consist of twelve 100-series SSTs and four 200-series SSTs. Physical tank descriptions and historical process knowledge associated with the WMA C tanks are provided in Section C2.0. Additional detail for individual or groupings of tanks will be provided in the respective component closure activity plans.

Closure of the individual tanks occurs in three major steps: 1) tank waste retrieval, 2) tank stabilization, and 3) physical and administrative isolation of the tank. Each of these steps will be described in the respective component closure activity plans. A general description of these steps follows.

HFFACO Milestone M-45-00 states: "Closure will follow retrieval of as much tank waste as technically possible, with waste residues not to exceed 360 ft^3 in each of the 100-series tanks, 30 ft^3 in each of the 200-series tanks, or the limit of waste retrieval technology capability, whichever is less." DOE will retrieve as much waste as technically possible, with a remaining residual of no more than 360 ft^3 for the 100-series tanks and 30 ft^3 for the 200-servies tanks. Following retrieval activities, DOE will use in-tank survey methods to determine whether retrieval volume criteria have been met. Also as part of this milestone a data report will be submitted to Ecology for approval to demonstrate completion of retrieval in accordance with M-45-00. For tanks that are not subject to milestones, an Ecology-approved data report will also be required to demonstrate completion of retrieval. In addition, the residual will be characterized to support risk assessments. DOE will follow a DQO process for conducting the tank waste characterization activities. As part of the DQO process, characterization requirements will be documented in tank-specific Component Closure Action Data Quality Objectives. DOE will request approval of the DQO by Ecology. The DQO will be attached to or referenced by the respective component closure activity plan.

If the residual waste in individual tanks meets the retrieval criteria and the risk metrics related to the residual waste are accepted, DOE will modify the closure activity plan and the Site-Wide Permit, if necessary, and then proceed with implementing the approved component closure activity plan. If residual waste exceeds the retrieval criteria, DOE will either attempt additional retrieval or request an exception to the retrieval criteria. This request will be prepared pursuant to the procedure in HFFACO, Appendix H, Attachment 2.

Tanks C-104 and C-106 have HFFACO milestones for retrieval and closure. The retrieval sequence for the remaining WMA C tanks is updated annually in accordance with HFFACO Milestone M-45-02. Section C6.0 lists the HFFACO Milestone M-45 series associated with

retrieval and closure operations for these tanks. In addition, tanks C-201, C-202, C-203, and C-204, which are outside of HFFACO milestone commitments, are being retrieved in FY 2004 as defined in the *Specification for the 241-C-200 Series Waste Retrieval System* (RPP-14075). Revisions to the WMA Closure Action Plan and addition of closure activity plans for these tanks as attachments to this plan will be forthcoming in this time frame.

Process Control Plan for Tank 241-C-106 Closure (RPP-13707) and *Process Control Plan for 241-C-106 Acid Dissolution* (RPP-16462) describe the technical operating controls for the waste retrieval and transfer of liquid wastes to the DST system. RPP-13707 includes a description of tank conditions, waste conditions, major equipment, overall process operating strategy, responses to off-normal conditions, and leak detection monitoring and mitigation. A 'Retrieval Functions and Requirements' document will be developed for each tank or group of tanks before commencement of retrieval operations within the WMA C. Additional detail on waste retrieval for individual tanks or groups of tanks will be documented in the respective component closure activity plans.

Once the waste retrieval criteria are met and risks associated with remaining contaminants are determined to be acceptable by Ecology, each tank will be stabilized. Generally, tank stabilization consists of adding grout* in layers in the retrieved tanks. For example, the stabilization approach proposed for C-106 is the addition of three grout* layers as follows:

- Phase I layer will be composed of a free-flowing cementitious grout*.
- Phase II layer will provide structural stability and fill the majority of the tank volume.
- Phase III fill will be a high-compressive-strength grout* designed to deter inadvertent intrusion of the tank from future drilling or excavation activities.

Stabilization activities may differ from tank to tank depending primarily on the volume and characteristics of the residual waste remaining after retrieval and the integrity of the tank. Additionally, information obtained from the field deployment and grout placement* demonstration at C-106 may alter emplacement methodology and grout recipes for future tank stabilization efforts in WMA C. Planned stabilization activities will be documented in the respective tank component closure activity plans.

Physical and administrative isolation of the tanks will occur before and after the tank retrieval and tank stabilization activities. Physical isolation refers to filling (such as by grouting*) and/or capping of pipelines, drains, ducting or other openings into the tank structure to prevent inadvertent liquid introduction. Physical isolation will occur progressively as individual tanks near final stabilization. Administrative isolation, such as lock and tag, controls tank access through procedural actions. Both physical and administrative isolation measures are intended to prevent inadvertent filling of adjacent tanks, lines, and equipment. Additional detail on

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* See Preface in *SST System Closure Plan* (RPP-13774).

implementation of tank isolation will be documented in the respective tank component closure activity plan.

C4.2.2 Ancillary Equipment Closure Activities

Ancillary equipment refers to steel, concrete, electrical, and other equipment both internal and external to the tank including pipelines, conduit, pits, diversion boxes, ventilation systems, electrical/service connections, tank risers, pumps, measuring equipment (such as liquid level detection systems, and thermocouples), shield plugs, and dip legs. A listing of ancillary equipment associated with WMA C is included in Table C2-2.

There are uncertainties associated with the level of contamination contained in ancillary equipment and with potential difficulties in accessing buried equipment. Disposition of in-tank ancillary equipment (such as in-tank measuring equipment and tank risers) will be described in the respective tank component closure activity plans. In-tank equipment will be dispositioned as in-tank debris during the tank closure activity. Disposition of ex-tank ancillary equipment (such as pipelines, diversion boxes, and cascade lines) will be described in either an ancillary equipment component closure activity plan, tank component closure activity plan, or other alternate decision documentation such as a corrective measures study or ROD upon approval through incorporation into the SST system chapter of the Site-Wide Permit. Integration activities for remediating ex-tank ancillary equipment are expected to be developed through the *SST System Implementation Plan* pursuant to HFFACO Milestone M-45-06-T20.

Ancillary equipment closure activities will be integrated as appropriate with soil and groundwater component closure activities and with the Ecology, EPA, and DOE Central Plateau regional closure strategies currently under development. Coordination of these integration actions is expected to occur through modification of the *SST System Implementation Plan*.

C4.2.3 Soils Component Closure Activities

The two primary steps in the WMA C soil component closure activities are 1) characterizing the nature, extent, and mobility of the contamination in the soil column, and 2) performing necessary cleanup in accordance with WAC 173-303-610 and –645. Characterization of soils will involve an assessment of known and suspected contamination. DQOs will be developed to ensure appropriate characterization data are collected to support the soil component closure activities. Characterization information will be used to assess the relative risk associated with the soil component. A corrective measures analysis based on the risk assessment will be conducted to define the appropriate remediation methodologies. Finally, the corrective measures alternative(s) will be implemented.

Soil characterization and corrective measures activities will be integrated as appropriate with ancillary equipment and groundwater component closure activities and with the Ecology, EPA, and DOE Central Plateau regional closure strategies currently under development. Coordination of these integration actions is expected to occur through the *SST System Implementation Plan*

pursuant to HFFACO Milestone M-45-06-T20. After regional closure strategies are finalized, the WMA C closure plan will be modified in accordance with WAC 173-303-830.

C4.2.4 Groundwater Component Closure Activities

The two primary steps in groundwater component closure activities are 1) characterizing the nature and extent of contamination, and 2) performing necessary corrective measures. Characterization of groundwater will involve an assessment of groundwater conditions based on existing groundwater monitoring data and supplemental groundwater data obtained throughout the course of field investigations. DQOs will be developed to ensure appropriate characterization data are collected to support subsequent groundwater component closure activities. Groundwater characterization will be conducted as a groundwater component closure activity under the auspices of WMA C closure actions and may be coordinated with soil component characterization efforts. Characterization information will be used to assess the relative risk associated with the groundwater component. A corrective measures alternatives analysis based on the risk assessment will be conducted to define the appropriate corrective measures.

In the event that it is determined that groundwater corrective measures are necessary, groundwater remediation may be performed pursuant to a RCRA corrective action or CERCLA ROD developed for the 200-PO-1 groundwater operable unit upon approval through incorporation into the Site-Wide Permit. Groundwater monitoring and response actions are integrated within the context of HFFACO Milestones M-24 and M-45 and, as feasible, will be integrated with the Central Plateau regional closure strategy. After groundwater regional strategies are finalized, the WMA C closure plan will be modified in accordance with WAC 173-303-830 to incorporate and/or change the WMA C groundwater monitoring network and/or program description.

C4.2.5 Risk Assessment Model

As described in Section C5.0 and depicted in the relative timeline (Figure C4-1), the risk assessment model developed for the WMA C will be used to support the decision-making processes during the various component closure activities described above. The purpose of the risk assessment is to demonstrate that the planned closure conditions meet the performance objectives. The risk assessment strategy will be implemented at the WMA level in a manner that will allow evaluation of risk contribution from individual components (such as individual tanks, groups of tanks, soil, ancillary equipment, and groundwater) or the entire WMA. The initial assessment will be performed based on current information, such as the BBI for the tank waste, geophysical vadose zone data, and groundwater monitoring data. The initial assessment will be refined by incorporating the results of new field and engineering data obtained as the WMA closure action matures. An iterative approach will allow the level of uncertainty in risk estimates to be progressively reduced as closure activities move from single component activities to eventual closure of the WMA C. New data generated from the major characterization efforts (such as for ancillary equipment and soil) will be documented in Interim-Closure Data Reports as attachments to the Risk Assessment description in Addendum C1.

The WMA C risk assessment will be integrated with other Hanford Site modeling efforts, such as those supporting nearby CERCLA-related characterization and cleanup, Central Plateau strategy development, and the composite analysis.

The System Assessment Capability (SAC) is a computational tool for use in preparing the Hanford site-wide composite analysis of long-term impacts to groundwater. The WMA C risk assessment will be integrated with the SAC by preparing a constituent breakthrough curve for constituents at the water table underlying the WMA. This data set will be inserted into the SAC computations to represent the WMA as a point source in the composite analysis, as available. This will allow the localized fate and transport analysis performed at the WMA level to be directly integrated into the large-scale analysis performed by the SAC. However, output from the SAC will not make any of the cleanup levels for WMA C any less stringent than the regulatory requirements.

C4.2.6 Groundwater Monitoring

During the time that WMA C component closure activities are underway and until WMA closure is achieved, groundwater monitoring will be conducted according to the current groundwater monitoring plan (PNNL-13024, PNNL-13024-ICN-1) or future modifications to that plan as implemented. WMA C specific groundwater monitoring will occur at the WMA C point of compliance. It is recognized that groundwater monitoring at WMA C may support numerous environmental and regulatory data needs, including evaluating the sources of groundwater and vadose contamination, the fate and transport of existing and potential future releases, and long-term risk assessment for purposes of developing component closure performance standards and postclosure care requirements. Groundwater monitoring will be coordinated with these activities, CERCLA remediation, and other site-wide activities as feasible. In addition, those monitoring wells deemed no longer useful (for regulatory purposes or due to a declining water table) will be decommissioned as necessary.

Prior to closure of WMA C, a postclosure groundwater-monitoring plan will be developed as part of the future modifications to the postclosure care plan (WAC 173-303-665(6)(b)(iv)). Postclosure groundwater monitoring will be integrated with the groundwater monitoring approach currently being developed by DOE, EPA, and Ecology as part of the Hanford groundwater strategy.

C4.2.7 Complete WMA Closure Actions

After completion of the tank, ancillary equipment, and soil component closure activities, any remaining closure activities for WMA C will be implemented. During this period, planning and implementation of the final remedy for the WMA C closure action will be conducted. Several factors will be considered for planning the completion of the WMA C closure action:

- Actions necessary to comply with the general performance standards and extent of removal or decontamination of dangerous wastes, waste residues, equipment, and soils

and groundwater containing or contaminated with dangerous waste or waste residue, as discussed in Section C4.3

- Groundwater monitoring at the WMA C point of compliance as necessary to comply with groundwater protection standards
- A risk assessment using site-specific characterization data obtained during the various component closure activities
- Characterization and/or remedial design information from contiguous waste sites
- The 200 Area CERCLA RODs, if available
- Central Plateau closure strategies, if available.

Should removal or decontamination of dangerous waste constituents not be achievable at WMA C, the proposed contingent final remedy for WMA C is closure in accordance with WAC 173-303-665 with the installation of an engineered surface barrier.

Engineered surface barriers are constructed to cover contaminated waste sites to minimize infiltration of precipitation and inhibit contact of moisture with contaminated media, and thus reduce or eliminate potential leaching of contamination to groundwater. In addition to their hydrological performance, barriers function to prevent intrusion by human and ecological receptors, limit wind and water erosion, and attenuate radiation from covered contaminants. The performance standards for barriers under the requirements of WAC 173-303-665 are discussed in Section C4.3. Surface barrier designs developed for application to waste sites located within the Hanford Site 200 Areas will meet or exceed RCRA design criteria, as well as incorporate established long-term performance and maintenance objectives and specified design criteria. A site-specific evaluation will be done to ensure that a surface barrier design candidate is appropriate for specific WMA C characteristics and will be ultimately incorporated into the Site-Wide Permit.

Applicable or relevant and appropriate requirements (ARARs) and technical guidance pertaining to surface barrier design for various RCRA TSD scenarios at the Hanford Site are currently defined in *Focused Feasibility Study of Engineered Barriers for Waste Management Units in 200 Areas* (DOE/RL-93-33). Based on current knowledge of waste sources associated with WMA C, it is anticipated that the minimum design criteria required for the waste site would be the modified RCRA Subtitle C Barrier, as defined in this report. However, any final barrier design will be incorporated into this permit prior to installation. Additional factors that may be considered in barrier design are aspects of risk and performance assessment modeling.

Contingent actions for barrier design and installation of the surface barrier over WMA C would be integrated with Central Plateau regional closure strategies. Additionally, barrier design criteria may need to be modified if the barrier cover encompasses multiple contiguous waste sites.

When the construction of the WMA C engineered surface barrier is complete, the barrier and surrounding disturbed area would be revegetated to further enhance evapotranspiration, limit erosion, and blend the site area into the surrounding landscape of the Central Plateau. Performance monitoring will be implemented to ensure the surface barrier is performing as designed. Monitoring the continued integrity of the surface barrier would be accomplished through visual inspection and will be supplemented with groundwater sampling. The long-term effectiveness of the surface barriers in the Central Plateau depends on maintaining each barrier throughout the natural attenuation of contaminants under its cover to prevent exposure to potential receptors. Maintenance activities would include erosion repairs and possible vegetation maintenance. Subsidence is not considered a major factor in maintenance activities for Central Plateau waste site barriers.

C4.2.8 Postclosure Care

Postclosure care activities would commence at completion of the installation of the final remedial action (such as the engineered surface barrier) if necessary, and would be defined in a postclosure permit. These activities would also satisfy groundwater protection standards. These activities would be integrated with the Hanford Site long-term stewardship program and the Central Plateau closure strategies. A discussion of future postclosure activities is found in Section C8.0.

C4.3 DETERMINATION OF COMPLIANCE WITH CLOSURE PERFORMANCE STANDARDS

The component closure activities and WMA closure actions are intended to satisfy general closure performance standard (WAC 173-303-610(2)), the tank closure standards (WAC 173-303-640(8)) and, should removal or decontamination of dangerous waste constituents not comply with those specified in WAC 173-303-610(2)(b), the landfill closure standards (WAC 173-303-665(6)). The key regulatory language is set forth below in quotations. The corresponding actions that DOE will undertake to meet the standards are shown in italics preceded by checkmarks.

"-610 (2) Closure performance standard. The owner or operator must close a facility in a manner that:

(a)(i) Minimizes the need for further maintenance;"

- ✓ *Retrieval of waste from WMA tanks*
- ✓ *Stabilization and isolation of WMA tanks*
- ✓ *Ancillary equipment removal, isolation, and/or stabilization, as required*
- ✓ *Contaminated soil remediation, as required*
- ✓ *Surface barrier placement, if required*

(ii) "Controls, minimizes or eliminates to the extent necessary to protect human health and the environment, postclosure escape of dangerous waste, dangerous

constituents, leachate, contaminated run-off, or dangerous waste decomposition products to the ground, surface water, or atmosphere"

- ✓ *Retrieval of waste from WMA tanks*
- ✓ *Stabilization and isolation of WMA tanks*
- ✓ *Ancillary equipment removal, isolation, and/or stabilization, as required*
- ✓ *Contaminated soil remediation , as required*
- ✓ *Surface barrier placement, if required*
- ✓ *Groundwater closure actions (coordinated with CERCLA groundwater operable unit remediation)*

(iii) "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."

- ✓ *Actions may include recontouring and revegetation, or placement of manmade surfaces depending on the nature of the land use determined appropriate following closure*
- ✓ *Surface barrier placement, if required*

(b) "Where the closure requirements of this section, or of WAC 173-303-630(10), 173-303-640(8), 173-303-650(6), 173-303-655(6), 173-303-655(8), 173-303-660(9), 173-303-665(6), 173-303-670(8), 173-303-680(2) through (4), or 40 CFR 264.1102 (incorporated by reference at WAC 173-303-695) call for the removal or decontamination of dangerous wastes, waste residues, or equipment, bases, liners, soils or other materials containing or contaminated with dangerous wastes or waste residue, then such removal or decontamination must assure that the levels of dangerous waste or dangerous waste constituents or residues do not exceed:

(i) For soils, ground water, surface water, and air, the numeric cleanup levels calculated using residential exposure assumptions according to the Model Toxics Control Act Regulations, chapter 173-340 WAC as now or hereafter amended. Primarily, these will be numeric cleanup levels calculated according to MTCA Method B, although MTCA Method A may be used as appropriate, see WAC 173-340-700 through 173-340-760, excluding WAC 173-340-745; and"

- ✓ *Contaminated soil remediation , as required*
- ✓ *Groundwater closure actions (coordinated with CERCLA groundwater operable unit remediation)*

(ii) "For all structures, equipment, bases, liners, etc., clean closure standards will be set by the department on a case-by case basis in accordance with the closure performance standards of WAC 173-303-610 (2)(a)(ii) and in a manner that minimizes or eliminates postclosure escape of dangerous waste constituents."

- ✓ *Retrieval of waste from WMA tanks*
- ✓ *Ancillary equipment removal, isolation, and/or stabilization, as required*

The closure requirements for tank systems, WAC 173-303-640(8), read as follows:

(a) "At closure of a tank system, the owner or operator must remove or decontaminate all waste residue, contaminated containment system components (liners, etc.),

contaminated soils, and structures and equipment contaminated with waste and manage them as dangerous waste, unless WAC 173-303-070(2)(a) applies. The closure plan, closure activities, cost estimates for closure, and financial responsibility for tank systems must meet all of the requirements specified in WAC 173-303-610 and 173-303-620."

- ✓ *Retrieval of waste from WMA tanks*
- ✓ *Ancillary equipment removal, isolation, and/or stabilization, as required*
- ✓ *Contaminated soil remediation, as required*
- ✓ *Groundwater closure actions (coordinated with CERCLA groundwater operable unit remediation)*
- ✓ *Waste managed as dangerous waste and sent for storage and ultimate treatment at a permitted treatment facility.*

(b) "If the owner or operator demonstrates that not all contaminated soils can be practicably removed or decontaminated as required in (a) of this subsection, then the owner or operator must close the tank system and perform postclosure care in accordance with the closure and postclosure care requirements that apply to landfills (see WAC 173-303-665(6)). In addition, for the purposes of closure, postclosure, and financial responsibility, such a tank system is then considered to be a landfill, and the owner or operator must meet all of the requirements for landfills specified in WAC 173-303-610 and 173-303-620."

- ✓ *Surface barrier design and placement*
- ✓ *Submittal and approval of Postclosure Permit Application through modification of the Site-Wide Permit*
- ✓ *Postclosure maintenance and monitoring*
- ✓ *Institutional controls*

(c) "If an owner or operator has a tank system that does not have secondary containment that meets the requirements of subsection 4(b) through (f) of this section and is not exempt from the secondary containment requirements in accordance with subsection 4(g) of this section, then:

(i) The closure plan for the tank system must include both a plan for complying with (a) of the subsection and a contingent plan for complying with (b) of this subsection."

- ✓ *Approval of SST System Closure Plan and modification of the Site-Wide Permit*
- ✓ *Further modification of the Site-Wide Permit to include future component closure activities, soil corrective measures, and groundwater remedial actions*

(ii) "A contingent postclosure plan for complying with (b) of this subsection must be prepared and submitted as part of the permit application."

- ✓ *Submittal and approval of Postclosure Permit Application through modification of the Site-Wide Permit*

(iii) "The cost estimates calculated for closure and postclosure care must reflect the costs of complying with the contingent closure plan and the contingent

postclosure plan, if those costs are greater than the costs of complying with the closure plan prepared for the expected closure under (a) of this subsection (not applicable)."

(iv) "Financial assurance must be based on the cost estimates in (c)(iii) of this subsection (not applicable)."

(v) "For the purposes of the contingent closure and postclosure plans, such a tank system is considered to be a landfill, and the contingent plans must meet all of the closure, postclosure, and financial responsibility requirements for landfills under this chapter (WAC 173-303-610 and 173-303-620)."

- ✓ *Surface barrier design and placement*
- ✓ *Submittal and approval of Postclosure Permit Application through modification of the Site-Wide Permit*
- ✓ *Postclosure maintenance and monitoring*
- ✓ *Institutional controls*

The closure requirements for landfills, WAC 173-303-665(6), read as follows:

(a) "At final closure of the landfill or upon closure of any cell, the owner or operator must cover the landfill or cell with a final cover designed and constructed to:

(i) Provide long-term minimization of migration of liquids through the closed landfill."

- ✓ *Surface barrier design and placement*

(ii) "Function with minimum maintenance."

- ✓ *Surface barrier design and placement*

(iii) "Promote drainage and minimize erosion or abrasion of the cover."

- ✓ *Surface barrier design and placement*

(iv) "Accommodate settling and subsidence so that the cover's integrity is maintained."

- ✓ *Surface barrier design and placement*

(v) "Have a permeability less that or equal to the permeability of any bottom liner system or natural subsoils present."

- ✓ *Surface barrier design and placement*

(b) "After final closure, the owner or operator must comply with all postclosure requirements contained in WAC 173-303-610(7), (8), (9), and (10), including maintenance and monitoring throughout the postclosure care period. The owner or operator must:

(i) Maintain the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events."

- ✓ *Postclosure maintenance and monitoring*

(ii) "Maintain and monitor the leak detection system in accordance with subsections (2)(h) and (4)(c) of this section, where such a system is present between double liner systems. (not applicable)

(iii) Continue to operate the leachate collection and removal system until leachate is no longer detected. (not applicable)

(iv) Maintain and monitor the groundwater monitoring system and comply with all other applicable requirements of WAC 173-303-645."

✓ *Postclosure groundwater monitoring system*

(v) "Prevent run-on and run-off from eroding or otherwise damaging the final cover."

✓ *Postclosure maintenance and monitoring*

(vi) "Protect and maintain surveyed benchmarks used in complying with subsection (5) of this section."

✓ *Postclosure maintenance and monitoring*

The postclosure care requirements for dangerous waste facilities are specified in WAC 173-303-610(7):

(a) "Postclosure care for each dangerous waste management unit subject to postclosure requirements must begin after completion of closure of the unit and continue for thirty years after that date and must consist of at least the following:

(i) Groundwater monitoring and reporting as required by WAC 173-303-645, 173-303-650, 173-303-655, 173-303-660, 173-303-665, 173-303-680, and"

✓ *Postclosure groundwater monitoring system*

(ii) "Maintenance and monitoring of waste containment systems as applicable."

✓ *Postclosure maintenance and monitoring*

(d) "Postclosure use of property on or in which dangerous wastes remain after partial or final closure must never be allowed to disturb the integrity of the final cover, liner(s) or any other components of any containment systems,. . . :"

✓ *Postclosure maintenance and monitoring*

✓ *Institutional controls*

✓ *Deed restrictions*

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C5.0 WMA RISK EVALUATION

Under the HFFACO, the Hanford Site SSTs are RCRA hazardous waste management units that will be eventually closed under Washington State "Dangerous Waste Regulations" (WAC 173-303). The risk assessment described in this closure action plan is intended to meet the requirements for closure risk assessment.

This section presents a summary of the initial estimates of the long-term human health associated with the closure of WMA C, an initial assessment of the impacts to workers, and an evaluation of risks posed by potential accident scenarios. The risk assessment assumes wastes or waste constituents are left within the WMA and that a surface barrier and postclosure care are required. Both radiological as well as dangerous waste constituents are included in the risk assessment consistent with HFFACO Action Plan, Section 6.3.2.

Only a summary of the results are provided in this Section C5.0; Addendum C-1 provides the complete risk assessment. Section 3.0 of the Addendum provides the methodology, assumptions, and conceptual model; Section 4.0 provides the numerical results and sensitivity analysis; Section 5.0 lists exposure scenarios; Section 6.0 gives the limitations and uncertainty; Section 7.0 provides the long-term risks related to groundwater; and Sections 8 and 9 provide short-term risk assessment related to closure activities.

The selection of times and points of assessment comply with past agreements (*Contents of Risk Assessments to Support the Retrieval and Closure of Tanks for the Washington State Department of Ecology* [RPP-14284]) and attempts to maximize information provided to decision makers. This assessment represents the first in a series of iterative risk assessments for WMA C. Additional risk assessments will be conducted as wastes are removed from the individual tanks within WMA C, as characterization activities continue, and as other important information is collected.

The simulated peak values for each of the source terms in the groundwater pathway evaluated are given in Table C5-1 for a number of different metrics (additional metrics can be found in Addendums C1 and C2). The risk assessment concludes that that all source terms are below the MCL Derived Constituent Concentration of technetium-99 (900 pCi/L) (note only the chemicals that provide the majority of the risk are presented here (see Addendum C1 Table 28). All source terms are below the incremental lifetime cancer risk (ILCR) of 1.0E-05 for the *Hanford Site Risk Assessment Methodology* (HSRAM, DOE/RL-91-45) industrial use scenario, but only residuals left in pipelines are below the performance objective for the HSRAM residential-user scenario. All source terms are below the radiological dose performance objective of 25 mrem in a year for the HSRAM All-Pathways Farmer.

As one moves downgradient from the WMA C fenceline to the 200 Area Core Zone Boundary (2,900 m [9,500 ft] from the WMA C fenceline) and the Columbia River (14,300 m [47,000 ft] from the WMA C fenceline), the simulated peaks (concentration, radiological dose, ILCR, and HI) drop by a factor of approximately 6 (Core Zone Boundary) and 18 (Columbia River) for non-sorbed mobile contaminants.

Table C5-1. Simulated Peak Values for Simulated Source Terms for Selected Metrics.[1]

Simulated Source Term	Concentration (pCi/L)		ILCR		Radiological Dose (mrem/yr)[3]
	Tc-99	I-129	Industrial	Residential	All-Pathways Farmer
Tank Residual	66	0.14	1.0E-6	2.3E-05	0.19
Hypothetical Retrieval Leaks	416	0.82	6.5E-6	1.4E-4	1.2
Pipeline Residuals	7.4	0.015	1.1E-7	2.6E-6	0.022
Past Unplanned Releases	497	0.96	8.1E-6	1.8E-4	1.7

[1] Additional Metrics can be found sections 4.3, 7.3-7.7 of Addendum C1, and Addendum C2
[2] Only technetium-99 and iodine-129 are presented, because these contaminants are the primary risk drivers (Table 28 of Addendum C1)
[3] effective dose equivalent (EDE)

This risk assessment was developed to show our present understanding of the risks associated with closure of WMA C as a landfill. However, significant limitations and uncertainties exist in this preliminary risk assessment of WMA C. Figure 4-2 of the *Framework Plan for Single Shell System Closure Plan* – Tier 1 (RPP-13774) conceptually shows how this uncertainty is addressed through a series of circles that represent uncertainty with the circles becoming smaller as more data is collected and the uncertainty about a parameter is reduced. Since this is a preliminary risk assessment, an understanding of this uncertainty is necessary before evaluating the summary of the results presented in the following sections. To deal with the uncertainty in this first iteration of the risk assessment, the parameters used to calculate the risk have been biased to yield higher risk numbers, for the most part. It is expected that as retrieval progresses, new information will become available that may potentially lower the risk. Table 27 in *Addendum C1: Risk Assessment for WMA C Closure Plan* - Tier 2 (RPP-13774) lists these uncertainties and the expected impact on the results. Where possible, the impact was estimated quantitatively by running additional sensitivity runs combined with additional field/laboratory work on a model parameter (i.e., hydraulic conductivity, release rate models), and qualitatively through an examination of past modeling results (i.e., recharge). There are cases where the uncertainty remains unknown, but there are programs in place to collect the additional data (i.e., post-retrieval inventory information). The identification of these gaps is integral to the iterative nature of the process agreed on by DOE and Ecology, and the risk assessment will be updated as additional information becomes available.

A short description of the key results from the risk assessment is provided in this section (and a detailed description of the results is provided in Addendum C1: *Risk Assessment for WMA C Closure Plan* - Tier 2 [RPP-13774]). Section C5.1 provides the results from the long-term fate and transport model in which simulated peak concentrations and arrival times are discussed. Section C5.2 provides the results from the exposure scenarios for ILCR and radiological dose. Section C5.3 contains the results for the worker and accident scenario assessment.

The results of an initial risk assessment were developed in accordance with the following documents:

- *Performance Objectives for Tank Farm Closure Risk Assessments* (RPP-14283)
- *Modeling Data Package for an Initial Assessment of Closure for C Tank Farm* (RPP-13310)
- *241-C Waste Management Area Vadose Zone Inventory Data Package* (RPP-15317)
- *Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments* (HNF-SD-WM-TI-707).

The information contained in those documents was developed during several workshops held for DOE and Ecology personnel.

C5.1 LONG-TERM FATE AND TRANSPORT MODELING RESULTS

The model used in this analysis considered four risk-contributing elements:

- Past leaks from tanks and operations that are currently known to exist in the vadose zone
- Hypothetical leaks that may occur during waste retrieval (such as sluicing)
- Releases from tank ancillary equipment residuals (transfer lines, CR-vaults, and C-301 catch tank) assumed to remain in place after closure
- Releases from residual waste assumed to remain in the tanks after retrieval.

The period of simulation for the risk assessment is 10,000 years. This period was selected because of the long-lived and mobile nature of certain risk-causing contaminants, the expected long residence time for major contaminants within the vadose zone, and regulatory considerations. It is also the period of time recommended by the EPA for long-term risk assessments involving nuclear waste (40 CFR 144 "Environmental Radiation Protection Standards"). The points of calculation for which the risk metrics (dose, ILCR, and hazard index) were evaluated are located at (1) the WMA C fenceline, (2) the edge of the 200 Area Core Boundary, and (3) the Columbia River. For the purpose of this risk assessment, only those selected contaminants assumed to be important (because of inventory, mobility, and/or toxicity/risk) to the estimation of the particular risk metric are featured. These are technetium-99, iodine-129, chromium, nitrate, nitrite, and uranium. Complete discussion of these contaminants is given in Addendum C1 Section 3.5, with summary discussions of technetium-99, iodine-129, chromium provided in this appendix. These contaminants provide the greatest risk (see Table 28 of Addendum C1, Section 7.1). In addition to these contaminants, a total for either radiological dose or ILCR, or HI is computed. The total includes all contaminants given in the best basis inventory (47 radionuclides and 24 non-radionuclides) that apply to either radiological dose, or ILCR, or HI. Futhermore, additional contaminants will be addressed when quantitative analysis results for the contaminants identified in *Tank 241-C-106 Component Closure Action Data Quality Objectives* (RPP-13889) are available from waste sampling efforts following retrieval.

The fate and transport modeling presented was developed in a manner generally consistent with past and current ongoing modeling work in DOE and the SAC (PNNL-11800). The simulated vadose zone travel and contaminant breakthrough times in the initial assessment are in general agreement with results in field investigation reports (RPP-7884, RPP-10098) for various WMAs. As laboratory and field data are developed, their impacts on predictions will be evaluated, updated, and computed as necessary.

The impacts of two tank waste release mechanisms are evaluated in this preliminary assessment: (1) a diffusion-dominated release, and (2) an advection-dominated release. The diffusion and advection mechanisms most closely correspond, respectively, to a stabilized waste form isolated from the environment with grout* and/or reinforced concrete (tank bottom), and an unstabilized waste form assumed to be in full contact with the vadose zone materials.

C5.1.1 Base Case for WMA C

Figure C5-1 shows the individual sources considered in this risk assessment. A complete description of the sources and associated inventories is given in Addendum C1. To begin the estimation of impacts, a base case must be defined for WMA C. For the base case, source terms are applied to the WMA to estimate the cumulative inventory impacts. The base case defines the assumed post-retrieval conditions based on current retrieval plans, except for C-106. After this analysis was completed, the retrieval technology for C-106 was changed from modified sluicing to acid wash[1]. Table C5-2 provides a listing of the selected conditions, constituents, and source terms for the base case. When a cumulative total is given for the WMA, the base-case condition is used.

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* See Preface in *SST System Closure Plan* (RPP-13774).

[1] Oxalic acid will be neutralized by the carbonate minerals naturally present in the soil and, given the amount and concentration of acid in an 8,000 gallon leak of 1M oxalic acid and the present level of carbonate minerals in the soil, it is likely that the soil will neutralize the acid a short vertical distance (tens of feet or less) below the leak. The neutralized pH will likely be in the range of 7 to 8. Oxalic acid is fully deprotonated at a pH of about 4; therefore, above this pH all of the oxalate will be present in solution as the oxalate anion (C204-2). This anion will complex with uranium (uranium oxalate stability constant → log K = +6.36 [*NIST Critically Selected Stability Constnats of Metal Complexes Database* (Smith and Martell 2003)]), although nowhere near as strongly as with other organic complexes such as EDTA (uranium EDTA stability constant → Log K = 9.28 [Smith and Martell 2003]). PNNL found that the formation of the uranium oxalate complex did not reduce the adsorption of uranium onto Hanford soils compared to an oxalate-free solution AUTHOR NEEDS TO CITE THE REFERENCE HERE TO PNNL!!. However, PNNL was not using 1M oxalate solutions so the results are not directly comparable; however, it is possible that the presence of oxalate will not significantly increase the mobility of uranium through the vadose zone.

Figure C5-1. Modeled Sources within WMA C and Surrounding Facilities.

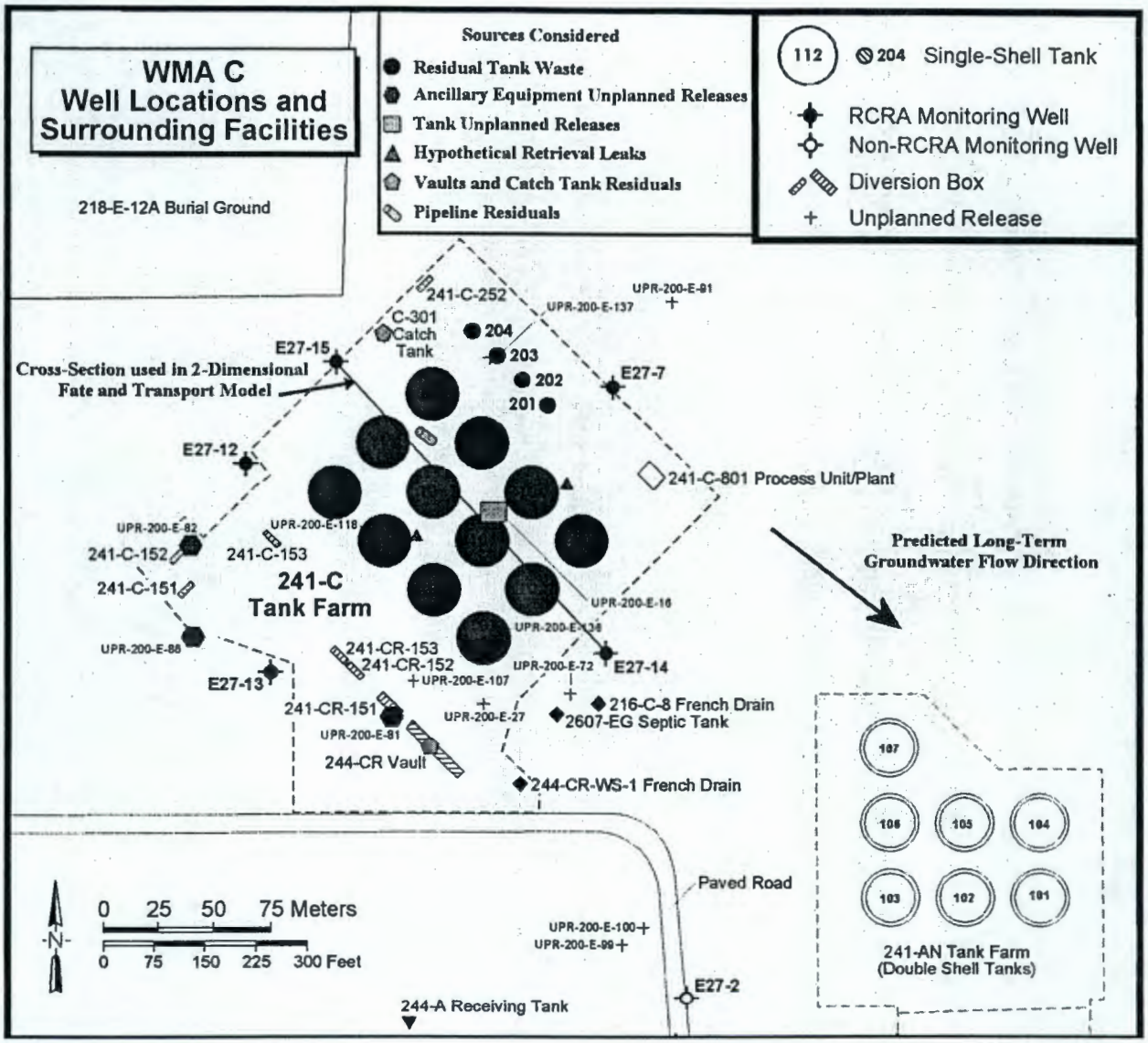

Table C5-2. Features of WMA C Base Case. (2 Pages)

Hydraulic Conductivity of Unconfined Aquifer	50 m/d
Release Model for Residual Waste	Diffusion (coefficient 6E-7 cm^2/s)
Contaminants of Concern (COCs) and Distribution Coefficients	Technetium-99, Iodine-129, Chromium, Nitrate, Nitrate, and Uranium Uranium = 0.6 mL/g All other COCs = 0.0 mL/g

Inventory and Source Terms

Tank Sources		Retrieval Method[a]	Residual Volume/ Inventory Used	Vadose Zone Contamination Associated with Past Tank Leak[b]	Hypothetical Retrieval Leak	Inventory[c]		
						Residual	Past Tank Leak	Retrieval Leak
Tanks	C-101	Crawler	360 ft^3/SPR[d]	No	Yes	Table 5-8b		Tables 5-10 and 5-11
	C-102	Crawler	360 ft^3/SPR	No	Yes	Table 5-8b		Tables 5-10 and 5-11
	C-103	Crawler	360 ft^3/SPR	No	Yes	Table 5-8b		Tables 5-10 and 5-11
	C-104	Crawler	360 ft^3/SPR	No	Yes	Table 5-8b		Tables 5-10 and 5-11
	C-105	Crawler	360 ft^3/SPR	Yes	Yes	Table 5-8b	Table 5-6	Tables 5-10 and 5-11
	C-106	Modified Sluicing	360 ft^3/SPR	No	Yes	Table 5-8c		Tables 5-10 and 5-11
	C-107	Past Practice Sluicing	360 ft^3/SPR	No	Yes	Table 5-8c		Tables 5-10 and 5-11
	C-108	Crawler	360 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-109	Crawler	360 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-110	Crawler	360 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-111	Crawler	360 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-112	Crawler	360 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-201	Vacuum	30 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-202	Vacuum	30 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-203	Vacuum	30 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11
	C-204	Vacuum	30 ft^3/SPR	No		Table 5-8b		Tables 5-10 and 5-11

Table C5-2. Features of WMA C Base Case. (2 Pages)

Past UPR Sources[f]	**Inventory**[c]	
UPR-200-E-81	Table 5-6	
UPR-200-E-82	Table 5-6	
UPR-200-E-86	Table 5-6	
Ancillary Equipment Sources	**Residual Vol/Type**	**Inventory**[c]
244-CR TK-CR-001	27 ft^3/SPR	Table 5-12
244-CR TK-CR-002	8 ft^3/SPR	Table 5-12
Ancillary Equipment Sources	**Residual Vol/Type**	**Inventory**[c]
244-CR TK-CR-003	8 ft^3/SPR	Table 5-12
244-CR TK-CR-011	27 ft^3/SPR	Table 5-12
241-C-301	19 ft^3/SPR	Table 5-12
Piping	250 ft^3/SPR	Table 5-12

[a] Present plans call for sluicing in all C-100 Tanks with the exception of C-106, which is undergoing an acid wash. A vacuum method is used in all C-200 Series tanks. Minimal water will be used with vacuum technology as opposed to sluicing, which uses large volumes of water to retrieve. Therefore, retrieval leaks will not be considered for the C-200 Series tanks.

[b] Past Tank Leaks - only tanks with verified vadose zone contamination were included in the model. Vadose contamination was verified by either borehole sampling or geophysical logs.

[c] Inventory tables are from Addendum C1, Section 3.6.

[d] SPR = Selected Phase Removal inventory after the retrieval of tank wastes, as reported in *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA: Inventory and Source Term Data Package* (DOE/ORP-2003-02)

[e] HTWOS = Hanford Tank Waste Operation Simulator model output. *Single-Shell Tank Retrieval Sequence and Double-Shell Tank Space Evaluation* (RPP-8554) modeled inventory after retrieval, simulating differential dissolution of waste constituents in high volume retrieval. (Please note that after this risk analysis was completed, the retrieval technology selected for C-106 was changed from modified sluicing to acid dissolution. An inventory analysis has not been completed for tank residuals using acid dissolution. Subsequent risk assessments will address acid-dissolution for this tank.)

[f] Past leaks and hypothetical retrieval leaks are simulated using advective transport through the vadose zone.

C5.1.2 Contaminant of Concern Modeling Results

The modeling results for technetium-99 are discussed in detail while the results for iodine-129, and chromium are briefly summarized. Complete discussions for all contaminants in this risk assessment are given in Addendum C1. Technetium-99, iodine-129, and chromium were chosen for this discussion because technetium-99 and iodine-129 account for 95 % of the total dose and incremental lifetime cancer risk, while chromium is the primary hazard index driver (see Addendum C1, Table 28).

Technetium-99

Table C5-3 provides the technetium-99 results for all sources in the WMA C under the base-case conditions. For comparison, the results for the advection-dominated residual tank waste release model are also included.

Table C5-3. Simulated Peak Concentrations [a] and Arrival Times for Technetium-99 at Various Boundaries. (2 Pages)

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time (years)	Conc. (pCi/L)	Time (years)	Conc. (pCi/L)	Time (years)	Conc. (pCi/L)
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved tank waste advection-dominated release [b]	4,653	9,639	4,676	1,520	4,883	560
Unretrieved tank waste diffusion-dominated release	5,614	3,030	5,637	474	5,839	178
Base Case Post-Retrieval [b]						
Retrieved tank residuals advection-dominated release [b]	4,653	208	4,676	33	4,883	12
Retrieval leak (8,000 gal)	2,082	420	2,107	66	2,324	22
Past tank leaks	2,092	156	2,117	25	2,333	9
Past ancillary equipment leaks (UPR)	2,117	353	2,141	56	2,355	20
Retrieved tank residuals diffusion-dominated release	5,610	66	5,637	10	5,839	4
Residuals in 244-CR vault and catch-tank release limited to diffusion	5,614	1	5,637	0.2	5,839	0.08
Residuals in ancillary pipeline release limited to diffusion (scaled)	4,891	7.4	4,925	1.1	5,130	0.4

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.

[b] Not part of the base case; only added for comparison purposes between release models.

UPR = unplanned release

The base-case composite analysis, which provides the sum for all sources, is given in Figure C5-2. In this figure, the following six breakthrough curves are shown:

- **Source: Hypothetical Retrieval Leaks** (Figure C5-2 line with hollow square symbols): Hypothetical retrieval leaks were modeled for all C-100 Series tanks, since the expected retrieval methodology is thought to be sluicing. The retrieval methodology for the C-200 series tanks is a dry vacuum. A retrieval leak was not applied to the C-200 Series tanks. The total estimated inventory for retrieval leaks is 5.0 Ci. The inventory from waste retrieval leaks was applied to simulation Case 1 (Table C5-4) with the higher hydraulic conductivity for the unconfined aquifer and then summed to estimate impacts of waste retrieval leaks from all C-100 series tanks. Although retrieval leaks are included in the cumulative curve, it is unrealistic to assume all tanks will leak 8,000 gal. The waste retrieval leaks peak breakthrough occurs approximately 80 years after retrieval with a peak concentration of 420 pCi/L, which is below the MCL derived constituent concentration of 900 pCi/L. The Hanford Advisory Board (HAB) consensus advice #132 states the core zone will have an industrial scenario for 150 years after site closure. At that time the concentration will have dropped to ~175 pCi/L. Following the emplacement of a barrier, contaminant levels would drop until the barrier degrades. After the barrier degrades, a second peak arrives approximately 1,135 years after the first peak with a peak value of 88 pCi/L.

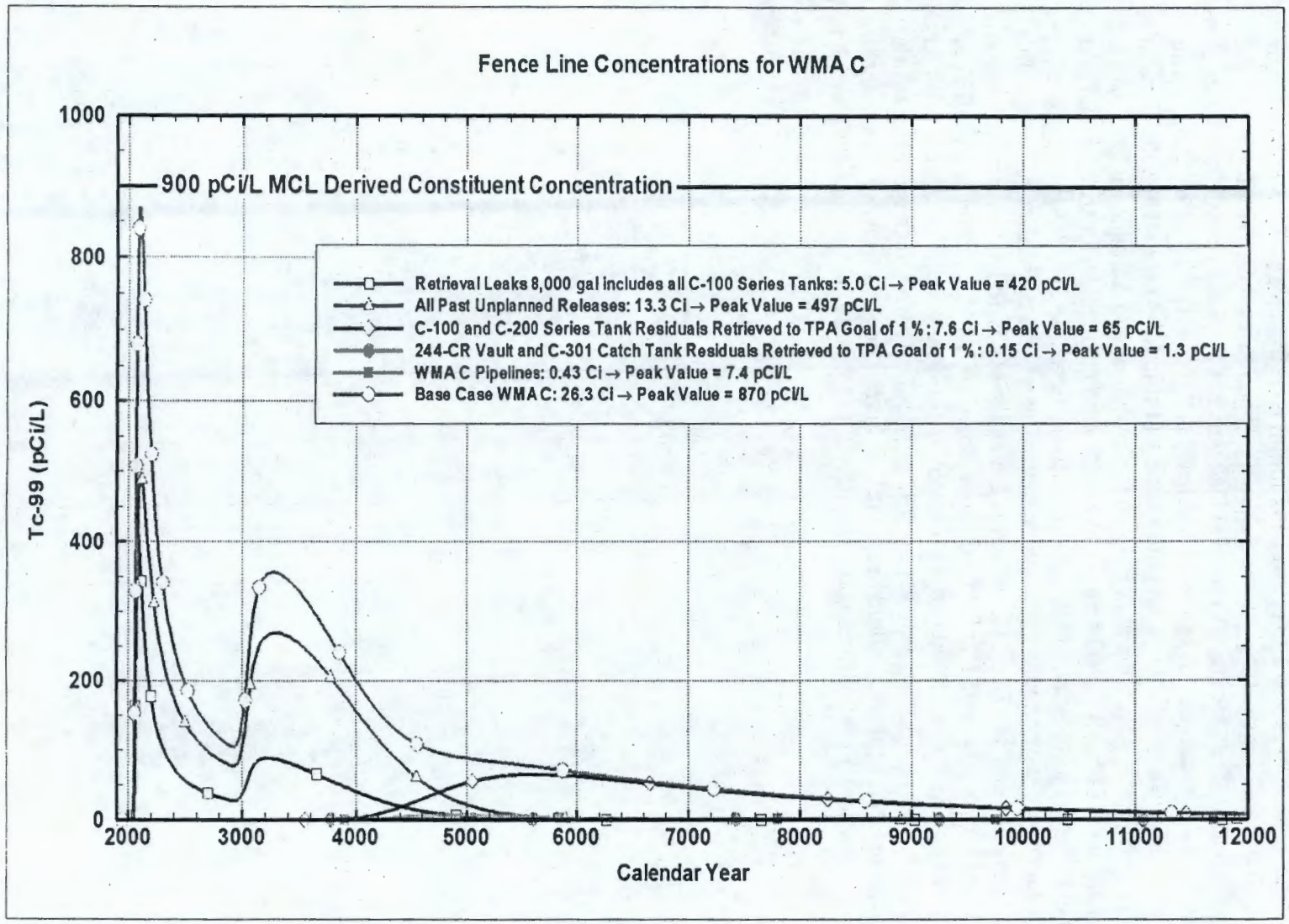

Figure C5-2. Technetium-99 Results for Hypothetical Retrieval Leaks, Past Unplanned Releases, and Tank and Ancillary Equipment Residuals (Diffusion-Dominated Release).

1

- **Source: Unplanned Releases** (Figure C5-2, line with triangle symbols): Past leaks from C-105 and ancillary equipment have released an estimated 13 Ci of technetium-99. The inventory from these sources was applied to the simulations identified as past tank leaks and past ancillary equipment leaks in Table C5-3. The simulations were then summed to estimate the concentrations for both tank and ancillary equipment leaks. The simulated peak concentration from these sources is 497 pCi/L (Figure C5-2) occurring approximately 110 years after leaking. This is below the MCL Derived Constituent Concentration of 900 pCi/L. Like the retrieval leaks, concentrations decrease following the emplacement of a surface barrier. After the barrier degrades, concentrations rise, reaching a peak approximately 1,180 years after the first peak, with a peak value of 270.6 pCi/L (Figure C5-2).

- **Source: Residual C-100 and C-200 Series Tank Waste Releases** (Figure C5-2, line with diamond symbols): Total technetium-99 inventory left in the residual waste within the tanks is 7.6 Ci using selected phase removal for all tanks and using the selected phase removal method for calculating residual inventory (see Addendum C1, Section 3.6.1 for description of methodology). The diffusion-dominated release model results for residuals are presented. Such a release model represents release from a stabilized waste form isolated from the environment with grout* and/or reinforced concrete. Using the diffusion-dominated release model, the simulated peak technetium-99 concentration for residual waste in all tanks is 66 pCi/L (Table C5-3 and Figure C5-2) occurring approximately 3,500 years after closure. In addition to the diffusion-dominated release, an advection model was run to evaluate the impact of an unstabilized waste form covered with backfill sand and gravel or a failed grout (i.e., the grout has cracked). The impact of having an unstabilized waste form or a failed grout would be to increase the concentration by approximately a factor of 3.

- **Source: Ancillary Equipment—CR-Vaults and C-301 Catch Tank Residual Releases** (Figure C5-2, line with filled circle symbols): This assumes that the waste in CR-vault and C-301 catch tanks will undergo waste retrieval. Assumed inventory for technetium-99 for this ancillary equipment is 0.15 Ci. (See Addendum C1, Section 3.6.1 for how inventory assumption was made.)_The inventory from these sources was applied to the simulation identified as residual 244-CR vault and catch-tank release limited to diffusion in Table C5-3. These tanks were modeled in the same manner as the 100- and 200-series tanks. The simulated peak for residual waste in these tanks is 1.3 pCi/L (Table C5-3 and Figure C5-2) occurring 3,500 years after closure.

- **Source: Ancillary Equipment—Pipeline Residual Release** (Figure C5-2, line with filled square symbols): This assumes a total technetium-99 inventory for the transfer piping system of 0.43 Ci (see Addendum C1, Section 3.6.1 for how inventory assumption was made). The inventory from this source was applied to residual ancillary pipeline release limited to diffusion (scaled) (Table C5-3), since this was not simulated with the

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* See Preface in *SST System Closure Plan* (RPP-13774).

hydraulic conductivity of the other cases. The scaling factor was determined by comparing the difference between diffusion-dominated tank residual release with the low hydraulic conductivity (4.8 m/d) for the unconfined aquifer against the same case with a high hydraulic conductivity (50 m/d) for the unconfined aquifer. This source was modeled the same as the 100- and 200-series tanks, with a diffusion-dominated release model assuming a waste form in which the pipelines are filled with grout*. With the assumed inventory for residual in the pipelines, the simulated peak technetium-99 concentration is 7.4 pCi/L (Table C5-3 and Figure C5-2). The arrival time for the peak occurs approximately 2,850 years after closure. The residual in the pipeline represents approximately 12% of cumulative impacts at the peak arrival time for release from the pipeline, which occurs 700 years before the impacts from tank residual waste.

- **Source: Cumulative Impacts from All Sources Within WMA C** (Figure C5-2, line with open circle symbols): For this curve, the breakthrough curves for the five sources listed above were summed to calculate a total technetium-99 concentration at the fenceline. The total technetium-99 inventory for the release to the surrounding environment would be 26.3 Ci. The simulated peak technetium-99 concentration for the composite WMA C is 870 pCi/L (Figure C5-2) occurring approximately 100 years into the future. This peak is slightly under the MCL Derived Constituent Concentration of 900 pCi/L. The principal source driver for the peak concentration is from the past leaks. Once the surface barrier is emplaced, the concentrations drop to 105 pCi/L (Figure C5-2). Once the barrier loses its effectiveness, concentrations rise to a second peak value of 356 pCi/L (Figure C5-2) approximately 1,180 years after the first peak. The past UPRs and hypothetical retrieval leaks are the primary source drivers for technetium-99, with the UPRs (tank and ancillary equipment) contributing slightly more than the hypothetical retrieval leak (Figure C5-2).

Iodine-129

Results for iodine-129 are given in Table C5-4 and Figure C5-3. For a retrieval leaks of 8,000 gal for all C-100 Series tanks, previous tank leaks, and previous UPRs, the simulated peak concentration is 0.82, 0.30, and 0.68 piCi/L, respectively, which are under the MCL Derived Constituent Concentration of 1 pCi/L. For no-action residuals, both the advection- and diffusion-dominated release models have peak concentrations well over the MCL Derived Constituent Concentration. For retrieved to HFFACO goals, the peak concentration for the advection-dominated release is 0.43 pCi/L. However, if the release mechanism is diffusion-dominated, the peak concentration decreases to 0.14 pCi/L. For the base-case composite analysis of WMA C, the peak concentration is 1.7 pCi/L (Figure C5-3), which is slightly higher than the MCL Derived Constituent Concentration of 1 pCi/L. The composite peak concentration occurs approximately 100 years from now, with the composite peak decreasing to below the MCL Derived Constituent Concentration approximately 100 years after the peak arrives. It is the impact of hypothetical retrieval leaks that drives the concentration over the MCL Derived Constituent Concentration. If retrieval leaks are mitigated, the peak concentration (0.96 pCi/L,

* See Preface in *SST System Closure Plan* (RPP-13774).

Figure C5-3) will be primarily due to past UPRs, which is slightly under the MCL Derived Constituent Concentration. Peaks resulting from residuals in tanks and pipelines are observed 3,500 and 2,900 years past closure, respectively, and are approximately one (0.14 pCi/L for tank residuals) and two orders (0.015 pCi/L for pipeline residuals) of magnitude lower than concentration peaks attributed to past leaks.

Table C5-4. Simulated Peak Concentrations[a] and Arrival Times for Iodine-129 at Various Boundaries.

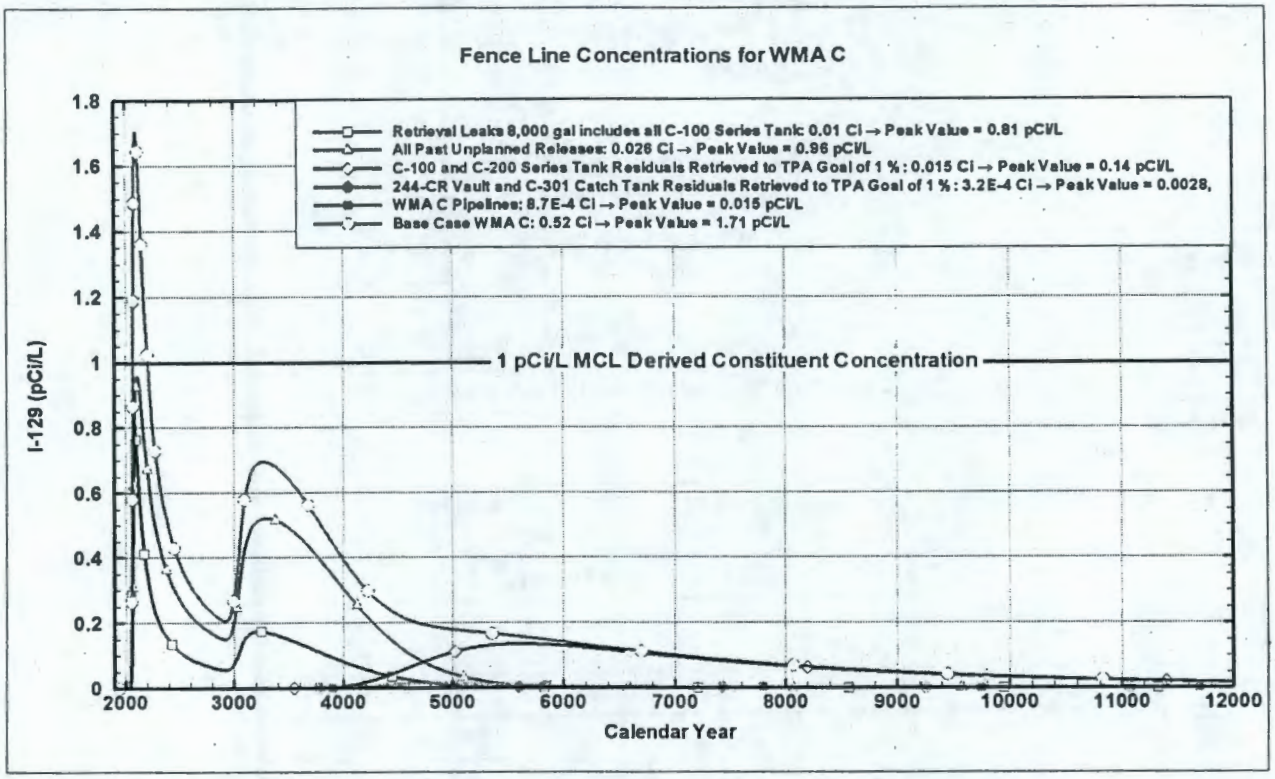
Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time (years)	Conc. (pCi/L)	Time (years)	Conc. (pCi/L)	Time (years)	Conc. (pCi/L)
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved tank waste advection-dominated release[b]	4,653	27.4	4,676	4.3	4,883	1.6
Unretrieved tank waste diffusion-dominated release	5,614	8.7	5,637	1.4	5,839	0.50
Base Case Post-Retrieval[b]						
Retrieved tank residuals advection-dominated release[b]	4,653	0.43	4,676	0.05	4,883	0.02
Retrieval leak (8,000 gal.)	2,082	0.82	2,107	0.11	2,324	0.055
Past tank leaks	2,092	0.30	2,117	0.05	2,333	0.02
Past ancillary equipment leaks (UPR)	2,117	0.68	2,141	0.11	2,355	0.04
Retrieved tank residuals diffusion-dominated release	5,614	0.14	5,637	0.025	5,839	0.012
Residuals in 244-CR vault and catch-tank release limited to diffusion	5,614	0.003	5,637	4.4 E-04	5,839	1.6 E-04
Residuals in ancillary pipeline release limited to diffusion (Scaled)	4,891	0.015	4,925	2.5 E-03	5,130	9.1 E-04

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.

[b] Not part of the base case; only added for comparison purposes between release models.

UPR = unplanned release.

Figure C5-3. Iodine-129 Composite WMA C Fenceline Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks.



Chromium

Results for chromium are given in Table C5-5 and Figure C5-4. To be conservative, all chromium was assumed to be chromium(IV) rather than chromium(III). Other than no-action residuals, all sources and release models, the simulated peak concentration is below the MCL (0.1 mg/L) for total chromium. Chromium(IV) is mobile compared to chromium(III). For the base case WMA composite analysis, the peak (0.006 mg/L) is a factor of approximately 15 less than the MCL.

Table C5-5. Simulated Peak Concentrations [a] and Arrival Times for Chromium$^{+6(b)}$ at Various Boundaries. (2 Pages)

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time (years)	Conc. (mg/L)	Time (years)	Conc. (mg/L)	Time (years)	Conc. (mg/L)
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved tank waste advection-dominated release[c]	4,653	0.16	4,676	0.02	4,883	0.009
Unretrieved tank waste diffusion-dominated	5,614	0.05	5,637	0.0077	5,839	0.0028

Table C5-5. Simulated Peak Concentrations [a] and Arrival Times for Chromium^{+6}[(b)] at Various Boundaries. (2 Pages)

release						
Base Case Post-Retrieval (see footnote for advection dominated release)						
Retrieved tank residuals advection-dominated release[c]	4,653	0.003	4,676	4.0 E-04	4,883	1.0 E-04
Retrieval leak (8,000 gal.)]	2,082	0.0064	2,107	1.0 E-03	2,324	3.0 E-04
Past tank leaks	2,092	7.9 E-04	2,117	1.2 E-04	2,333	4.3 E-05
Past ancillary equipment leaks (UPR)	2,117	0.003	2,141	5.2 E-04	2,355	1.9 E-04
Retrieved tank residuals diffusion-dominated release	5,614	7.9 E-04	5,637	1.23 E-04	5,839	4.55 E-05
Residuals in 244-CR vault and catch-tank release limited to diffusion	5,614	2.1 E-05	5,637	3.2 E-06	5,839	1.1 E-06
Residuals in ancillary pipeline release limited to diffusion	4,891	1.0 E-04	4,925	1.8E-05	5,130	6.8 E-06

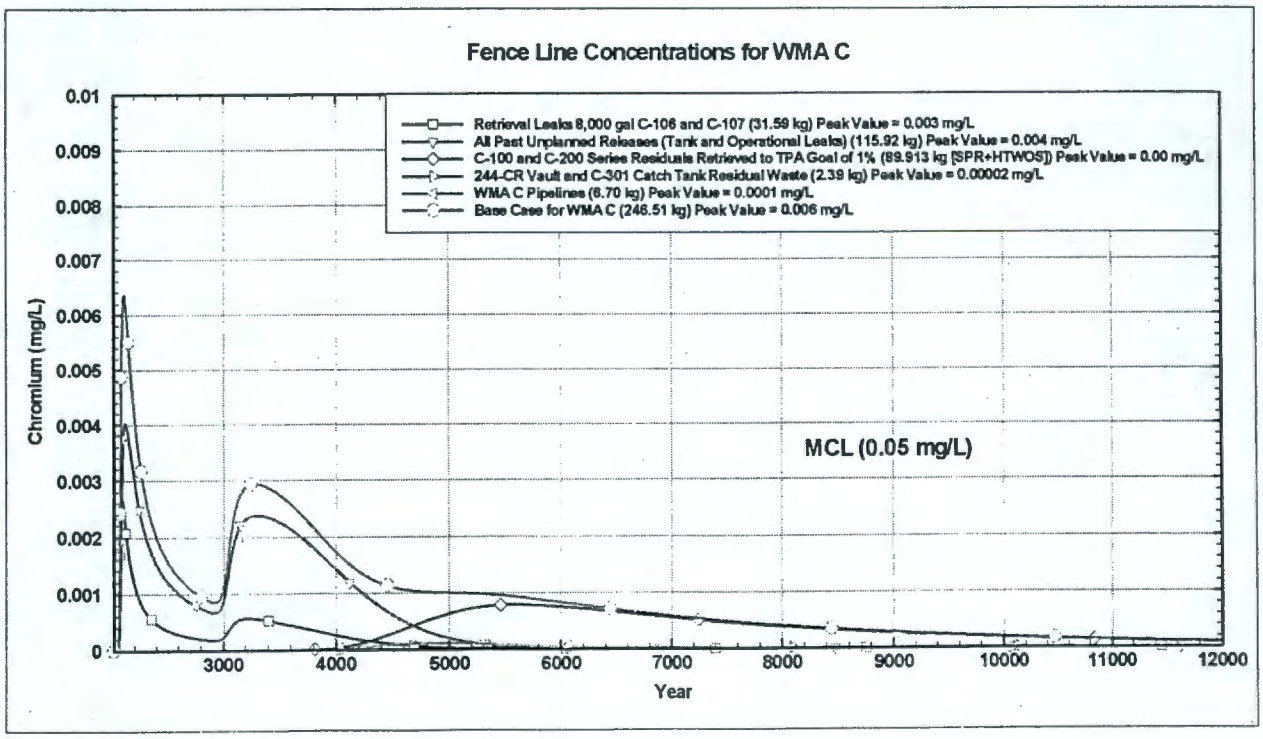
[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.

[b] For conservative purposes all chromium was assumed to be chromium^{+6}.

[c] Not part of the base case; only added for comparison purposes between release models.

UPR = unplanned release.

Figure C5-4. Chromium Composite WMA C Fenceline Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks.



Dual Peak Trends

A dual peak trend is shown on all of the previously referenced figures. This results from the leak occurring before the emplacement of a surface barrier and some, but not all, of the contaminant traveling through the vadose zone before the barrier becomes effective. Once the surface barrier becomes effective, the contaminant movement slows until the barrier degrades (in 500 years) and the recharge changes from 0.5 to 3.5 mm/yr, causing a rise in groundwater contamination. The contaminant continues to travel through the vadose zone until all of the mass from the initial leak is released (in 6,500 years).

Downgradient Concentrations

In addition to the breakthrough curves presented in the previous sections, an analytical stream tube model solution from Domenico and Schwartz (*Physical and Chemical Hydrogeology* [Domenico and Schwartz 1990]) was used to model groundwater flow and transport to various points of calculation downgradient from the WMA. The results from the stream tube model are summarized in Tables C5-3 through C5-5. The concentrations in groundwater are expected to attenuate as the contaminants move from the tank farm fenceline. For the base-case model, results indicated that none of the selected COCs are expected to be found at concentrations exceeding their respective MCL at the proposed core boundary (2,900 m [9,500 ft] from the WMA C fenceline) or at the Columbia River (14,300 m [47,000 ft] from the WMA C fenceline).

At the currently proposed core boundary for the 200 Areas, the only contaminants that exceed their respective MCL Derived Constituent Concentration are iodine-129, resulting from the advection- and diffusion-dominated releases without tank waste retrieval (4.3 pCi/L and 1.4 pCi/L, respectively), and technetium-99, resulting from the advection-dominated release case without tank waste retrieval (1,520 pCi/L). The inclusion of the effects of inventory reduction associated with retrieval to HFFACO limits for the advection- and diffusion- dominated releases at the Core Zone Boundary has the effect of reducing the predicted iodine-129 concentrations to 0.05 pCi/L and 0.025 pCi/L, respectively, and the technetium-99 concentration to 32 pCi/L and 10 pCi/L, respectively. When calculations are extended to the river, the calculated concentrations of all of the contaminants for all of the release and inventory cases decrease to levels below the MCL Derived Constituent Concentration (1 pCi/L), except for the iodine-129 concentration (1.6 pCi/L), resulting from the no-action inventory with advection-dominated release.

C5.1.3 No-Action and Post- Retrieval Residual Results for Different Tank Residual Release Models

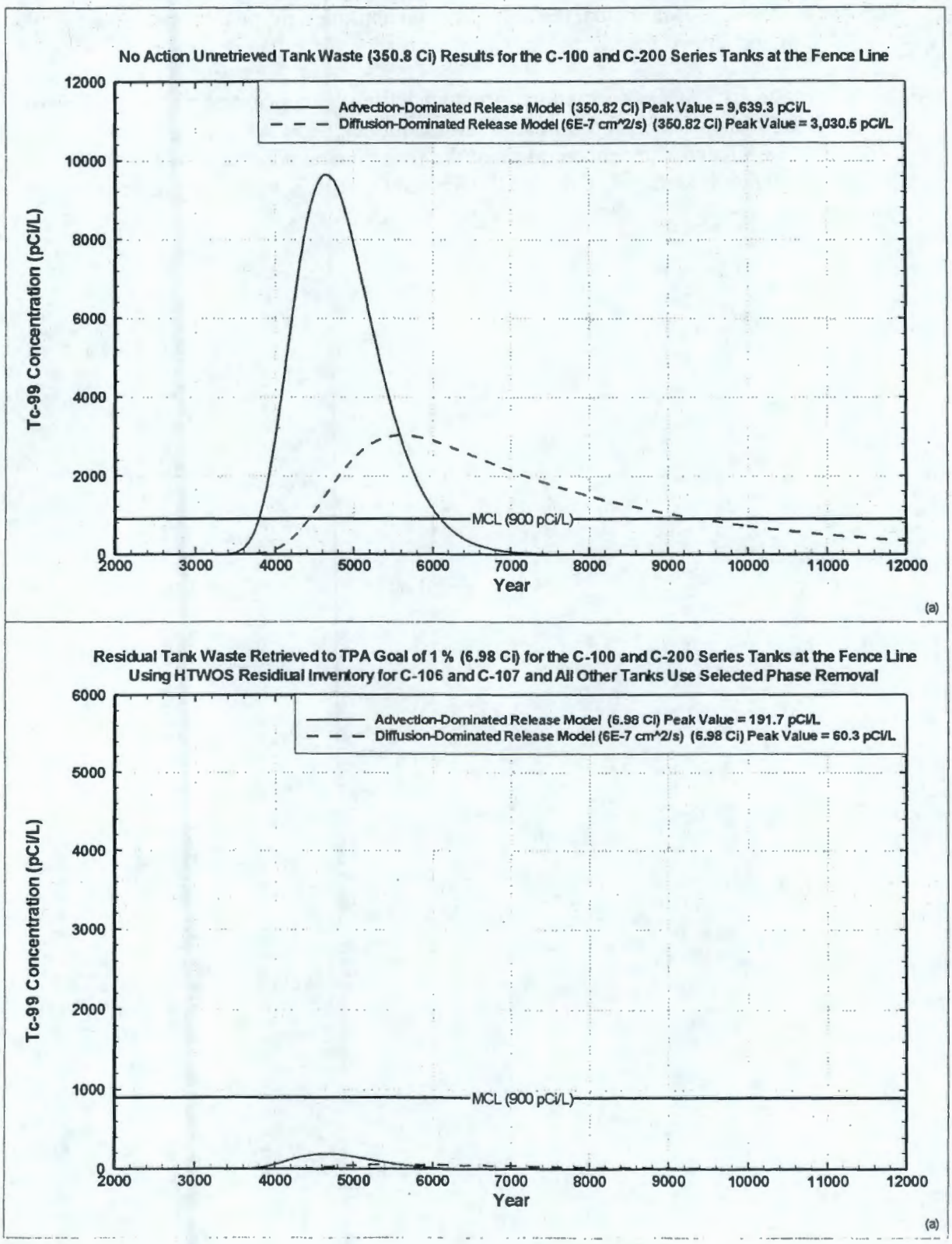
Figure C5-5 shows the simulated fenceline concentrations for technetium-99 for both no-action inventory and post-retrieval inventory. Figure C5-5(a) presents the no-action technetium-99 results for the C farm 100- and 200-series tanks. The total technetium-99 inventory for these tanks before retrieval is 350.8 Ci. Figure C5-5(b) shows simulated post-retrieval technetium-99 results. The total technetium-99 inventory for these tanks after retrieval is 6.98 Ci. (Note: the vertical scale has been increased by a factor of two over the upper figure.) Included in each of the figures is a comparison between the advection- and diffusion-dominated release mechanisms.

- If the release is advection-dominated (that is from a sand or gravel fill material for the tank), the peak concentration at the fenceline is 9,639 pCi/L for the present-day BBI. However, if the tank is filled with a stabilizing agent (such as grout* or concrete) and the release is diffusion-dominated, the resulting concentration drops by approximately 70% to 3,030 pCi/L.

- Retrieving to HFFACO goals reduces the technetium-99 concentration from 9,639 to 208 pCi/L for the advection-dominated release model. However, if the release is diffusion-dominated, the concentration at the fenceline is reduced from 3,030 to 66 pCi/L, which is well below the MCL Derived Constituent Concentration.

* See Preface in *SST System Closure Plan* (RPP-13774).

Figure C5-5. Advection- and Diffusion-Dominated Technetium-99 Release Model Results for All WMA C 100- and 200-Series Tanks Using Both No-Action and Post-Retrieval Inventories.



C5.1.4 Conclusions from Fate and Transport Modeling Results

- The primary contributors to groundwater contamination are contaminants contained in past leaks from tanks and ancillary equipment, with a distribution coefficient of 0.0 mL/g and relatively long half-lives.

- The placement of the surface barrier greatly reduces recharge through vadose contamination, which results in a decrease in the predicted groundwater concentration until the barrier degrades.

- Key parameters affecting the predicted groundwater contaminant concentrations resulting from tank residual waste releases are inventory, groundwater flow rate under the WMA, recharge, release rate, and contaminant mobility (that is, the distribution coefficient).

- Past leaks potentially have the largest impact (depending on inventory).

- Retrieval of tank residuals to the HFFACO goal of 360 ft^3(100-series tanks) and 30 ft^3 (200-series tanks) can reduce fenceline concentrations to below the MCL or MCL Derived Constituent Concentration.

- The foundation for the risk assessment calculations presented in this document is the inventory established by the BBI, which is based on both process knowledge and sampling data. As more knowledge about a tank becomes available, the inventory estimates for a tank are updated. In some cases, this has led to significant changes in inventory values. Post-retrieval sampling and analysis of residuals must be made to further assess the risk associated with the residuals. The risk assessment presented here could easily over/under estimate the risk without this information.

- Work to establish the type of release from a tank waste residual is important in direct proportion to the amount of waste that remains in the tank after retrieval. The more waste left behind, the more important the release model becomes.

C5.2 QUANTITATIVE DOSE AND RISK ESTIMATES FOR WMA C CLOSURE SCENARIO

A summary of the dose and risk estimates is provided in this section for selected exposure scenarios (see Addendums C1 and C2 for additional exposure scenarios). In these scenarios, a human receptor is exposed when that receptor uses groundwater contaminated by release of contaminates from the various sources within WMA C. Intruder scenarios were not considered in this document. However, in the future, DOE O 435.1-based intruder calculations will be provided to Ecology as part of a performance assessment. Based on preliminary discussions on implementing the recently proposed TPA Closure Process, performance assessments will replace risk assessments. The performance assessments will be designed to meet DOE, Ecology, and EPA's needs in this area. The performance assessment will become a central document in the

effective integration of each agencies regulations and guidelines. The performance assessment document's contents will generally follow the DOE O 435.1 but with modifications based on local discussions among Ecology, EPA, and DOE.

The long-term fate and transport modeling provided a series of quantitative estimates for contaminant groundwater concentrations over time assuming different waste sources and their associated release and migration characteristics. To calculate dose and risk values for a given waste source and exposure scenario, the peak groundwater contaminant concentrations from the corresponding waste source analysis are multiplied by the appropriate dose and/or risk conversion factor derived for that exposure scenario. The appropriate dose and/or risk conversion factor is provided in *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment* (HNF-SD-WM-TI-707, Rev. 3). Use of the groundwater included a number of exposure pathways (direct exposure, ingestion, inhalation, and food chain). Please see Addendum C1, Section 7.1, Tables 25 and 26 for exposure pathways related to groundwater.

The following source terms were evaluated to describe the relative impacts to groundwater:

- Residual tank waste following retrieval to a maximum of 360 ft^3 in each 100-series tank (30 ft^3 in each 200-series tank) and residual waste in ancillary equipment (pipes, vaults, and catch tanks)
- Estimated inventory of past leaks from tanks and ancillary equipment
- Hypothetical retrieval leaks resulting in the release of liquid waste during sluicing-type retrieval operations.

Resultant groundwater effects of these source terms are evaluated at the following locations:

- The downgradient WMA C fenceline
- A proposed nearest boundary of the 200 Area Core Zone Boundary (2,900 m (9,500 ft) from the WMA C fence line)
- The extent of groundwater immediately before discharge of the aquifer into the Columbia River (14,300 m (47,000 ft) east of the WMA C fenceline).

Radiological dose from groundwater contaminants is presented in terms of EDE for defined receptors along with estimated ILCR, and non-carcinogenic hazard index. The results presented here cover radiological dose and ILCR. For non-carcinogenic hazard risk, please see Addendum C1.

C5.2.1 Radiological Dose

An analysis of the radiological dose for the All-Pathways Farmer and Residential Drinking Water (2 L/day) scenarios are presented in Table C5-6. These are DOE exposure scenarios for radiological dose required by DOE O 435.1. Other exposure scenarios for radiological dose are

presented in Addendum C1, Section 7.0. Table C5-6 has been divided into three sections to show the relative contribution from each source term (residual tank waste [diffusion-dominated release], all past UPRs [tank leaks and ancillary equipment], and hypothetical retrieval leaks). The results for radiological dose are briefly summarized. Only major sources are discussed; see Addendum C1 for discussion of minor sources (i.e. ancillary equipment). Highlights from Table C5-6 are as follows:

- **Residual Tank Waste:** Cumulative groundwater dose at the WMA C fenceline from all radionuclides is 0.194 mrem/yr with technetium-99 and iodine-129 accounting for 96% of the dose (Addendum C1, Table 28). The cumulative dose from tank residuals is well below the target maximum value of 25 mrem/yr performance objective for the All Pathways Farmer scenario at all locations evaluated. The Residential Drinking Water scenario is based on a daily ingestion rate of 2 L/day, and the dose is calculated for each radionuclide based on a conversion factor utilizing a derived concentration for each constituent, resulting in an annual dose of 4 mrem/yr EDE. The Industrial Drinking Water scenario assumes a 1 L/day ingestion rate and only 250 days on site rather than 365 days on site; thus, the dose for each constituent is reduced by 66% as compared to the residential scenario. Calculated doses for Residential Drinking Water scenarios and Industrial Drinking Water scenarios are 0.097 mrem/yr and 0.033 mrem/yr, respectively, and are below the target maximum value of 4 mrem/yr. Dose contributions from technetium-99 and iodine-129 make up approximately 71% and 27%, respectively, of the total dose.

- **All Past Leaks:** Cumulative groundwater dose from all radionuclides originating from post-retrieval residual tank waste is 1.7 mrem/yr, which is well below the target maximum value of 25 mrem/yr performance objective for the All Pathways Farmer scenario. Calculated doses for Residential and Industrial Drinking Water scenarios are 0.8 and 0.27 mrem in a year, respectively. Dose contributions from technetium-99 and iodine-129 account for 88% of the drinking water dose.

- **Hypothetical Retrieval Leaks:** In this analysis all C-100 series tanks leak 1,000 gallons. The cumulative groundwater dose from all radionuclides originating from hypothetical retrieval leaks is 1.2 mrem/yr, which is well below the target maximum value of 25 mrem/yr performance objective for the All Pathways Farmer scenario. Calculated doses for Industrial and Residential Drinking Water scenarios are 0.62 and 0.21 mrem/yr, respectively. Dose contributions from technetium-99 and iodine-129 accounts for 97% of the total drinking water dose.

- **Cumulative Effects for All Source Terms:** The summary results for the All-Pathways Farmer scenario are presented in Figure C5-6, including individual contribution curves for the individual source terms and the cumulative curve representing the additive effects of the source terms. All of the results of this analysis are based on groundwater concentrations at the WMA C fenceline. The maximum dose for the WMA C is 2.8 mrem/yr, occurring approximately 100 years into the future. This dose is related to past leaks. Peak impacts from residual waste are not observed until 3,500 years after closure.

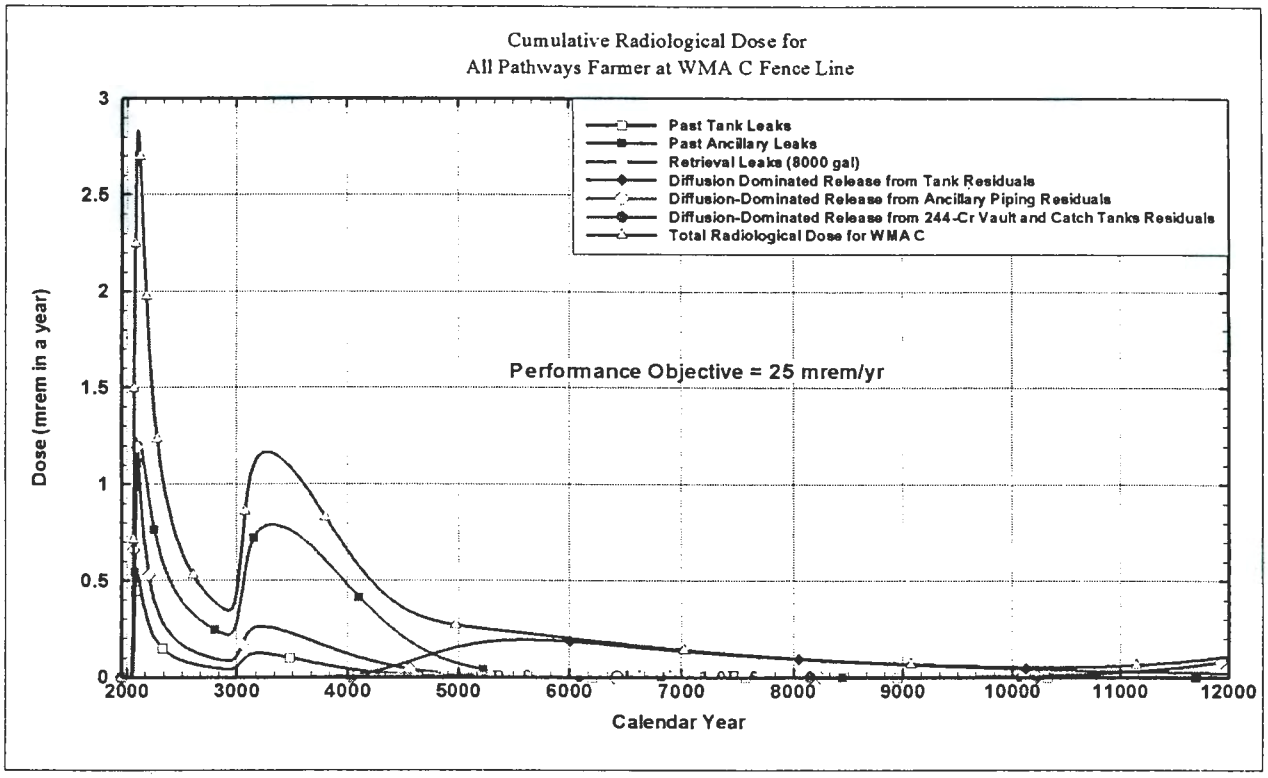
Table C5-6. Radiological Dose from Exposure to Groundwater and Drinking Water for Technetium-99 and Iodine-129 along with the Cumulative for All Radionucldes.

Constituent	WMA C Fenceline		Core Zone Boundary		Columbia River (Groundwater)	
	Time (CY)	Dose (mrem/yr)	Time (CY)	Dose (mrem/yr)	Time (CY)	Dose (mrem/yr)
Contribution from Tank Residuals						
All Pathways Farmer (compare to 25 mrem/yr target)						
Technetium-99	5,610	1.2 E-01	5,637	1.8 E-02	5,839	6.8 E-03
Iodine-129	5,614	7.1 E-02	5,637	1.1 E-02	5,839	4.2 E-03
Cumulative		1.9 E-01		3.0 E-02		1.1 E-03
Residential Drinking Water Dose (compare to 4 mrem/yr EDE target)[a]						
Technetium-99	5,610	6.9 E-02	5,637	1.1 E-02	5,839	3.8 E-03
Iodine-129	5,614	2.6 E-02	5,637	4.0 E-03	5,839	1.5 E-03
Cumulative		9.7 E-02		1.5 E-02		5.3 E-03
Contribution from Past Tank Leaks and Unplanned Releases						
All Pathways Farmer (compare to 25 mrem/yr target)						
Technetium-99	2,117	8.7 E-01	2,141	1.4 E-01	2,355	5.1 E-02
Iodine-129	2,117	5.1 E-01	2,141	7.8 E-02	2,355	3.0 E-02
Cumulative		1.7 E+00		2.7 E-01		1.0 E-02
Residential Drinking Water Dose (compare to 4 mrem/yr EDE target)[a]						
Technetium-99	2,117	5.2 E-01	2,141	8.2 E-02	2,355	2.9 E-02
Iodine-129	2,117	1.8 E-01	2,141	2.8 E-02	2,355	1.0 E-02
Cumulative		8.0 E-01		1.3 E-01		4.4 E-02
Contribution from Hypothetical Retrieval Leaks						
All Pathways Farmer (compare to 25 mrem/yr target)						
Technetium-99	2,082	7.3 E-01	2,107	1.2 E-01	2,324	3.9 E-02
Iodine-129	2,082	4.3 E-01	2,107	6.9 E-01	2,324	2.3 E-02
Cumulative		1.2 E-00		2.0 E-01		6.6 E-02
Residential Drinking Water Dose (compare to 4 mrem/yr EDE target)[a]						
Technetium-99	2,082	4.4 E-01	2,107	7.0 E-02	2,324	2.3 E-02
Iodine-129	2,082	1.6 E-02	2,107	2.6 E-03	2,324	8.5 E-03
Cumulative		6.2 E-01		9.9 E-02		3.3 E-02

[a] Based on 2 L/day ingestion.

CY = calendar year

Figure C5-6. Impacts of Base-Case Multiple Source Terms on Groundwater Dose—Tank Residuals after Retrieval, Past Leaks, and Hypothetical Retrieval Leaks from Selected Tanks in WMA C for the All-Pathways Farmer Receptor at Downgradient Fenceline.



C5.2.2 Drinking Water Dose Calculation Methods

The radiological dose resulting from the presence of radionuclides in drinking water may be calculated by either of the following two methods:

- Target Organ
- Effective Dose Equivalent.

The derivation and application of these two methods are described in the following subsections.

C5.2.2.1 Target Organ Method. The Target Organ method, as presented in this discussion, is the method prescribed by EPA for determination of compliance of drinking water supply systems with the MCL requirements of the "National Primary Drinking Water Regulations" (40 CFR 141.66, Final Rule 7, December 2000). The MCL for beta/photon emitters in drinking water is 4 mrem/yr. This method is derived from dose calculations described in *National Bureau of Standards Handbook 69* (NBS 1963, *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure*).

The Radionuclide Rule is implemented according to procedures described by EPA in the *Implementation Guidance for Radionuclides* (EPA 2002. *Implementation Guidance for Radionuclides*) utilizing a sum-of-fractions calculation based on observed radionuclide concentrations in water and predetermined derived concentrations for each radionuclide that would result in a 4 mrem/yr dose if the nuclide was the only nuclide present. The 4 mrem/yr MCL, based on the target organ calculation, has been in place as the drinking water standard since 1976. The derived concentrations for selected radionuclides of interest to tank closure are shown in Table C5-7.

Table C5-7. Comparison of Derived Concentrations for Selected Beta and Photon Emitting Radionuclides.

Nuclide	Concentration resulting in 4 mrem/yr MCL to critical organs (pCi/L)	Risk at MCL	1991 proposed concentration resulting in 4 mrem/yr EDE (pCi/L)	Risk at EDE
Tritium	20,000	3.57 E-05	60,900	1.09 E-04
Carbon-14	2,000	1.09 E-04	3,200	1.75 E-04
Technetium-99	900	7.28 E-05	3,790	3.07 E-04
Antimony-125	300	4.12 E-05	1940	2.67 E-04
Iodine-129	1	4.22 E-06	21	8.87 E-05

Source: EPA 2000, *Radionuclides Notice of Data Availability Technical Support Document*, Table III-3.

C5.2.2.2 Effective Dose Equivalent Method. The EDE method of calculating radiological dose from drinking water was proposed for use in determining compliance with the radionuclide MCL in 1991. This method was proposed because it would result in a more consistent risk level within EPA's target risk range, and would be more consistent with similar dose calculations used by other agencies (such as DOE). In codifying the final rule in December 2000, however, EPA decided to retain the existing Target Organ calculation method on the basis that it is protective of public health. The EDE dose calculation method is prescribed by DOE in DOE Order 5400.5 (DOE 1990, *Radiation Protection of the Public and the Environment*). The EDE dose is implemented in the same manner as the Target Organ dose method utilizing a sum-of-fractions calculation. The derived concentrations for individual nuclides that result in 4 mrem/year EDE drinking water dose are different from those established for the Target Organ method. The EDE derived concentrations for selected radionuclides are shown in Table C5-7.

C5.2.2.3 Comparison of Dose Calculation Methods. The EDE calculation method was selected for use in the WMA C closure risk evaluation because of the apparent direct applicability of DOE Order 5400.5 to the Hanford site. For the selected nuclides shown in Table C5-7, the difference between derived concentrations for EDE and Target Organ methods ranges from a low of about 1.5 times higher for the EDE method for carbon-14 to as much as 21 times higher for the EDE method for iodine-129. This difference means that for a specific concentration of a particular nuclide present in drinking water, the dose resulting from that nuclide will be lower using the EDE calculation method than for the Target Organ method. For drinking water containing a mixture of nuclides, the difference between the two methods is

greater when nuclides such as iodine-129 or antimony-125 are present because of the greater difference in the derived concentration for these nuclides between the two methods. Because iodine-129 and technetium-99 account for the majority of calculated dose in the preliminary WMA C dose estimates, there is a substantial difference between the two methods. There remains substantial uncertainty in the actual iodine-129 and technetium-99 content of the wastes contained in WMA C tanks. The iodine-129 concentration may actually be substantially lower that current estimates. Sampling and analysis of residual waste is planned and should result in reduced uncertainty and more accurate dose estimates.

C5.2.3 Incremental Lifetime Cancer Risk (ILCR)

The ILCR analysis is presented in this section. Results for the cumulative impacts for tank residuals (diffusion-dominated release), past leaks (tank leaks and ancillary equipment), and hypothetical retrieval leaks are discussed first, followed by cumulative releases for all sources. Two of the HSRAM Exposure Scenarios are discussed. These are the Industrial and Residential scenarios for ILCR which are described in HNF-SD-WM-TI-707. Additional exposure scenarios are given in Section 7 of the Addendum C-1 and in Addendum C-2.

The HSRAM Industrial is presented because the Hanford Advisory Board Advice recommends the industrial scenario for the 200 Core Zone Boundary for the next 150 years. The results of the risk assessment show that highest risks are due to past leaks and hypothetical retrieval leaks. The highest predicted release from WMA C occurs within the next 150 years due to past leaks and hypothetical retrieval leaks. Therefore, the industrial scenario is presented. The HSRAM residential scenario is presented because it is unrealistic to assume that an industrial scenario is appropriate once the existing groundwater plumes have been remediated or have naturally attenuated. It is expected that the existing groundwater plumes will have been either remediated or naturally attenuated by the time contamination due to residual tank waste arrives at the water table. Both of the HSRAM scenarios account for multiple exposure pathways (food chain, ingestion, inhalation, etc. See Table 26 of Addendum C1 for a complete listing of exposure pathways).

The ILCR results are presented in Table C5-8. The table has been divided into three sections to show the relative contribution from each of the major source terms (residual tank wastes [diffusion-dominated release], all past UPRs [tank leaks and ancillary equipment], and hypothetical retrieval leaks). Only these major sources are discussed; see Addendum C1 for discussion of minor sources (i.e., ancillary equipment). Highlights of this table include the following:

- **Residual Tank Waste:** Cumulative ILCR risk is 1.0 E-06 from all radioactive chemicals (inventory from RPP-15317), of which technetium-99 and iodine-129 contribute 99% of the total risk (see Addendum C1, Table 28). The cumulative ILCR is below the performance objective value of 1.0 E-05 at all evaluation points for the HSRAM Industrial exposure scenario. However, for the HSRAM Residential scenario, at the WMA fenceline, cumulative ILCR is approximately twice (2.3 E-05) the performance objective, but below the performance objective at calculation points located

downgradient from the fenceline. Risk from technetium-99 and iodine-129 account for more than 98% of the total risk (see Addendum C1, Table 28).

- **Past Leaks:** For the HSRAM Industrial exposure scenario, cumulative total ILCR from all radioactive chemicals at the WMA C fenceline is 8.1 E-06, which is below the performance objective value. Technetium-99 and iodine-129 are responsible for 94% of the total risk (see Addendum C1, Table 28). For the HSRAM Residential scenario at the WMA fenceline and 200 Area Core Zone Boundary, cumulative ILCR is 1.8 E-04 and 2.7 E-05, respectively, which are both above the performance objective. At the Columbia River calculation point, the risk drops to 1.9 E-05, which is right at the performance metric. Risk from technetium-99 and iodine-129 accounts for greater than 98% of the total risk.

- **Hypothetical Retrieval Leaks:** For the HSRAM Industrial exposure scenario, cumulative total ILCR from all radioactive chemicals at the WMA C fenceline is 6.5 E-06, which is below the performance objective value. For the HSRAM Residential scenario at the WMA fenceline and 200 Area Core Zone Boundary, cumulative ILCR is 1.4 E-4 and 2.2 E-05, respectively, which are both above the performance objective. At the Columbia River calculation point, the risk drops to 7.4 E-06.

- **Incremental Lifetime Cancer Risk Cumulative Impacts from All Sources:** An analysis of cumulative effects of all source terms (radioactive chemicals), including the minor source terms, for the HSRAM Industrial ILCR is presented Figure C5-7. Note that the highest peak ILCR (1.4 E-05) occurs early in the postclosure period. Existing past leaks and hypothetical retrieval leaks contribute almost the entire peak value. Without the hypothetical retrieval leaks, the peak value would be below the target performance objective of 1.0 E-05. After approximately calendar year (CY) 4,800, the residual waste contribution becomes the primary contributor to risk. For the HSRAM Residential Scenario, the values shown on this curve can be scaled by a factor of approximately 22 and the peak value 3.0 E-04 ILCR.

Table C5-8. Incremental Lifetime Cancer Risk from Exposure to Groundwater for Selected Constituents. (3 Pages)

Constituent	WMA C Fenceline		Core Zone Boundary		Columbia River (Groundwater)	
	Time (CY)	Risk	Time (CY)	Risk	Time (CY)	Risk
Contribution from Tank Residuals						
HSRAM Industrial Scenario – RISK (compare to 1.0 E-05 Target)						
Technetium-99	5610	9.0 E-07	5637	1.4 E-07	5839	5.2 E-08
Iodine-129	5614	1.0 E-07	5637	1.6 E-08	5839	5.8 E-09
RAD TOTAL[a]		1.0 E-06		1.6 E-07		6.0 E-08
Chromium^{+6}[b]	5614	2.8 E-08	5637	4.4 E-09	5839	1.6 E-09
Non-RAD Total		2.8 E-08		4.4 E-09		1.6 E-09

Table C5-8. Incremental Lifetime Cancer Risk from Exposure to Groundwater for Selected Constituents. (3 Pages)

Constituent	WMA C Fenceline		Core Zone Boundary		Columbia River (Groundwater)	
	Time (CY)	Risk	Time (CY)	Risk	Time (CY)	Risk
HSRAM Residential Scenario – RISK (compare to 1.0 E-05 Target)						
Technetium-99	5610	2.2 E-05	5637	3.4 E-06	5839	1.3 E-06
Iodine-129	5614	5.2 E-07	5637	8.2 E-08	5839	3.0 E-08
RAD TOTAL[a]		2.3 E-05		3.5 E-06		1.3 E-06
Chromium^{+6} [b]	5614	6.3 E-08	5637	9.8 E-09	5839	3.6 E-09
Non-RAD Total		6.3 E-08		9.8 E-09		3.6 E-09
Contribution from Past Tank Leaks and Unplanned Releases						
HSRAM Industrial Scenario – RISK (compare to 1.0E-5 Target)						
Technetium-99	2117	6.9 E-06	2141	1.1 E-06	2355	3.8 E-07
Iodine-129	2117	7.1 E-07	2141	1.1 E-07	2355	4.0 E-08
RAD TOTAL[a]		8.1 E-06		1.3 E-06		4.5 E-07
Chromium^{+6} [b]	2117	1.1 E-07	2141	1.7 E-08	2355	6.1 E-09
Non-RAD Total		1.1 E-07		1.7 E-08		6.1 E-09
HSRAM Residential Scenario – RISK (compare to 1.0E-5 Target)						
Technetium-99	2117	1.7 E-04	2141	2.6 E-05	2355	1.0 E-06
Iodine-129	2117	3.7 E-06	2141	5.7 E-07	2355	2.1 E-07
RAD TOTAL[a]		1.8 E-04		2.8 E-05		1.0 E-05
Chromium^{+6}[b]	2117	2.4 E-07	2141	3.8 E-08	2355	1.5 E-8
Non-RAD Total		2.4 E-07		3.8 E-08		1.5 E-8
Contribution from Hypothetical Retrieval Leaks						
HSRAM Industrial Scenario – RISK (compare to 1.0 E-05 Target)						
Technetium-99	2082	5.7 E-06	2107	9.1 E-07	2324	3.0 E-07
Iodine-129	2082	6.1 E-07	2107	9.7 E-08	2324	3.2 E-08
RAD TOTAL[a]		6.5 E-06		1.0 E-06		3.4 E-07
Chromium^{+6}[b]	2082	1.7 E-07	2107	2.8 E-08	2324	9.2 E-09
Non-RAD Total		1.7 E-07		2.8 E-08		9.2 E-09
HSRAM Residential Scenario – RISK (compare to 1.0 E-05 Target)						
Technetium-99	2082	1.4 E-04	2107	2.2 E-05	2324	7.4 E-06
Iodine-129	2082	3.2 E-06	2107	5.0 E-07	2324	1.7 E-08
RAD TOTAL[a]		1.4 E-04		2.3 E-05		7.6 E-06
Chromium^{+6}[b]	2082	3.8 E-07	2107	6.1 E-08	2324	2.0 E-08
Non-RAD Total		3.8 E-07		6.1 E-08		2.0 E-08

Table C5-8. Incremental Lifetime Cancer Risk from Exposure to Groundwater for Selected Constituents. (3 Pages)

Constituent	WMA C Fenceline		Core Zone Boundary		Columbia River (Groundwater)	
	Time (CY)	Risk	Time (CY)	Risk	Time (CY)	Risk

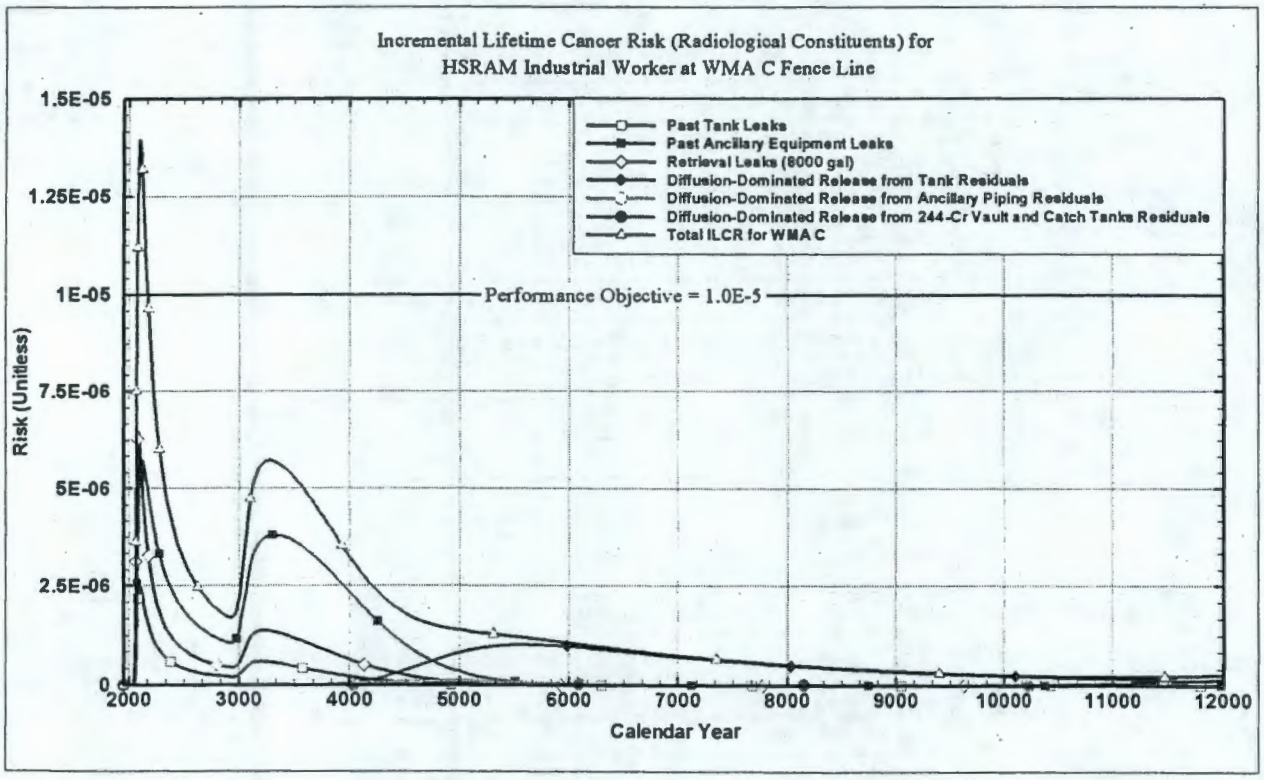
CY = calendar year.

RAD = radiological component of ILCR

[a] Cumulative includes all COPCs listed in *Inventory and Source Term Data Package* (DOE/ORP-2003-02) and *241-C Waste Management Inventory Data Package* (RPP-15317) that contribute to this risk metric

[b] For conservative purposes, all chromium is assumed to be in the +6 valence state additionally, when calculating ILCR, only the slope factors for inhalation are available, chromium is assumed to be inhaled through shower, sprinklers, and/or dust contaminated with it

Figure C5-7. Impacts of All Source Terms – Tank Residuals after Retrieval, Past Leaks, and Hypothetical Retrieval Leaks for the WMA C HSRAM Industrial Receptor at Downgradient Fence Line.



C5.2.4 Conclusions from Exposure Scenarios

The following conclusions can be drawn from the exposure scenarios:

- Following retrieval of tank waste to meet the maximum residual specified in the HFFACO, known past leaks and hypothetical retrieval leaks are responsible for the largest peak values for dose and cancer risk.

- Radiological dose resulting from the contribution of the various source terms (tank residuals, past UPRs, and hypothetical retrieval leaks) do not exceed target values at any of the points of computation.

- Cumulative ILCR exceeded the target value of 1.0E-05 at the WMA C fenceline for both the HSRAM Industrial and Residential receptor with technetium-99 responsible for the majority of the estimated risk.

- Cumulative ILCR exceeded the targe value of 1.0 E-05 for the HSRAM residential scenario at core zone boundary and was at the target value at the Columbia River. This is primarily due to past UPRs and hypothetical retrieval leaks.

C5.3 WORKER AND PUBLIC EXPOSURE RISK ASSESMENT

The worker and public exposure human health risk analysis estimated the potential health impacts from both accident and normal (non-accident) conditions resulting from various scenarios for C-106 and the C farm during closure activities. However, a safety analysis that identifies accident scenarios for closure activities is currently being developed under the document safety analysis effort and will be considered in the future evaluation of short-term risk. The analysis provided below shows the methodology and calculations used in a worker and public exposure risk assessment. It uses the safety analysis completed for retrieval of wastes from tanks for its accident scenarios. Thus, these are expected to provide conservatively high risk estimates because much of the waste has been removed and less contact between waste and workers is expected during closure.

C5.3.1 Assumptions

Occupational injuries, illnesses, and fatalities resulting from potential accidents are calculated based on the following assumptions:

- C-106 labor requirements for Phase I grouting* of the tank
  - Phase I grouting of tank = 3,800 hours
  - Phase I grouting of all C farm tanks = 60,800 hours.
- Hanford-specific incidence rates for occupational accidents

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* See Preface in *SST System Closure Plan* (RPP-13774).

- Total recordable cases = 1.93×10^{-5} total recordable cases/hour
- Lost workday cases = 8.04×10^{-6} lost workday cases/hour
- Fatalities = 1.35×10^{-8} fatalities/hour.

In calculating the radiological latent cancer fatality (LCF) risk from routine exposure approach, the following assumptions were made:

- Volume of respirable waste released in the accident is as calculated in *Potential Accidents with Radiological and Toxicological Source Terms for Hanford Tank Waste Remediation System Environmental Impact Statement* (WHC-SD-WM-ANAL-041).
- Concentration of radionuclides is calculated from the inventory presented in *Inventory and Source Term Data Package* (DOE/ORP-2003-02) and provided in Addendum C1, Table 8(b).
- For the noninvolved workers and general public exposure scenarios, the atmospheric dispersion coefficients were calculated using the GXQ computer code (WHC-SD-GN-SWD-30002).
- For the involved workers it was assumed the respirable waste released in the accident would be released as a "puff" and spread instantaneously and uniformly around the exhaust port over a hemisphere 10 m (33 ft) in radius (WHC-SD-WM-ANAL-041).
- Breathing rates for the various receptors are provided in HNF-SD-WM-TI-707.
- Inhalation dose conversion factors for a 50-year dose commitment for each radionuclide are taken from HNF-SD-WM-TI-707.
- Dose-to-risk conversion factors for converting receptor doses to LCFs are referenced in "Preamble to Standard for Protection Against Radiation" (56 FR 23363) and *1990 Recommendations of the International Commission on Radiological Protection* (ICRP 1991) and apply as follows:
  - Involved worker and noninvolved worker = 4.0×10^{-4} LCF/rem for low doses under 20 rem, 8.0×10^{-4} LCF/rem for high doses over 20 rem
  - General public = 5.0×10^{-4} LCF/rem for low doses under 20 rem, 1.0×10^{-3} LCF/rem for doses equal to or over 20 rem.

The number of accidents is calculated by multiplying the annual frequency of the accident by the time required to perform the activity. The annual frequency of a ventilation failure accident is referenced in WHC-SD-WM-ANAL-041. The time required to close the tanks is based on *Engineering Report for Interim Closure for Tank 241-C-106 and the 241-C Farm 200-Series Tanks* (RPP-14590).

In calculating the chemical hazard index from accident and routine exposure approach, the following assumptions were made:

- The chemical inventory used for these assessments were made up of two components, the organic chemicals and the inorganic chemicals. The emission rates for organic chemicals are taken from *Organic Vapor Source Term for Tanks 241-C-201, 241-C-202, 241-C-203, and 241-C-204 During Waste Retrieval Operations* (RPP-14841).

- Organic pollutant release concentrations and ammonia release concentrations were calculated assuming that 900 m^3/hr of air containing the pollutant concentrations observed in C-204 are exhausted year around.

- The mean concentrations of the organic pollutant and ammonia release were increased by two times the standard deviation to reflect statistical variability in the results. Two times the standard deviation represents a 95% confidence that the actual concentration is bounded.

- Only 33% of total chromium was assumed to be chromium(VI).

C5.3.2 Worker and General Public Exposure Risk Assessment Conclusions

Based on the worker and general public exposure human health risk analysis, the estimated potential health impacts from both accident and normal (non-accident) conditions resulting from WMA C tank closure activities are as follows:

- For the scenarios analyzed, the administrative control level of 0.5 rem/yr for a worker and the standard for routine exposure to the public of 0.1 rem/yr are not exceeded.

- In all cases, the acute exposure limit of 5.0 rem to an involved worker (located at 10 m [33 ft] from the point of release) from a radiological accident with an extremely unlikely probability of occurrence ($>10^{-6}$ to $\leq 10^{-4}$) would be exceeded. Mitigative measures are currently in place to prevent this type of accident from occurring through administrative procedures, worker training, and other types of preventive measures. As indicated, this accident is extremely unlikely. However, the assumptions used in calculating this probability are extremely conservative.

- For the scenarios analyzed, in no case would there be a fatality from occupational accidents nor would there be at least one lost workday case.

- Short-term radiation risk to the public for closure activities, expressed as LCFs, is very small, and of the order of 1.0 E-07 LCF.

- Conservative chemical accident impacts do not exceed the TEEL/ERPG-3 threshold for the involved worker, however small refinements to the methodology may allow the impacts to meet the TEEL/ERPG-2 threshold as the current estimate exceeds the

threshold values by only 2 percent. The impacts to the non-involved worker and the general public would not exceed the TEEL-0 threshold, of no impact.

- Routine chemical exposures would exceed the regulatory limit of 1.0 for noncarcinogenic chemicals.

Because the safety analysis of tank closure activities is not yet available, analogous safety data from other tank-related activities (retrieval) were used for the worker and public exposure risk assessment.

It is assumed that the accident scenarios developed for retrieval activities would be considered a bounding case for closure activities, since closure does not involve removing waste from tanks.

C6.0 CLOSURE SCHEDULE FOR WMA C

The timeline presented in Section C4.0 (Figure C4.1) depicts the relative sequence of closure activities associated with the WMA closure and postclosure actions.

The HFFACO Milestone M-45 series (revised per change number M-45-02-03) defines major, interim, and target milestones for the SST system closure. Specific milestones related to WMA C component closure activities or the WMA C closure action are listed below:

- M-45-05I-T01 – Conduct C-106 waste retrieval and closure demonstration project 30% design consultation. Milestone date 1/31/2003 (completed).
- M-45-05J-T01 – Complete C-106 waste retrieval and closure demonstration project design. Milestone date 4/30/2003 (completed).
- M-45-05K-T01 – Complete C-106 waste retrieval and closure demonstration project construction. Milestone date 9/30/2003.
- M-45-05L-T01 – Complete full-scale C-106 waste retrieval. Milestone date 11/1/2003.
- M-45-05M-T01 – Submit C-106 waste retrieval results, analysis of residual waste(s), and (if appropriate) request for exception to the criteria pursuant to HFFACO Appendix H. Milestone date 2/27/2004.
- M-45-05H – Interim completion of C-106 waste retrieval and closure demonstration project. Milestone date 4/30/2004.
- M-45-05N-T01 – Final completion of C-106 retrieval and closure demonstration project. Milestone date 12/31/2004.
- M-45-03-T04 – Submit C-104 sludge/hard heel, confined sluicing and robotic technologies, waste retrieval functions and requirements document. Milestone date 12/31/2001 (completed).
- M-45-03G – Complete C-104 sludge/hard heel, confined sluicing and robotic technologies, waste retrieval cold demonstration. Milestone date 6/30/2004.
- M-45-03H – Complete C-104 sludge/hard heel, confined sluicing and robotic technologies, waste retrieval demonstration design. Milestone date 9/30/2004.
- M-45-03I – Complete C-104 sludge/hard heel, confined sluicing and robotic technologies, waste retrieval demonstration construction. Milestone date 9/30/2006.
- M-45-03F – Complete full-scale sludge/hard heel, confined sluicing and robotic technologies, waste retrieval demonstration at tank C-104. Milestone date 12/31/2007.

- M-45-06A – Submit a certified (framework) SST system closure plan modification and C-106 waste retrieval and closure demonstration plan to Ecology. Milestone date 12/19/2002 (completed).

- M-45-06D – Submit a certified (framework) SST system closure plan modification and C-104 waste retrieval and closure demonstration plan to Ecology. Milestone date 6/30/2007.

- M-45-14 – Interim completion of tank C-104 SST waste retrieval and closure demonstration project. Milestone date 6/30/2008.

- M-45-14-T01 – Final completion of tank C-104 SST waste retrieval and closure demonstration project. Milestone date 6/3/2009.

- M-45-06 – Complete closure of all SST farms in accordance with approved closure/postclosure plan(s). Milestone date 9/30/2024.

DOE will work closely with the regulators to develop the schedule for the WMA C closure action as component closure activities progress and as specific scheduling information becomes available.

C7.0 CLOSURE CERTIFICATION, NOTICE IN DEED, AND SURVEY PLAT

In accordance with WAC 173-303-610(6), "Certification of Closure," within 60 days of completing the final closure of WMA C, DOE will submit to Ecology by registered mail, a certification that WMA C has been closed according to the specifications in this closure action plan. The certification will be signed by DOE and an independent registered professional engineer.

In accordance with WAC 173-303-610(9) and (10), "Notice to local land authority," and "Notice in deed to property," no later than the date of submission of the certification of closure of WMA C, DOE will provide a survey plat to Benton County indicating the location and dimensions of the closed dangerous waste units with respect to permanently surveyed benchmarks. The survey plat will be prepared and certified by a professional land surveyor. After the final closure, the survey plat of the WMA will be submitted to Benton County and Ecology. In addition, any restrictive covenants on the use of the land also will be submitted to Benton County for attachment to the property deed, as necessary.

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C8.0 POSTCLOSURE CARE

In accordance with WAC 173-303-640(8)(c)(ii), a contingent postclosure plan is required to be included in a closure plan for a tank system that does not comply with secondary containment, such as the SST system. This postclosure plan must provide for contingent postclosure care in accordance with the requirements for landfills contained in WAC 173-303-665(6). Further details regarding postclosure care will be developed on completion of a WMA C surface barrier design. This information will be submitted in modifications to the WMA C Closure Action Plan prior to final closure as described in the relative timeline (Figure C4-1) and, if required, should removal or decontamination actions leave dangerous waste constituents in place above clean closure standards.

The DOE will provide to Ecology an amended WMA C Closure Action Plan if it determines that WMA C must be closed as a landfill. Should this determination be made, the contingent postclosure plan provided in this section would be amended and would become the WMA C Postclosure Plan.

C8.1 CONTINGENT POSTCLOSURE PLAN

After completing final closure activities and if closed with waste in place, WMA C would enter a postclosure care period. When this occurs, the postclosure requirements for WMA C will be incorporated into Part VI, "Unit-Specific Conditions for Units in Postclosure," of the Site-Wide Permit.

C8.1.1 Groundwater Monitoring

Prior to closure of WMA C, a RCRA-compliant postclosure groundwater monitoring plan will be developed as identified in Figure C4-1. Postclosure groundwater monitoring will be integrated with the Central Plateau regional groundwater monitoring system. At that time, a description of the planned groundwater monitoring activities, frequencies at which they will be performed, and reporting requirements as required by WAC 173-303-645 and -665 will be included.

C8.1.2 Maintenance Activities

Barrier performance monitoring and maintenance activities, including inspections, will be performed as part of postclosure care of dangerous waste units (WAC 173-303-610(7)) and of tanks closed as landfills (WAC 173-303-665(6)). WMA inspection activities will be developed to include inspecting the institutional controls, the surface barrier (after final closure action), security elements, benchmarks, subsurface monitoring systems, groundwater monitoring wells, and other equipment that may be installed as part of postclosure monitoring. Surface barrier inspections will monitor such things as the condition of the vegetation, signs of intrusion, and run-on/run-off control. Maintenance will be scheduled when a problem is discovered during the

inspections. Maintenance activities would include repairs to the surface barrier as necessary to correct the effects of settling, subsidence, erosion, or other effects.

C8.1.3 Institutional Controls

Institutional controls generally include non-engineered restrictions on activities and access restrictions to land, groundwater, surface water, waste sites, waste disposal areas, and other areas or media that contain hazardous substances. The institutional controls are grouped into five main types of controls in the *Sitewide Institutional Control Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41). These five types of controls are warning notices or signs, entry restrictions, land-use management, groundwater-use management, and waste site information management. Entry restrictions include fencing and procedural requirements for access, and land-use management includes land-use and real property controls, and excavation permits.

Institutional controls will be implemented following WMA remedial measures if the endstate of the selected remedy cannot support unrestricted human use and unlimited human exposure (DOE/RL-2001-41). The institutional controls required will be specified in the postclosure permit for WMA C. The scope and duration of institutional controls will be based on an evaluation of residual contamination, the location of that material, reasonably anticipated future human land uses and environmental impacts.

C8.1.4 Postclosure Contact

DOE will be the official contact for WMA C during the postclosure activities at the following address:

U.S. Department of Energy
P.O. Box 450 (H6-60)
Richland, Washington 99352

C8.2 CERTIFICATION OF COMPLETION OF POSTCLOSURE CARE

No later than 60 days after completion of the established postclosure care period for WMA C, DOE will submit to Ecology, by registered mail, a certification that the postclosure care period for WMA C was performed in accordance with the specifications in the approved postclosure plan. The certification will be signed by DOE and an independent registered professional engineer. Documentation supporting the independent registered professional engineer's certification will be furnished to Ecology upon request.

C9.0 REFERENCES

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40 CFR 144, "Environmental Radiation Protection Standards," *Code of Federal Regulations*, as amended.

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ADDENDUM C1

RISK ASSESSMENT FOR WMA C CLOSURE PLAN

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LIST OF TERMS

BBI	best-basis inventory
BTC	breakthrough curve shows peak concentration and arrival time at a specified location
COC	contaminant of concern
COPC	contaminant of potential concern
DOE	U.S. Department of Energy
DST	double-shell tank
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
ERPG	emergency response planning guideline
HAB	Hanford Advisory Board
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HTWOS	Hanford Tank Waste Operations Simulator
ILCR	incremental lifetime cancer risk
K_d	distribution coefficient
LCF	latent cancer fatality
MCL	maximum concentration limit
MEI	maximally exposed individual
MTG	minimum technology guidance
RCRA	*Resource Conservation and Recovery Act of 1976*
SPR	selected phase removal
SST	single-shell tank
TEDE	Total Effective Dose Equivalent
TEEL	threshold emergency exposure limit
TWINS	Tank Waste Information System database
UPR	unplanned release
WMA	waste management area
WTP	waste treatment plant
χ/Q	atmospheric dispersion coefficient

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1.0 INTRODUCTION

Under the *Hanford Federal Facility Agreement and Consent Order* (HFFACO; Ecology et al. 1989) the Hanford Site single-shell tanks (SST) and double-shell tanks (DST) are *Resource Conservation and Recovery Act of 1976* (RCRA) hazardous waste management units that will be eventually closed under Washington State "Dangerous Waste Regulations" (WAC 173-303). A closure plan for the tanks must be submitted to and approved by the Washington State Department of Ecology (Ecology).

Appendix C to the *Single-Shell Tank System Closure Plan* (RPP-13774) for the Hanford Site 200 Area contains the Waste Management Area C (WMA C) Closure Action Plan. Tank 241-C-106 (hereinafter referred to as C-106) is scheduled to have almost all of the remaining waste it contains removed and to undergo interim closure. To determine that the necessary amount of waste is removed for the interim closure of this tank, a risk assessment is required that determines the long-term human health and environmental impacts caused by the waste that cannot be removed from all of the tanks in the WMA C, including C-106.

This addendum to the WMA C Closure Action Plan presents a preliminary risk assessment (summarized in Section 5 of the plan), and was written before retrieval of C-106 waste to the HFFACO goal of 360 ft^3 to demonstrate the methods, data, and related analyses that will be used in the post-retrieval performance assessment. Consequently, this preliminary risk assessment highlights analyses and findings when data is sufficient, and identifies gaps in existing data. Assumptions have been made when data is insufficient or absent to enable impacts to be estimated and tentative findings to be made. Where data is insufficient, areas requiring additional data collection are identified.

1.1 BACKGROUND

The basis for the contents of this initial risk assessment is the result of a workshop on "Tank Closure Risk Assessments" that was held on December 13, 2002 in Ecology offices. In this workshop, the following categories of risk assessment were identified:

- Field investigation reports
- Pre-retrieval functions and requirements
- Post-retrieval tank risk assessment
- Pre-closure tank risk assessment
- Tank farm feasibility study
- Tank farm closure risk assessment.

These six categories represent the iterative nature of risk assessments, with each iteration providing greater detail and understanding of how the overall system behaves. The first category covers reports that are part of the RCRA Corrective Action Program and deals with past leaks. The next three categories deal with decisions on SSTs, but the information is presented in the context of WMA C. The risk assessment categories for tank farm feasibility study and tank farm closure risk assessment deal with decisions on a WMA basis. Unlike the first category, the remaining categories will include past leaks as well as hypothetical retrieval leaks and residual

waste (in tanks and tank ancillary equipment) as sources of contamination. An overview of these categories is given in Table 1.

Table 1. Important Features of Risk Assessment.

Category	Purpose	Significant Feature
Field investigation reports	Determine additional corrective actions needed to address past leaks	Gather field/laboratory data to fill in data gaps. Perform numeric calculations to understand transport conceptual model. Recommend additional corrective actions, if any.
Pre-retrieval functions and requirements	Provide environmental information for the design of retrieval systems	Use existing data to estimate risk (based on technetium-99) of no action, residual waste, and potential future leaks.
Post-retrieval tank risk assessment	Determine whether additional retrieval of waste is necessary	Determine inventory of key contaminants in residual waste in tank and in any retrieval leaks. Perform numeric calculations of impacts of waste remaining (including impacts from other tanks and equipment in WMA) assuming no impacts from tank fill.
Pre-closure tank risk assessment	Determine whether closure of tank can proceed using the methods proposed	Determine impacts from various options to close a tank (including fill and barriers). Impacts will include impacts from other tanks and equipment in WMA. Provide worker risk information for proposed closure options.
Tank farm feasibility study	Determine actions that are needed to close a WMA	Determine impacts from various options to close tank farm or WMA. Provide worker risk information for proposed closure options. Also includes ecological risk.
Tank farm closure risk assessment	Determine whether or not closure actions as implemented have been successful	Determine impacts from closed WMA, once all closure activities (except possibly final surface barrier) are completed. Also includes ecological risk.

WMA = waste management area

The categories of risk assessments, the scope, and decisions supported are provided in *Contents of Risk Assessments To Support the Retrieval and Closure of Tanks for the Ecology* (RPP-14284), which was written shortly after the workshop. The risk assessment presented in this closure action plan is considered preliminary post-retrieval and includes the risk assessment for C-106 as well as impacts from other tanks, equipment, and past leaks in WMA C. The plan is preliminary because it is being prepared before important information is known (such as post-retrieval residual waste characterization data and the content of the fill material). Also, the plan includes some aspects of the pre-closure tank risk assessment to identify data needs for closure. The final version of the risk assessment is expected in early 2004 as part of the process to verify that sufficient waste has been retrieved from C-106.

1.2 SCOPE AND OBJECTIVES

The overall scope of the closure risk assessment is to provide quantitative estimates of both short- and long-term human health risks related to closure activities and the anticipated final conditions in WMA C. The long-term human health risk estimates are placed in the perspective of potential risk contributions from all sources within WMA C. Specific assumptions (such as inventory in post-retrieval residuals) are made for tanks and other sources within the WMA

for which information is not available. The general objectives of the risk assessment are as follows:

- Provide quantitative estimates of long-term human health risk associated with the activities related to WMA C tank closure and final conditions of the WMA C tank systems.
- Identify short-term human health risks and accident scenarios related to tank closure activities that may produce unacceptable risks to Hanford Site workers or the public. These scenarios will be used to ensure that adequate controls are implemented to mitigate the risks.

The scope of this initial risk assessment includes the following four types of contaminant sources within WMA C:

- Past leaks from tanks
- Past leaks from tank ancillary equipment
- Potential leaks during waste retrieval
- Residual waste in tanks and tank ancillary equipment.

The primary focus of this risk assessment is to evaluate impacts to long-term human health risk for the WMA C over a 10,000-year time period as a result of exposure to a long-lived mobile radionuclide, such as technetium-99. However, to assess impacts from other mobile and relatively immobile contaminants, contaminants are grouped into several categories according to their distribution coefficient (K_d). All impact calculations are performed for unit curie (or unit mass) as a source term for each of the four contaminant sources. The resulting contaminant breakthrough curves (BTC) at the WMA C fenceline are then scaled for the appropriate source term inventory. BTCs show peak concentration and arrival time at a specified location.

1.3 BASIS OF METHODOLOGY AND LONG-TERM HUMAN HEALTH RISK ASSESSMENT DATA PACKAGES

The methodology for conducting long-term human health risk assessments is given in Figure 1. Key to conducting the risk assessments is the development of data packages. The following data packages were developed in support of the long-term human health risk assessment:

- *Performance Objectives for Tank Farm Closure Risk Assessments* (RPP-14283)
- *Modeling Data Package for an Initial Assessment of Closure for C Tank Farm* (RPP-13310)
- *241-C Waste Management Area Vadose Zone Inventory Data Package* (RPP-15317)
- *Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments* (HNF-SD-WM-TI-707).

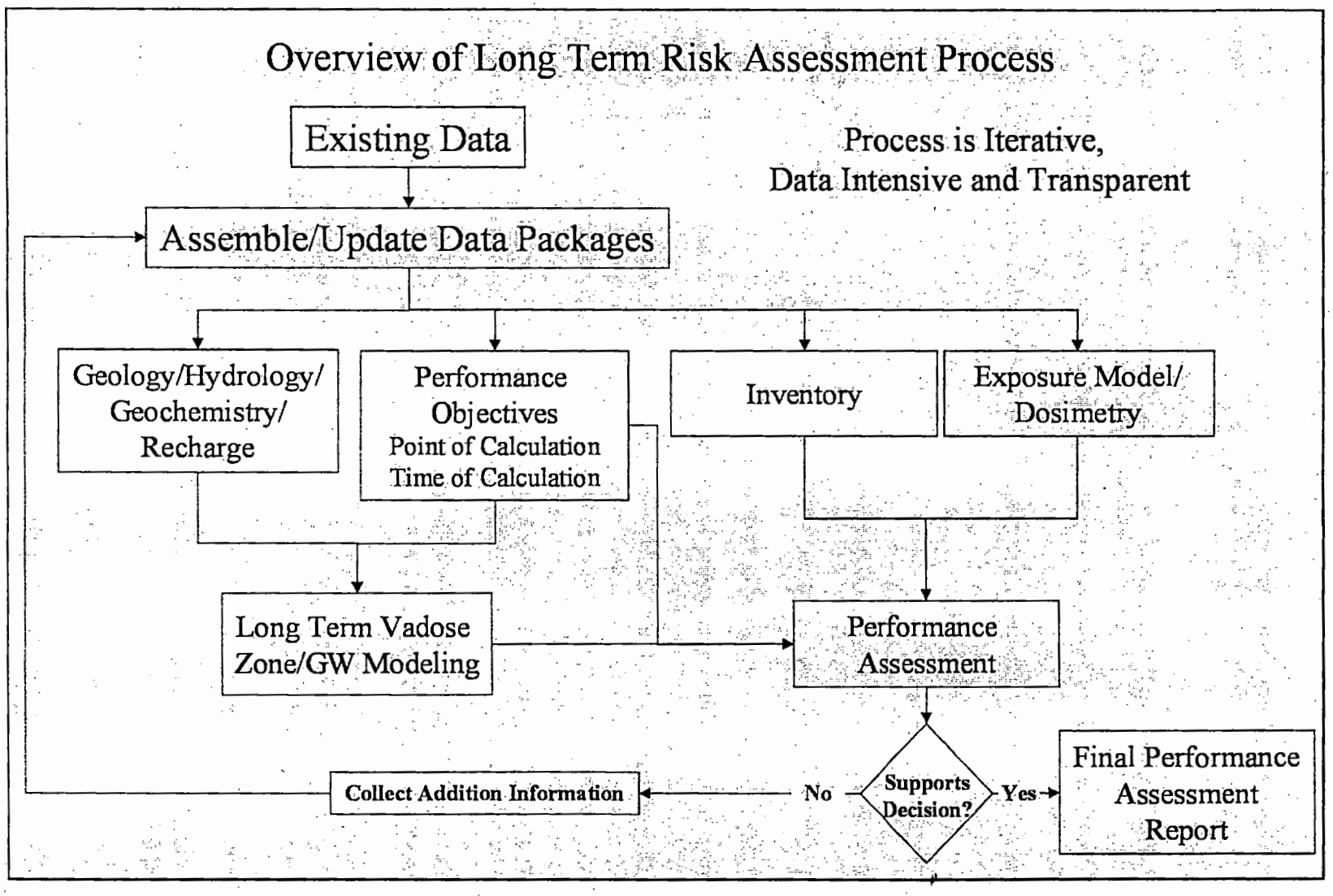

Figure 1. Long-Term Human Health Risk Assessment Process for Closure.

These data packages are briefly summarized in the following sections and were used as the basis for this initial long-term human health risk assessment.

The analysis methodology is based on the following documents:

- *Field Investigation Report for Waste Management Area S/SX* (RPP-7884)
- *Field Investigation Report for Waste Management Area B/BX/BY* (RPP-10098)
- *Hanford Immobilized Low-Activity Waste Performance Assessment* (DOE/ORP-2000-24)
- *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* (WHC-EP-0645)
- *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Burial Grounds* (WHC-EP-0875).

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2.0 PERFORMANCE OBJECTIVES AND METRICS

To be meaningful, results from a numeric risk assessment of the consequences of an action must be compared to the standards for such an action. That is, before one disposes of waste or closes a facility with waste, one must show that the disposal or closure action protects the public health and safety and the environment. These standards are called performance objectives.

Regulations requiring performance assessments usually require that the determination of performance objectives be one of the first steps performed. This is true whether they are federal regulations such as *Radioactive Waste Management* (DOE O 435.1[1]) and its implementing guides or state regulations like the regulations implementing "Model Toxics Control Act – Cleanup" (WAC 173-340). These performance objectives set comparison levels for the numeric results and define the media, pathways, exposure scenarios (receptors), spatial locations, and times that the performance assessment must consider. Thus, a performance objective consists of a metric level, place(s) of assessment, and time(s) of assessment.

Performance objectives are those levels to which the results of the numeric simulation will be compared to judge the success of the proposed cleanup or disposal actions. Additional comparison levels may be requested for information purposes, but are not officially part of the decision on the adequacy of the proposed action. Performance objectives are not the levels that a regulatory agency will enforce in a permit or authorization. Those levels, often called enforcement levels, will be set in the permit or authorization.

The initial step in identifying performance objectives is to note the requirements that could be applied to the proposed action. If that action is the disposal of radioactive mixed waste on the Hanford Site, a variety of requirements should be considered:

- U.S. Department of Energy (DOE) requirements
- U.S. Nuclear Regulatory Commission requirements
- U.S. Environmental Protection Agency (EPA) requirements
- Ecology requirements
- Programmatic requirements
- Public involvement.

An analysis of these requirements shows that the risk assessment must evaluate the following:

- General public
- Workers
- Inadvertent intruders

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[1] *Implementation Guide* for use with DOE M 435.1-1, July 9, 1999, Chapter IV, Section IV.P.(1) through IV.P.(4).

- Groundwater
- Surface water.

In addition, there are restrictions on the waste itself if it is land disposed.

The evaluation for risk assessment is done by defining exposure scenarios. The exposures scenarios describe the affected individuals (industrial worker, resident, recreational user, Native American), the exposure media (water, soil, and air), and the exposure pathway (ingestion, inhalation, and direct [dermal contact] exposure). A complete description of these exposure scenarios is given in Section 5.1 of this Addendum. Ecological risk assessment for native plants and animals will be done at WMA Closure (see Section 4.0 of the *Framework Plan for Single Shell System Closure Plan*, RPP-13774). Once the risk assessment evaluation of the different exposure scenarios is completed, the numbers are then compared against the performance objectives.

This entire process, along with all the regulations and values considered, is documented in RPP-14283. The major performance objectives are summarized in Table 2. These objectives are the same as those of RPP-14283 (please see that document for additional performance objectives), except in this preliminary assessment the air pathway is not calculated.

Table 2. Performance Objectives for Tank Closure [a].

Protection of General Public and Workers [b, c, d]	
All-pathways dose from only this facility	25 mrem in a year [e]
All-pathways dose including other Hanford Site sources	100 mrem in a year [e]
Chemical carcinogens (incremental lifetime cancer risk)	10^{-5} [f]
Non-cancer-causing chemicals (Hazard Index)	1 [f]
Protection of an Inadvertent Intruder [e, g]	
Acute exposure	500 mrem
Continuous exposure	100 mrem in a year
Protection of Groundwater Resources [b, c, d, h, j, n]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	5 pCi/L
All others (excluding uranium)	15 pCi/L
Beta and photon emitters	4 mrem in a year
Technetium-99	900 pCi/L
Iodine-129	1 pCi/L
Protection of Surface Water Resources [b, k]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	0.3 pCi/L [m]
All others (excluding uranium)	15 pCi/L [m]
Beta and photon emitters	4 mrem in a year [m]

[a] All doses are calculated as effective dose equivalent. Values given are in addition to any existing amounts or background. The risk assessment provides calculations of dose based on the results of a review of all pertinent regulations. As noted, regulations vary in how dose is calculated (see Appendix C *WMA C Action Closure Plan*, Chapter 5.2.2 Drinking Water Dose Calculation Methods for a comparison between different methodologies for calculating dose)

[b] Evaluated for 1,000 years, but calculated to the time of peak or 10,000 years, whichever is longer.

[c] Groundwater use starts at the time when groundwater contaminated by Hanford Site operations before the year 2000 is estimated to be potable.

[d] Evaluated at the point of maximal exposure, but no closer than the fenceline of the waste management area in which the tank farm belongs. Also calculated at the edge of the 200 Area Core Zone and just before groundwater enters the Columbia River.

[e] Main driver is DOE O 435.1.[2]

[f] Main driver is WAC 173-340.

[g] Evaluated for 500 years, but calculated from 100 to 1,000 years.

[h] All concentrations are in water taken from a well.

[j] Main driver is DOE Order 5400.5 (II)(d).

[k] Evaluated at well at the edge of the Columbia River. No mixing with the river is assumed.

[m] Main driver is WAC 173-201A-250 (which states that Surface Water can be U.S. EPA Drinking Water Regulations for radionuclides, which is 4 mrem/yr.

[n] MCL Derived Constituent Concentration

[2] *Implementation Guide* for use with DOE M 435.1-1, July 9, 1999, Chapter IV, Section IV.P.(1) through IV.P.(4).

As noted in RPP-14283, a number of options were considered for metric levels, places of assessment, and times of assessment. Based on past experience in performing risk assessments for the Hanford Site (*Hanford Immobilized Low-Activity Tank Waste Performance Assessment* [DOE/ORP-2000-24]), the most important metrics are the following:

- All-pathways exposure (25 mrem in a year as established by DOE O 435.1[3]), Incremental Lifetime Cancer Risk (10^{-5}), and the chemical hazard index (1), the latter two established by WAC 173-340

- Groundwater protection (4 mrem in a year for beta and photon emitters as established in DOE Order 5400.5 (II)(d), "Radiation Protection of the Public and the Environment."

- Groundwater Drinking water standard after the existing plumes have either been remediated or have naturally attenuated.

The selection of times and places of assessment was driven by the desire to provide maximum information to the decision makers. Because of the relatively long travel time in the vadose zone associated with disposal of dry waste forms at the Hanford Site (approximately 3,000 years), calculations for such actions must extend past the 1,000 years often used in risk assessments. Calculations will be carried out for at least 10,000 years to show the peak impact (for events/waste forms having relative short release times compared to vadose zone travel) or the plateauing level (for waste forms having long release times). Various places of assessment will be used (WMA C fenceline, 200 Area Core Zone Boundary, shore of the Columbia River). However, because the WMA C fenceline, being closest, is expected to have the largest impacts, most comparisons will be performed there.

Potential risk provided by assumed final closure conditions is determined by using performance objectives-specific exposure scenarios that yield risk estimates that can be compared to Table 2 metrics. To evaluate the impact of final closure conditions on groundwater and surface water resources, contaminant leaching and migration analyses have been completed to estimate maximum groundwater concentrations from contaminants released from the WMA sources. These calculated contaminant concentrations are then compared directly with the groundwater and surface water concentration performance objectives. The relevant dose performance objectives (4 and 1 mrem/yr from beta and photon emitters for groundwater and surface water resources, respectively) are compared to calculated concentrations by converting concentrations to dose using radionuclide-specific dose conversion factors.

Evaluation of protection to the general public, workers, and inadvertent intruders requires the use of exposure scenarios. For the general public and workers, exposure primarily results from the use of contaminated groundwater. In this analysis, several scenarios and their respective limits are considered, including the following:

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[3] *Implementation Guide* for use with DOE M 435.1-1, July 9, 1999, Chapter IV, Section IV.P.(1) through IV.P.(4).

- All pathways farmer who lives 100 m downgradient of the waste site (25 mrem/yr performance objective)
- Native American who lives near the site (i.e., within the core zone boundary) and at the Columbia River (incremental lifetime cancer risk [ILCR] of 10^{-5} and a Hazard Index of 1)
- Industrial worker who works near the site (ILCR of 10^{-5} and Hazard Index of 1)
- Resident who lives near the site (ILCR of 10^{-5} and Hazard Index of 1)
- Farmer who lives near the site (ILCR of 10^{-5} and Hazard Index of 1)
- Recreational shoreline user who participates in leisure activities at the Columbia River (ILCR of 10^{-5} and Hazard Index of 1).

Evaluation of intruder protection (acute exposure of 500 mrem and chronic exposure of 100 mrem/yr) has been completed using two scenarios, the well driller who exhumes waste and the post-intruder resident who distributes exhumed waste in a garden. The waste contaminants are the primary sources of dose in these scenarios.

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3.0 MODELING APPROACH: EXISTING DATA AND ASSUMPTIONS

As part of the WMA C closure, an assessment is conducted to evaluate impacts on groundwater resources (the concentration of contaminants in groundwater) and long-term human health risk (associated with groundwater use). The evaluations consider the extent of contamination from residual wastes in tanks and tank ancillary equipment; past leaks, spills, and retrieval leaks; contaminant movement through the vadose zone to the saturated zone (groundwater); contaminant movement in the groundwater to various locations in groundwater; and assumed human receptor activities at those locations. A plan view of WMA C and associated sources is shown in Figure 2.

The following information is included in this section:

- Modeling approach
- Recharge (infiltration) data for C farm under current and post-closure conditions
- Source-term release scenarios and numerical cases considered
- Stratigraphic cross-sectional model for the C farm
- Contaminants of concern (COCs)
- Inventory data for various sources.

3.1 OVERVIEW OF LONG-TERM HUMAN HEALTH RISK ASSESSMENT MODELING APPROACH

The overall modeling approach is illustrated in Figure 3. The dominant pathway is through groundwater, as indicated by previous Hanford Site performance assessments and environmental impact statements (DOE/ORP-2000-24). Following closure, it is assumed that infiltration of moisture from precipitation eventually enters the tank facility (Step 1), most water is diverted by the tank structure or the barrier (Step 2), and contaminants are released into the vadose zone from the degraded tank structure (Step 3a-b). The released contaminants then travel through the vadose zone where they meet and mix with already-released contaminants, if any, from past leaks, spills, and leaks during the retrieval process (Step 4). The contaminants travel through the vadose zone until they reach the water table and the unconfined aquifer (Step 5). The contaminant breakthrough curves ([BTC] provide the concentration history through time) from residual wastes, past leaks, and retrieval for all tanks in C farm are combined via a spatial and temporal superposition (Step 6). The combined BTCs are then routed to various locations within the unconfined aquifer and the Columbia River, using an analytical solution (streamtube model) (Step 7). In the final step, the exposure scenarios are applied to determine risk (Step 8).

Figure 2. Waste Management Area C, Sources Considered in the Risk Assessment, and Surrounding Facilities.

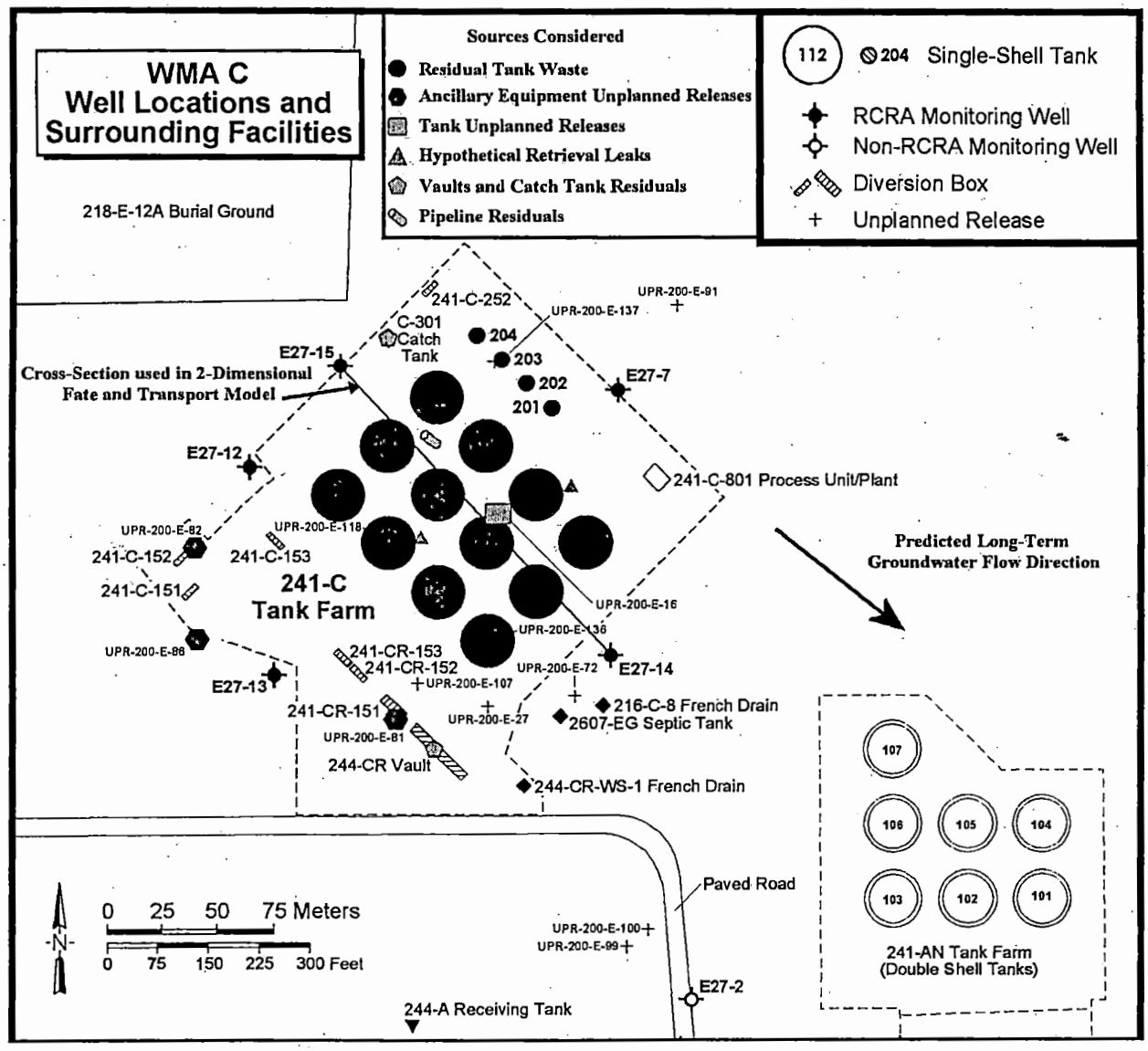
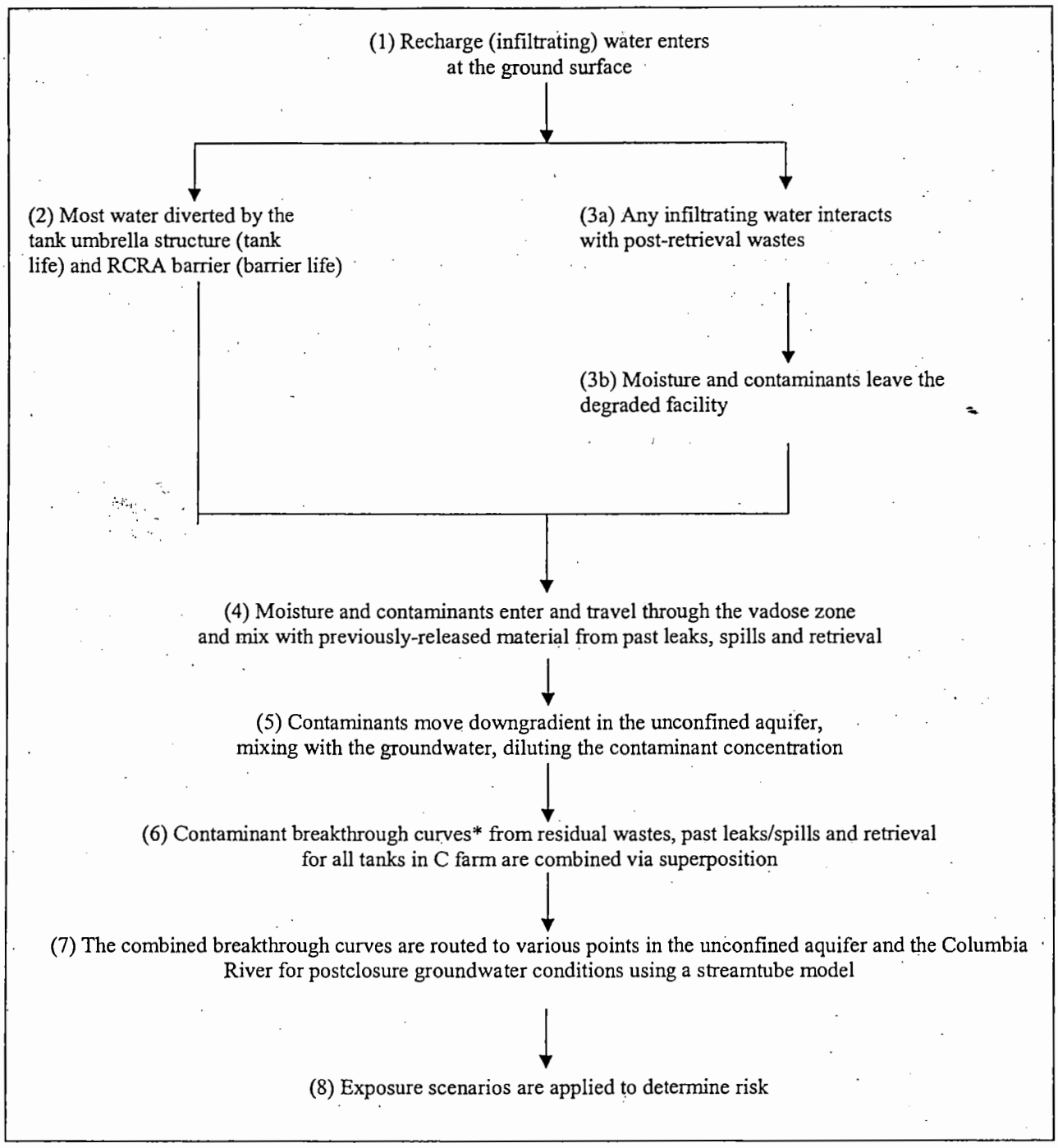


Figure 3. Overall Modeling Approach for Risk Assessment.



*Contaminant Breakthrough Curves are concentration history at a given point

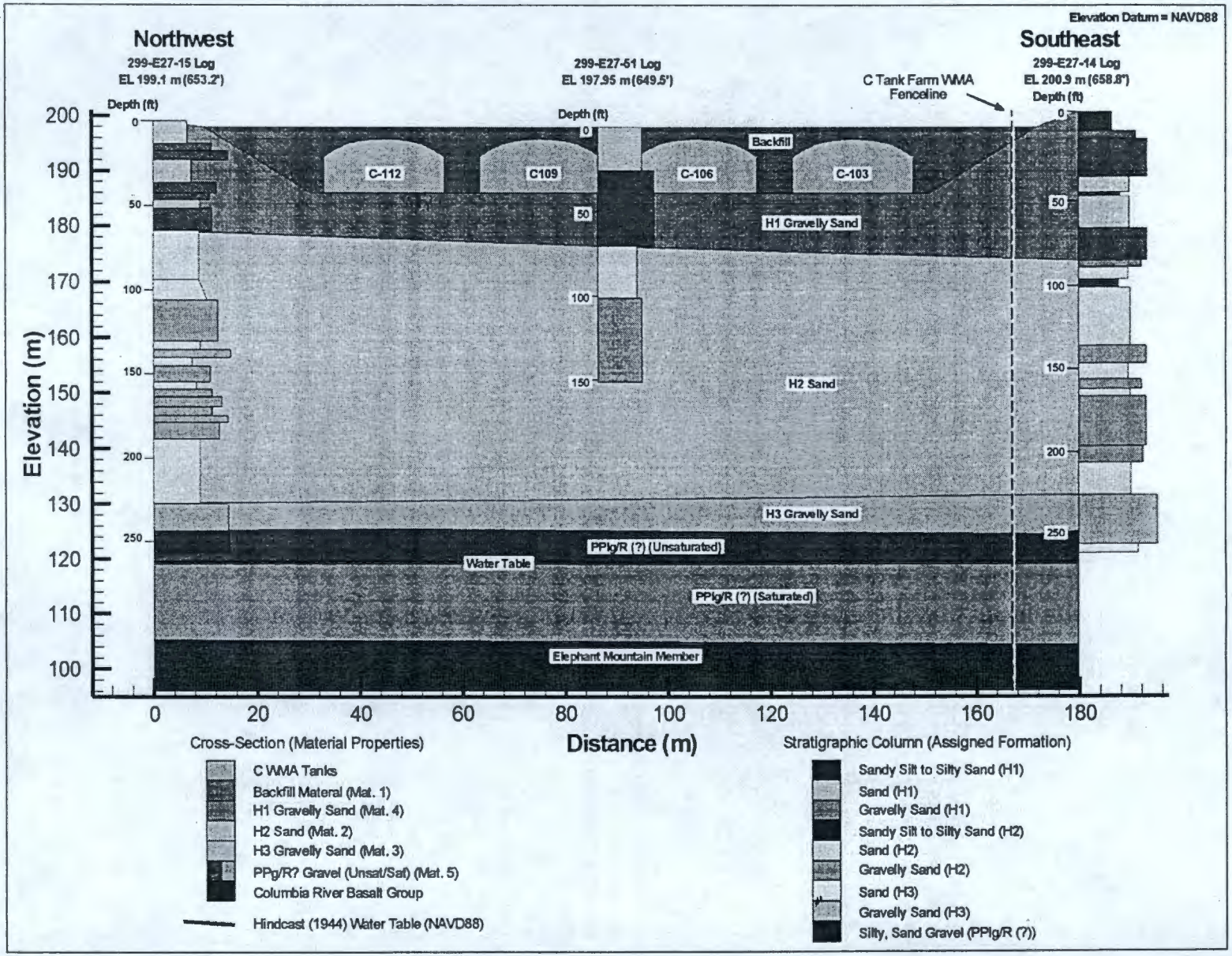
The concentration of the individual contaminants at the points of assessment is calculated by scaling unit inventory results from the various sources, and applying the principle of superposition to sum the concentrations. Each tank may have up to four sources of contamination associated with it: past leaks and spills, retrieval, residual tank wastes, and ancillary equipment. The model calculations are performed using one unit Curie (or one unit mass) as a source term for each of the four possible sources. The concentration of the individual contaminants resulting from the individual sources may then be calculated by scaling the unit source results by the actual contaminant inventory for each of the sources. The results associated with the different sources and different tanks may then be summed, using the principle of superposition, to produce a total fenceline concentration. Any one tank in a row may represent any other tank in the model simply by changing the distance from the tank to the fenceline for the following reasons: 1) the tanks were constructed and placed in a grid-like manner, 2) the geology beneath the tank farm appears to be consistent beneath the tanks, and 3) the rows of tanks are aligned parallel to the generalized future direction of groundwater flow. Thus the model constructed for C-112 (approximately 114 m from the WMA fenceline; see Figure 4) may be applied to C-109, C-106, and C-103 by collecting the model output at locations approximately 83 m, approximately 52 m, and approximately 21 m, respectively, from the tank. Verification tests were performed for all simulation cases (discussed in Section 3.3) in which sources are present at all four tank locations (in the row containing C-112, C-109, C-106, and C-103) and compared against the case with sources for C-112 only. The results of this comparison are given in Section 4.4.

The two-dimensional, cross-sectional simulations yield the contaminant mass flux and BTCs at the WMA C fenceline along the tank centerlines for the selected cross-section. To account for three-dimensional aspects, the tank centerline mass flux and BTCs are transformed to average values across the WMA C fenceline using two translations given in *FY00 Initial Assessment for S-SX Field Investigation Report (FIR): Simulations of Contaminant Migration and Surface Barriers* (PNWD-3111). In the first translation, the centerline quantities are converted to average quantities on the WMA C fenceline as the cross-sectional projections. The length of the cross-sectional projection equals the mean inventory diameter, where the mean inventory diameter is computed for each source inventory. The inventory diameter is not necessarily the tank diameter. In the second translation, the cross-sectional average mass flux or BTCs for various cross-sections are translated to a single average mass flux or BTC across the entire WMA C fenceline length using a length-weighted averaging scheme (PNWD-3111).

3.2 RECHARGE ESTIMATES FOR CURRENT AND POST-CLOSURE CONDITIONS

WMA C ground surfaces are presently covered with gravel to prevent vegetation growth and provide radiation shielding for site workers. Bare gravel surfaces, however, enhance net infiltration of meteoric water, compared to undisturbed naturally vegetated surfaces. Infiltration is further enhanced in tank farms by the effect of percolating water being diverted by an impermeable, sloping surface of the tank domes. This umbrella effect is created by the 23-m-diameter buried tank domes. Water, shed from the tank domes, flows down the tank walls into underlying sediments. Sediments adjacent to the tanks, while remaining unsaturated, can attain elevated moisture contents. Enhanced infiltration from a gravel-covered tank dome can provide potential for faster transport of contaminants to the water table.

Figure 4. Northwest-Southeast Cross-Section through C Farm



Infiltration (recharge) can vary greatly depending on factors such as climate, vegetation, surface condition, and soil texture. For the purpose of this risk assessment, a base case infiltration estimate of 100 mm/yr will be used before closure (Table 3).

Table 3. WMA C Infiltration (Recharge) Estimates for Pre-Construction Period, Current Conditions, and Following Emplacement of Closure Barrier.

Condition Simulated	Recharge Estimate (mm/yr)	Duration	Comment
Before 1943-1944 construction of C farm	3.5*	Until steady state moisture conditions are achieved for the year 1945	Vadose zone flow simulated at the recharge rate of 3.5 mm/yr to develop initial moisture conditions for subsequent simulations.
Current conditions	100	1945 to 2050	Recharge is assumed to increase from the pre-construction period estimate of 3.5 mm/yr to the current value of 100 mm/yr. During this period, the ground cover is gravel with no vegetation. An enhanced RCRA Subtitle C barrier is assumed to be in place by 2050.
Transition to conditions of restricted recharge with enhanced RCRA Subtitle C barrier	0.5	2050 to 2550	Recharge is assumed to decrease from a current estimate of 100 mm/yr to the barrier design value of 0.5 mm/yr. The barrier is assumed to function to its design estimate of 500 years.
Degraded barrier condition	3.5	2550 to 12000	The barrier is degraded and recharge increases from 0.5 mm/yr to 3.5 mm/yr until the end of simulation at 12,000 years.

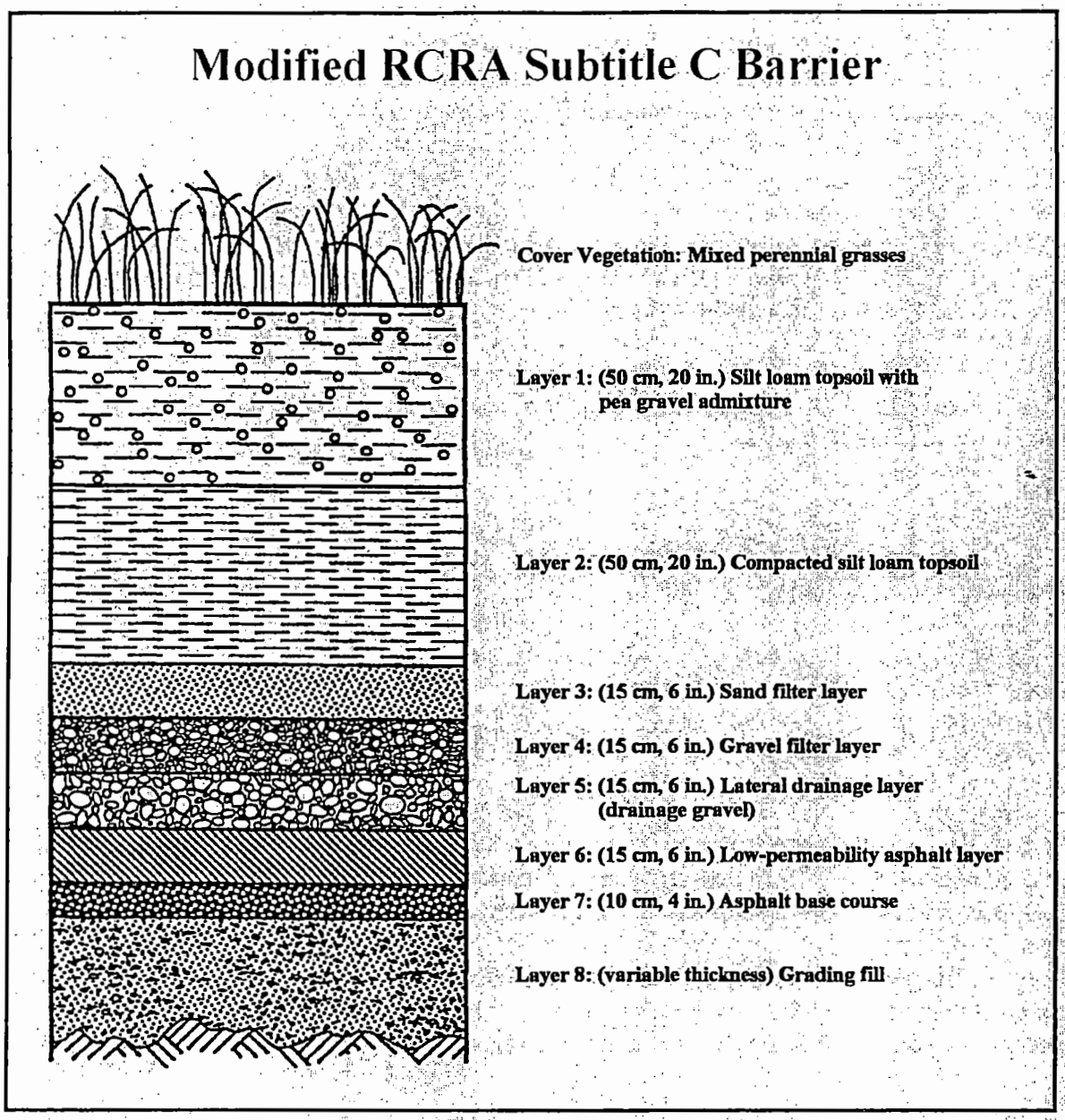
*Based on 8-year lysimeter data for graveled surface (PNNL-13033).

RCRA = *Resource Conservation and Recovery Act of 1976.*

3.2.1 Modified RCRA Subtitle C Barrier

The closure barrier for tank farms is assumed to be a Modified RCRA Subtitle C Barrier. The design of this barrier is given in *Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas* (DOE/RL-93-33 Rev. 1). This barrier is designed to provide long-term containment and hydrologic protection for a period of performance of 500 years. It is composed of eight layers of durable material with a combined minimum thickness of 1.7 m (5.5 ft) (Figure 5). This design incorporates RCRA minimum technology guidance (MTG) with modifications for extended performance. One major change is the elimination of the clay layer, which may desiccate and crack over time in an arid environment. The geomembrane component has also been eliminated because of its uncertain long term durability.

Figure 5. Modified RCRA Subtitle C Barrier Profile from DOE/RL-93-33.



The Modified RCRA Subtitle C Barrier is similar in structure to the Hanford Barrier (DOE/RL-93-33), but layer thicknesses are reduced and there is no fractured basalt. The design incorporates provisions for biointrusion and human intrusion control. The design of this barrier could be enhanced by increasing the thickness of the topsoil layers and by including some type of intrusion layer (similar to the fractured basalt in the fractured basalt layer in the Hanford Barrier) so that it would provide additional protection. It is assumed that the barrier placed over the WMA will be at least 15 ft (4.6 m) thick.

The recharge through such the Modified RCRA Subtitle C Barrier is estimated to be as low as 0.1 mm/yr (*Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance*

Assessment, PNNL-13033). For these simulations, a recharge rate of 0.5 mm/yr will be used. This is based on experimental data from a prototype Hanford barrier that has been designed and built in 200 Area to limit recharge to ≤ 0.5 mm/yr ("Quest for the Perfect Cap," Wing and Gee 1994). This is also supported by the numerical simulation results of *Simulations of Infiltration of Meteoric Water and Contaminant Plume Movement in the Vadose Zone at Single-Shell Tank 241-T-106 at Hanford* (WHC-EP-0332), which shows that with a relatively impermeable barrier over the tank farm, the drainage to a 2-m backfill depth decreased to less than 0.5 mm/yr after 8 years for cases of either a backfill or a clean graveled surface. For a degraded closure barrier, recharge rates are expected to return to predevelopment conditions (i.e., shrub-steppe ground cover), with a recharge estimate of 3.5 mm/yr. Such an estimate is within the range of values reported in *Estimated Recharge Rates at the Hanford Site* (PNL-10285).

Table 3 also summarizes the timeline estimates for barrier emplacement at the C farm and the corresponding recharge estimates.

3.3 SOURCE TERM RELEASE SCENARIOS, TRANSPORT MODELING, AND NUMERICAL CASES

This section provides an overview of the source term release scenarios, transport modeling, and numerical cases used in this risk assessment.

3.3.1 Source Term Release Scenarios

The source terms for the long-term closure assessment consist of four separate sources: past leaks and spills, leakage during retrieval, residual waste leachate from tanks following closure, and residual waste leachate from tank ancillary equipment following closure. The past leaks represent tank waste that has leaked into the vadose zone and has been migrating through the vadose zone for a number of years. Retrieval leakage refers to leakage to the vadose zone that could occur during waste retrieval operations using water-based sluicing. Releases from the residual wastes (both from tank and tank ancillary equipment) would typically occur over an extended period following closure of the tank farm when infiltrating water would enter the tank or tank ancillary equipment, dissolve contaminants, and migrate into the vadose zone and to the groundwater.

As discussed in Section 3.1, for each simulation unit, the curie or mass (unit source) is used as the source-term inventory for each of the four sources. A unit source means that for a particular source (i.e., residuals, past leaks, retrieval leaks), the numerical model simulated the release of one curie (radionuclides) or one kg (non-radionuclides) of contaminant. The results from the numerical model are then multiplied by the appropriate number of curies (radionuclides) or kg (non-radionuclides) for that source term (see Section 4.2 of this addendum for further discussion of unit source inventory). This is a logical approach when dealing with uncertainty and sensitivity of inventory estimates for various sources. As the best-basis inventory (BBI) and vadose zone inventory data are updated and refined, the contaminant breakthrough results, on the basis of unit source inventory, can be easily scaled to account for total inventory.

Past Leaks and Retrieval Losses. The retrieval case simulations assume that leaks occur over a specified area at the base of the tank near the edge, generally considered to be of low structural integrity (*Description of Vadose Zone/Groundwater Flow and Transport Numerical Modeling for S Tank Farm Retrieval Performance Evaluation* [PNWD-31-11]). The simulations for past leaks and spills do not attempt to model a waste release; instead, they model the potential risk posed by the existing vadose zone contamination footprint from past leaks and spills. Information on contamination footprint (inventory diameter with unit source) is based on spectral gamma data for drywells in the vicinity of WMA C.

Residual Waste Release. In contrast to releases from past leaks and retrieval losses, releases from residual waste generally are expected occur over a much longer time period. For residual tank wastes and residual ancillary equipment wastes, actual release mechanisms are unknown at this time. For an accurate determination of the source term, the chemical and physical processes controlling contaminant release from the residual wastes must be explicitly modeled. In the absence of post-retrieval tank waste characterization data and a lack of information of the controlling processes, a series of scenarios are assumed for contaminant release from tank wastes and tank ancillary equipment such that the modeling results include the range of possible outcomes.

One set of release scenarios assumes essentially uniform release rates over specified release periods, with the unit source inventory released over the entire release duration. A similar approach has been used in various versions of the immobilized low-activity tank waste performance assessment (DOE/ORP-2000-24). The other set of release scenarios allows the release duration to vary on the basis of various controlling processes (advection, diffusion, or solubility) that are active during release from residual wastes. In addition to recharge (infiltration) rates, these models consider the mixing (advection and diffusion) processes occurring within the residual wastes. A similar approach has been recommended by the U.S. Nuclear Regulatory Commission for the low-level waste performance assessment (*Background Information for the Development of a Low-Level Waste Performance Assessment Methodology* [NUREG/CR-5453]) and has been used for the 200 East and 200 West Areas solid waste performance assessment analyses at the Hanford Site (WHC-EP-0645; WHC-EP-0875). The advection-dominated release model is used to simulate contaminant release from unstabilized wastes (a waste form covered with backfill sand and gravel or a failed grout). The diffusion-dominated release model is used to simulate contaminant release from stabilized, contained wastes (a waste form covered with grout or cementitious grout). The solubility-dominated release model represents a waste form bound in a material that releases risk-driving contaminants congruently with the dissolution of the material. Details are presented in the modeling data package (*Modeling Data Package For An Initial Assessment of Closure for C Tank Farm* RPP-13310).

For some of the first set of scenarios, because of the assumed slow release of contaminants from the residual wastes, the anticipated BTCs in the groundwater are expected to show a relative broadening of the peak concentration rather than a sharp peak. In any case, the two sets of scenarios for release from residual wastes in tanks and tank ancillary equipment are chosen to produce conservative estimates.

3.3.2 Transport Modeling

Two-dimensional flow and transport models along the row of tanks are used for all vadose zone simulations. Figure 4 shows the NW-SE geologic cross-section through WMA C, and Figure 2 shows the location of the cross-section within WMA C. The simulations are composed of steady-flow and transient components, where flow fields developed from the steady-flow component are used to initialize the transient simulation. Steady-state initial conditions are developed by simulating from a prescribed unit hydraulic gradient condition to a steady-state condition, dictated by the initial meteoric recharge at the surface, water table elevation, water table gradient, no flux vertical boundaries, variation of hydrologic properties, and location of impermeable tanks.

The steady-flow simulation, representing flow conditions for the year 1945 (when WMA C tank farm construction was completed), is used as the initial condition for all subsequent flow and transport simulations. From the starting conditions, transient transport simulations are conducted for a 10,000-year period (i.e., years 2000 to 12000) that involve changes in the flow fields in response to current conditions, placement of closure barrier, and effects of degraded barrier. The infiltration (recharge) estimates for various times are described in Section 3.2. All simulations are run assuming isothermal conditions. The vadose zone is modeled as an aqueous-gas porous media system where transport through the gas phase is neglected.

Fluid flow within the vadose zone is described by Richards' Equation, whereas the contaminant transport is described by the conventional advective-dispersive transport equation with an equilibrium linear distribution coefficient formulation. A series of mobile to moderately retarded contaminant species (K_d = 0, 0.01, 0.03, 0.1, 0.3, 0.6, and 1.0) are considered for each run. The purpose of simulating the system with a suite of distribution coefficients with the unit source allows applying inventories to a wide range of COCs following retrieval.

No site-specific data are available on soil moisture characteristics for the C farm. Data catalogs are, however, available for 200 Area soils. For this work, data on laboratory measurements for moisture retention, particle-size distribution, saturated and unsaturated hydraulic conductivity, and bulk density for individual stratum are based on data for similar soils in 200 East and 200 West Areas. Details on modeling inputs are provided in the modeling data package (RPP-13310).

The computer code STOMP (*STOMP Subsurface Transport Over Multiple Phases, Version 2.0, Theory Guide* [UC-12030]) was chosen to model transport through the vadose zone and groundwater out to the WMA C fenceline. STOMP was chosen because it meets the requirements of *Computer Code Selection Criteria for Flow and Transport Code(s) To Be Used in Vadose Zone Calculations for Environmental Analyses in the Hanford Site's Central Plateau* (HNF-5294) and has been used for a number of risk assessments on the Hanford Site (RPP-7884; RPP-10098).

An analytical/streamtube approach is used to model groundwater flow and transport away from the WMA. The analytical solution in *Physical and Chemical Hydrogeology* (Domenico and Schwartz 1990) is used to model saturated transport.

3.3.3 Numerical Cases

As discussed in Section 3.3.1, the source terms for the risk assessment consist of four separate sources: leakage during retrieval, past leaks and spills, residual waste leakage from the tanks following closure, and residual waste leakage from the tank ancillary equipment following closure. Table 4 lists the release scenarios and numerical cases considered. The following provides a rationale for the selection of individual cases.

Table 4. Release Scenarios and Numerical Cases Considered (2 Pages).

Retrieval Leak

- **Case 1: Retrieval leaks, 8,000 gal.** A retrieval leak of 8,000 gal on the tank corner with start of leakage on January 1, 2000 and continuing for 14 days, with the leak occurring at the bottom east corner of tank C-112.
- **Case 2: Retrieval leaks, 20,000 gal.** A retrieval leak of 20,000 gal on the tank corner with start of leakage on January 1, 2000 and continuing for 14 days, with the leak occurring at the bottom east corner of tank C-112.

Past Leak

- **Case 3: Past leaks.** A past leak with its vadose zone inventory at a depth of 80 ft (based on drywell data) below ground surface (bgs) and an inventory diameter of 25 ft (based on drywell data) as of January 1, 2000, with the inventory distributed between tanks C-112 and C-109.
- **Case 4: Past leaks from ancillary equipment.** A past leak with its vadose zone inventory at a depth of 30 ft bgs (based on drywell data) and an inventory diameter of 25 ft (based on drywell data) as of January 1, 2000, with the inventory distributed between tanks C-112 and C-109.

Residual Waste Leak

- **Case 5: Residual tank waste; release rate R_0.** Residual tank waste source with a release rate R_0 (10^{-3} Ci/yr for 500 yr and 0.1 Ci/yr for 5 yr), a release start date of January 1, 2050 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 6: Residual tank waste; release rate R_1.** Residual tank waste source with a release rate R_1 (10^{-4} Ci/yr for 500 yr, 10^{-2} Ci/yr for 95 yr), a release start date of January 1, 2050 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 7: Residual tank waste; release rate R_2.** Residual tank waste source with a release rate R_2 (10^{-5} Ci/yr for 500 yr, 10^{-3} Ci/yr for 995 yr), a release start date of January 1, 2050 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 8: Residual tank waste; release rate R_3.** Residual tank waste source with a release rate R_3 (10^{-6} Ci/yr for 500 yr, 10^{-4} Ci/yr for 9,995 yr), a release start date of January 1, 2050 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 9: Residual tank waste; release rate R_4.** Residual tank waste source with a release rate R_4 (0.1 Ci/yr for 10 yr), a release start date of January 1, 2500 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 10: Residual tank waste; advection-dominated release.** Residual tank waste source with advection-dominated release, a release start date of January 1, 2050 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 11: Residual tank waste; diffusion-dominated release.** Residual tank waste source with a diffusion-dominated release rate ($K_d = 6 \times 10^{-7}$ cm^2/s; *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford* [WHC-SD-WM-EE-004]), a release start date of January 1, 2050 and release over the tank bottom.

Table 4. Release Scenarios and Numerical Cases Considered. (2 Pages)

- **Case 12: Residual tank waste; solubility-controlled release.** Residual tank waste source with a solubility-dominated release; a release start date of January 1, 2050 (i.e., date tank integrity is lost) and release over the tank bottom.
- **Case 14: Residual tank waste; diffusion-dominated release.** Residual tank waste source with a diffusion-dominated release rate ($K_d = 5 \times 10^{-8}$ cm^2/s; *Hanford Waste-Form Release and Sediment Interaction A Status Report and Rational and Recommendations for Additional Studies* [PNL-7297]), a release start date of January 1, 2050 and release over the tank bottom.

Ancillary Equipment Waste Leak

- **Case 13: Residual ancillary equipment waste.** Residual tank ancillary equipment waste source with inventory located at a depth of 20 ft bgs, a release start date of January 1, 2050, and a diffusion-dominated release ($K_d = 6 \times 10^{-7}$ cm^2/s;WHC-SD-WM-EE-004) over an inventory diameter of 25 ft for the grouted* residual waste.

- **Retrieval Leak Loss.** There is considerable uncertainty regarding the performance of retrieval technologies and the ability to respond to a retrieval leakage event. This initial assessment used the assumption that hydraulic sluicing will be used to retrieve waste and if a leak were to occur, all tanks would experience an equal leak loss volume of 8,000 gal per tank (Case 1). Such an estimate of 8,000 gal per tank has been used in earlier retrieval performance evaluation analyses (*Retrieval Performance Evaluation Methodology for the AX Tank Farm* [DOE/RL-98-72]). However, a higher leakage loss of 20,000 gal per tank was also used as a sensitivity case (Case 2). These estimated retrieval leaks are higher than the hypothetical retrieval leaks (4,000 gal) reported in *Waste Retrieval and Storage Data Package* (DOE/ORP-2003-06).

- **Past leaks and spills.** As stated in Section 3.3.1, the simulated cases for past leaks (Case 3) and spills (Case 4) do not attempt to model a waste release; instead they model the potential risk posed by their existing vadose zone contamination footprint (RPP-15317). Information on contamination footprint and its location within the vadose zone for Cases 3 and 4 is based on spectral gamma data for drywells in the vicinity of C-106.

- **Residual waste leakage.** Residual waste leakage is considered for both tank (Cases 5 through 12 and Case 14) and tank ancillary equipment (Case 13). As discussed in Section 3.3.1, a series of post-closure scenarios are assumed for contaminant release from tank wastes and tank ancillary equipment such that the modeling results include the range of possible outcomes.

One set of scenarios (Cases 5 through 9) assumes uniform release rates over specified release periods, with the unit source inventory released over the entire release duration. The other set of release scenarios (Cases 10 through 12 and Case 14) allows the release duration to vary on the

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* See Preface in *SST System Closure Plan* (RPP-13774).

basis of various controlling processes (advection, diffusion, or solubility) that are active during release. In effect, Cases 5, 6, 7, 8, and 9 arbitrarily release half of the unit inventory in the first 500 years, with the remaining inventory released in 5-, 10-, 100-, 1,000-, and 10,000-year release periods, respectively.

Cases 10, 11, 12, and 14 recognize whether the tank wastes are stabilized or unstabilized. The stabilized tank wastes (Cases 11 and 14) correspond to a waste form covered with grout* or cementitious grout (diffusion-dominated release), whereas the unstabilized wastes (Case 10) refer to a waste form covered with backfill sand and gravel/failed grout (advection-dominated release). Case 12 represents a waste form bound in a material that releases risk-driving contaminants congruently with the dissolution of the material (solubility-dominated release). Although both Cases 11 and 14 use diffusion-dominated release, Case 11 uses a distribution coefficient of 6×10^{-7} cm^2/sec, whereas Case 14 uses almost an order of magnitude lower distribution coefficient of 5×10^{-8} cm^2/sec.

The waste in the tank ancillary equipment, following closure, is assumed to be stabilized (i.e., grouted* waste form). Therefore, Case 13 for residual waste release from ancillary equipment considers only a diffusion-dominated release.

3.4 WASTE MANAGEMENT AREA C GEOLOGY

A detailed discussion of WMA C geology is provided in *Subsurface Conditions Description of the C and A-AX Waste Management Areas* (RPP-14430). A geologic cross-section taken through the middle of WMA C is provided in Figure 4. RPP-14430 identifies the following sedimentary sequences (from top to bottom) overlying the basalt beneath the WMA C:

- Backfill (material type 1, sandy gravel) – backfill materials consist of unstructured, poorly sorted mixtures of gravel, sand, and silt removed during tank excavation, and then later used as fill around the tanks.

- Hanford formation – upper gravelly sequence (H1 unit, material type 4, gravelly sand); Hanford formation H1 unit consists of predominantly loose coarse-grained gravel and sand deposits, with minor beds of sand to silty sand. Coarser beds may contain boulder-sized materials.

- Hanford formation – sand sequence (H2 unit, material type 2, sand); Hanford formation H2 unit consists of predominantly fine- to coarse-grained sand with lenses of silty-sand to slightly gravelly sand. Minor sandy gravel to gravelly sand beds occur sporadically.

- Hanford formation – lower gravelly sequence (H3 unit, material type 3, gravelly sand); Hanford formation H3 unit consists of predominantly gravelly facies of clast-supported, sandy, pebble- to boulder-sized gravel to matrix-supported pebbly sand.

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* See Preface in *SST System Closure Plan* (RPP-13774).

- Undifferentiated Plio-Pleistocene unit gravel (PPlg) and/or Ringold Formation Unit A? (PPlg/R(?) unit, material type 5). The PPLg/R(?) unit consists of predominantly sandy pebble- to cobble-sized gravel with occasional boulders. The unit shares characteristics of both coarse-grained facies of the Ringold Formation and the Plio-Pleistocene unit.

The geologic strata (Figure 4) are assumed to be continuous but not of constant thickness; the model includes the effect of dipping strata. The water table is located about 79.84 m (approximately 262 ft) bgs. The hydraulic and transport properties used for these sedimentary sequences in the flow and transport modeling are given in RPP-13310.

Hydraulic Conductivity of the Unconfined Aquifer: For all cases listed in Section 3.3.3, a hydraulic conductivity value of 4.8 m/day was used for the undifferentiated Plio-Pleistocene/ Ringold gravels. Although this value is consistent with laboratory measured values, it is inconsistent with the large-scale hydraulic conductivities for the unconfined aquifer reported within the 200 East Area, which are typically higher by at least factor of 10. To address the inconsistency in hydraulic conductivity values until additional data is obtained, Cases 1, 3, 4, 10, and 11 were also simulated with a hydraulic conductivity of 50 m/day, which is the lower limit of the hydraulic conductivity reported in Section 4.3. Drilling of RCRA monitoring wells in the vicinity of WMA C is scheduled for the summer of 2003. One well is scheduled to be drilled to the base of the unconfined aquifer. The hydraulic conductivity of the unconfined aquifer will be estimated during the development phase of that well.

3.5 CONTAMINANTS OF POTENTIAL CONCERN FOR CLOSURE

As part of the C-106 closure demonstration project, *Accelerated Tank Closure Demonstration Data Assessment* (RPP-10950) identifies that the primary pathway of concern from a human health risk standpoint is the groundwater pathway. On this basis, the COCs for these tanks are the more mobile long-lived contaminants that could migrate and impact groundwater at concentrations greater than the federal drinking water standards or maximum concentration limit (MCL). For the groundwater pathway, RPP-10950 lists the following contaminants:

- Carbon-14
- Iodine-129
- Technetium-99
- Selenium-79
- Uranium
- Nitrite
- Nitrate
- Cyanide.

The risk-based COCs listed by RPP-10950 are also consistent with past performance assessments (DOE/ORP-2000-24; WHC-EP-0645; WHC-EP-0875), as well as groundwater monitoring of the unconfined aquifer. For the COCs identified by RPP-10950, this risk assessment provides detailed information on the following COCs for the long-term risk assessment:

- Technetium-99
- Iodine-129

- Chromium(IV)
- Nitrate
- Nitrite
- Total uranium (moderately retarded $K_d = 0.6$ mL/g).

Note that carbon-14, selenium-79, and cyanide have been dropped from the RPP-10950 list, and chromium has been added. The basis for changing the list is that empirical information from the Hanford Site-wide groundwater monitoring indicates that chromium is a COC for groundwater protection, but that carbon-14, selenium-79, and cyanide may not be COCs. Additionally, Section 7.1 provides the relative contribution of these contaminants to the total risk metric (i.e., radiological dose, Incremental Lifetime Cancer Risk, and Hazard Index). The total risk metric provides includes all contaminants that are listed in the inventory estimates given in the *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that contribute to the risk metric.

The post-retrieveal risk assessment will address additional potential COCs identified from the post-retrieval sampling and analysis, as well as the COCs identified in the regulatory category. To facilitate the post-retrieval risk assessment, this analysis used multiple distribution coefficient categories to address, at a later date, a wide range of contaminants.

3.6 INVENTORY

The conceptual model for WMA C has been developed to include multiple source terms, including tanks, ancillary equipment, and past releases. Although detailed, quantitative inventories are not yet available for many of these sources, the risk assessment has identified them for inclusion when characterization is complete before final closure of the WMA. The sources identified in Table 5 have been incorporated into the computational basis for the WMA C risk assessment. These sources include components specifically identified in the RCRA Part A permit application, inactive miscellaneous underground storage tanks, RCRA past-practice sites associated with the WMA, and other components and systems (such as piping systems) that are geographically associated with the WMA (such as Building 801-C). The following discussion presents the current state of understanding of the estimated inventory associated with known source terms in WMA C.

3.6.1 Source Term Inventory

The inventories for the data sources listed in Table 5 are given in Tables 6 through 12. However, only the inventories for the examined COCs for this risk assessment are given in those tables. A complete listing of inventories can be found in *241 Waste Management Area C Inventory Data Package* (RPP-15317). Inventory information compiled in RPP-15317 came from *Subsurface Conditions Description of the C and A-AX Waste Management Areas* (RPP-14430) and *Inventory and Source Term Data Package*, (DOE/ORP-2003-02), which supports preparation of the Closure Environmental Impact Statement. Tank leak and pipe leak inventory estimates shown in Table 6 were developed as part of the WMA C subsurface description report (RPP-14430). The Best Basis Inventory (BBI) estimate for current tank inventory estimates is shown in Table 7, which was taken from DOE/ORP-2003-02. Retrieval leak inventory was estimated from Hanford Tank Waste Operations Simulator runs, while the residual pipeline and ancillary tank

inventories were developed from assumptions on pipe length, and estimated percentage of blockage in pipes and assumed retrieval inventories for catch tanks and CR-Vaults. A completed description of the basis of these assumptions is given below.

Table 5. Sources Included in the WMA C Risk Assessment Conceptual Model (2 Pages).

Source Type	Individual Sources	Inventory	Included in Risk Assessment
Past leaks from tanks	One confirmed leak near tank C-105	Yes Estimated. See Table 6.	Yes
	UPR-200-E-136	No Reported 24,000-gal leak from C-101[a]	No Please See Footnote[4]
	UPR-200-E-136	No Reported 400-gal leak from C-203.[a]	
Past leaks from tank ancillary equipment	UPR-200-E-81	Yes Estimated. See Table 6	Yes
	UPR-200-E-82	Yes Estimated. See Table 6.	Yes
	UPR-200-E-86	Yes Estimated. See Table 6.	Yes
	UPR-200-E-16	No Small leak (50 gal).[a]	No Size of unplanned release was significantly smaller than unplanned releases E-81, E-82, and E-86.
	UPR-200-E-107	No Small leak (4 gal).[a]	
	UPR-200-E-72	No Solid waste located outside of WMA C.[a]	No Release is nearby, but outside WMA C. It is solid waste consisting of miscellaneous trash and debris.
	UPR-200-E-91	No Contaminated soil remediated.[a]	No Site has been remediated.

[4] Only leaks or discharges that have been verified either through geophysical logging or sampling in the vadose zone and/or groundwater were included in the risk assessment model. HNF-EP-0182 (2002) lists tank C-101 as a "known or suspected leaker" with a leak volume estimate of 20,000 gallons. Decreases in waste levels were documented in the late 1960s, a time when this tank contained aged PUREX high-level supernatant. A 20,000-gallon loss of this waste type would have released approximately 127,000 curies of cesium-137 (BHI-01496), more than all of the cesium-137 projected to have been lost from all of the SX tank farm leaks (RPP-6285). The spectral gamma logging data, reported in *Subsurface Conditions Description of the C and A-AX Waste Management Areas* (RPP-14430), from drywells around tank C-101 show little evidence of any leaks and certainly nothing of that order of magnitude. The lack of high levels of cesium-137 activity in nearby drywells provides strong evidence that the leak information from HNF-EP-0182 (2002) is incorrect. A far more likely scenario is the liquid level drops in the late 1960s were associated with evaporation caused by the continuing high heat load of the aged PUREX high-level waste supernatants. Furthermore, although no leaks have been reported from Tank C-105, there is contamination reported in the vadose zone from routine geophysical monitoring between this tank and C-104, therefore, C-105 was included in this risk assessment. (Please See RPP-15317, RPP-14430, and *Vadose Zone Characterization Project at the Hanford Tank Farms C Tank Farm Report* (DOE-GJO, 1998 & 2000) for additional information on vadose zone contamination)

Table 5. Sources Included in the WMA C Risk Assessment Conceptual Model (2 Pages).

Source Type	Individual Sources	Inventory	Included in Risk Assessment
Past leaks from tank ancillary equipment (cont'd)	UPR-200-E-27	No Airborne release. [a]	No Airborne releases not considered.
	UPR-200-E-68		
	UPR-200-E-99		
	UPR-200-E-100		
	UPR-200-E-118		
(including intentional discharge sites)	216-C-8 french drain	Yes System Assessment Capability has estimated technetium-99 and iodine-129, but not the inorganics. Estimated volume discharged to French drain is 2,640 gal	No Reported inventories for technetium-99 and iodine-129 are much smaller than unplanned releases E-81, E-82, and E-86.
Residual waste in tanks and ancillary equipment	Twelve 100-series tanks	Yes TWINS BBI. See Tables 8b and 8c.	Yes
	Four 200-series Tanks		
	300-series catch tank	Yes Assumed inventory based on TWINS BBI. See Table 9.	Yes
	Four 244-CR vault tanks		
	Three CR-150 series diversion boxes	No [a]	No Diversion boxes are designed to drain to catch tank. Contamination is mainly surficial. Residual in catch tank is examined.
	Three C-150 series diversion boxes		
	One C-252 diversion box		
	Building 801-C	No [a]	No Building is expected to be decontaminated and decommissioned.
(minor ancillary equipment)	Pipes and valves, associated WMA	Yes Assumed inventory based on TWINS BBI. See Table 9.	Yes
Potential leaks during waste retrieval	Two 100-series tanks (C-106 and C-107) are scheduled for liquid retrieval, all others scheduled for dry retrieval	Yes TWINS BBI. See Table 7.	Yes Calculated inventory based on TWINS BBI.

[a] Waste information data system report, http://ww.bhi-erc.com/eisdata/wids/.
BBI = best-basis inventory.
TWINS = Tank Waste Information System
UPR = unplanned release
WMA = waste management area

Table 6. Vadose Inventory Estimates for C Farm Waste Loss Events.

Tank	C-105	UPR-200-E-81	UPR-200-E-82	UPR-200-E-86
Leak volume	1,000 gal	36,000 gal	2,600 gal	17,400 gal
Analyte	**kg**	**kg**	**kg**	**kg**
Chromium	9.82 E+00	2.18 E+01	2.55 E+01	5.88 E+01
Nitrite	3.15 E+02	5.79 E+03	8.18 E+02	1.21 E+03
Nitrate	2.69 E+02	1.82 E+03	6.98 E+02	1.45 E+03
Uranium-total	7.06 E+00	1.30 E+02	1.83 E+01	3.73 E+01
Radionuclides				
Analyte	**Ci**	**Ci**	**Ci**	**Ci**
Technetium-99	1.93 E+00	1.02 E-01	5.01 E+00	6.22 E+00
Iodine-129	3.73 E-03	1.97 E-04	9.69 E-03	1.20 E-02

Table 7. Best-Basis Inventory for Waste Management Area C.

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)
	Ci	**Ci**	**kg**	**kg**	**kg**	**kg**
C-101	1.34 E-03	0.697	299	9,180	61,400	9,610
C-102	2.74 E-03	1.32	735	16,900	73,200	8,150
C-103	0.0662	34.2	690	16,300	1,380	5,960
C-104	0.754	58	1460	36,500	19,600	35,300
C-105	0.093	81.4	413	8,420	8,140	9,840
C-106	0.017	3.14	61.8	1,530	76.9	132
C-107	4.83 E-02	37.9	930	35,300	47,800	9,290
C-108	1.32 E-03	6.19	232	8,740	15,700	153
C-109	2.00 E-03	32.3	118	12,200	18000	4,060
C-110	1.10 E-03	31.8	420	6,530	98000	1,970
C-111	2.01 E-03	2.7	85.2	9,490	17300	4,250
C-112	4.26 E-03	61.1	139	27,800	37200	24,100
C-201	2.74 E-05	0.0141	2.29	41.8	227	1.14
C-202	2.85 E-05	0.0147	2.39	214	639	1.19
C-203	5.46 E-05	0.0282	4.57	245	838	2.26
C-204	3.52 E-05	0.0181	2.95	158	541	1.46
Totals	0.993	350.8221	5,595.2	189,548.8	400,041.9	112,821.05

Table 8a. Summary of Tank Residuals Final Inventory Estimates Based on Simple Volume Ratio Following Waste Retrieval with 360 ft^3 Remaining (30 ft^3 in 200-Series Tanks).

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)
	Ci	Ci	kg	kg	kg	kg
C-101	4.10 E-05	0.0213	9.15	281	1,880	294
C-102	2.34 E-05	0.0113	6.27	144	624	69.5
C-103	8.83 E-04	0.456	9.21	218	18.4	79.5
C-104	7.84 E-03	0.603	15.2	380	204	367
C-105	1.90 E-03	1.66	8.42	172	166	201
C-106	1.26 E-03	0.232	4.57	113	5.68	9.75
C-107	5.24 E-04	0.411	10.1	383	518	101
C-108	5.38 E-05	0.252	9.46	356	640	6.24
C-109	8.50 E-05	1.37	5.01	518	765	172
C-110	1.66 E-05	0.481	6.35	98.8	1,480	29.8
C-111	9.44 E-05	0.127	4	446	813	200
C-112	1.11 E-04	1.59	3.61	721	965	625
C-201	5.82 E-06	0.00299	0.486	8.88	48.2	0.242
C-202	6.05 E-06	0.00312	0.508	45.5	136	0.253
C-203	4.64 E-06	0.0024	0.388	20.8	71.2	0.192
C-204	2.99 E-06	0.00154	0.251	13.4	46	0.124
Totals	0.0128	7.22	93	3,920	8,380	2,160

Table 8b. Summary of Tank Residuals Final Inventory[1] Estimates Based on Selected Phase Removal Following Waste Retrieval with 360 ft^3 Remaining (30 ft^3 in 200-Series Tanks).

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)
	Ci	Ci	kg	kg	kg	kg
C-101	4.09 E-05	0.0213	9.15	281	1,880	294
C-102	2.34 E-05	0.0113	6.26	145	623	69.5
C-103	1.13 E-03	0.583	14.7	244	23.7	100
C-104	7.84 E-03	0.602	15.2	380	204	368
C-105	1.90 E-03	1.66	8.43	172	166	201
C-106	3.67 E-03	0.457	25.3	35.8	5.23	18.2
C-107	5.24 E-04	0.411	10.1	384	518	101
C-108	5.37 E-05	0.252	9.47	356	641	6.22
C-109	8.46 E-05	1.37	5.02	519	765	172
C-110	1.67 E-05	0.484	6.38	99.1	1,490	30
C-111	9.47 E-05	0.127	4	446	811	200
C-112	1.11 E-04	1.59	3.61	720	963	626
C-201	5.82 E-06	2.99 E-03	0.486	8.88	48.2	0.242
C-202	6.05 E-06	3.12 E-03	0.508	45.5	136	0.253
C-203	4.64 E-06	2.40 E-03	0.388	20.8	71.2	0.192
C-204	2.99 E-06	1.54 E-03	0.251	13.4	46	0.124
Totals	0.016	7.57865	119.253	3,870.48	8,390	2,190

[1]See RPP-15317 for complete BBI inventory, which includes the following radionuclides and non-radionuclides:

Radionuclides	Tritum, Carbon-14, Nickel-59, Cobalt-60, Nickel-63, Selenium-79, Strontium-90, Yttrium-90, Niobium-93m, Zirconium-93, Techneitum-99, Ruthenium-106, Cadmium-113m, Antimony-125, Tin-126, Iodine-129, Cesium-134, Barium-137m, Cesium-137, Samarium-151, Europium-152, Europium-154, Europium-155, Radium-226, Actinium-227, Radium-228, Thorium-229, Protactinium-231, Thorium-232, Uranium-232, Uranium-233, Uranium-234, Uranium-235, Uranium-236, Neptunium-237, Plutonium-238, Uranium-238, Plutonium-239, Plutonium-240, Americium-241, Plutonium-241, Curium-242, Plutonium-242, Americium-243, Curium-243, Curium-244
Non-Radionuclides	Aluminum, Bismuth, Calcium, Chlorine, Chromium, Fluorine, Iron, Lanthanum, Lead, Manganese, Mercury, Nickel, Nitrate, Nitrite, Phosphate, Potassium, Silicon, Sodium, Strontium, Sulfate, Total inorganic carbon as carbonate, Total organic carbon, Uranium total, Zirconium

Table 8c. Summary of Tank Residuals Final Inventory Estimates Based on HTWOS Predictions Following Waste Retrieval with 360 ft^3 Remaining (30 ft^3 in 200-Series Tanks).

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)[1]
	Ci	Ci	kg	kg	kg	kg
C-101	5.17 E-06	0.0027	1.16	35.5	238	37.2
C-102	6.44 E-06	0.0031	1.72	39.8	171	19.1
C-103	8.29 E-05	0.0428	1.25	20.3	1.98	8.5
C-104	1.03 E-03	0.0791	1.99	49.9	26.7	48.1
C-105	1.43 E-04	0.125	0.633	12.9	12.5	15.1
C-106	1.08 E-03	0.199	3.91	97	4.87	8.4
C-107	7.95 E-05	0.0681	2.15	76.7	116	9.2
C-108	1.34 E-05	0.0628	2.36	88.6	160	1.6
C-109	1.58 E-05	0.256	0.937	96.8	143	32.2
C-110	8.43 E-06	0.243	3.2	49.8	747	15.1
C-111	1.47 E-05	0.0197	0.622	69.3	126	31.1
C-112	2.85 E-05	0.408	0.929	186	248	161.4
C-201	6.15 E-07	3.17 E-04	0.0514	0.938	5.1	0.026
C-202	6.33 E-07	3.27 E-04	0.0531	4.75	14.2	0.026
C-203	6.31 E-07	3.26 E-04	0.0528	2.83	9.69	0.026
C-204	6.29 E-07	3.23 E-04	0.0527	2.82	9.67	0.026
Totals	2.51 E-03	1.51	21.1	834	2,030	387.0

HTWOS = Hanford Tank Waste Operations Simulator.

[1]Not included in HTWOS estimate, but calculated from isotopic uranium, which is included in HTWOS estimate.

Table 9. Concentration of Retrieval Fluid as Predicted by HTWOS Model.

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)[1]
	Ci/L	Ci/L	g/L	g/L	g/L	g/L
C-101	5.48E-10	2.86E-07	1.23E-01	3.77E+00	2.52E+01	3.95E+00
C-102	6.80E-10	3.29E-07	1.83E-01	4.20E+00	1.82E+01	2.03E+00
C-103	9.88E-09	5.12E-06	1.29E-01	2.13E+00	2.09E-01	8.79E-01
C-104	2.50E-07	1.92E-05	4.84E-01	1.21E+01	6.50E+00	1.17E+01
C-105	1.50E-08	1.31E-05	6.65E-02	1.36E+00	1.31E+00	1.58E+00
C-106	1.50E-08	2.76E-06	5.44E-02	1.35E+00	6.77E-02	1.16E-01
C-107	2.23E-08	1.75E-05	4.29E-01	1.63E+01	2.20E+01	4.29E+00
C-108	1.41E-09	6.64E-06	2.49E-01	9.38E+00	1.68E+01	1.64E-01
C-109	1.66E-09	2.70E-05	9.83E-02	1.02E+01	1.50E+01	3.39E+00
C-110	9.07E-10	2.61E-05	3.45E-01	5.37E+00	8.06E+01	1.63E+00
C-111	1.55E-09	2.08E-06	6.57E-02	7.32E+00	1.33E+01	3.29E+00
C-112	2.96E-09	4.24E-05	9.67E-02	1.93E+01	2.59E+01	1.68E+01
C-201	7.23E-10	3.73E-07	6.05E-02	1.10E+00	6.00E+00	3.01E-02
C-202	7.55E-10	3.89E-07	6.31E-02	5.65E+00	1.69E+01	3.14E-02
C-203	4.80E-10	2.48E-07	4.02E-02	2.16E+00	7.38E+00	2.00E-02
C-204	3.09E-10	1.60E-07	2.60E-02	1.39E+00	4.76E+00	1.29E-02

HTWOS = Hanford Tank Waste Operations Simulator.

[1]Not included in HTWOS estimate, but calculated from isotopic uranium, which is included in HTWOS estimate.

Table 10. Inventory for an 8,000 Gallon Retrieval Leak.

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)[1]
	Ci/L	Ci/L	g/L	g/L	g/L	g/L
C-101	1.7E-05	0.01	3.72	114.10	763.16	119.50
C-102	2.1E-05	0.01	5.53	127.25	551.18	61.41
C-103	3.0E-04	0.16	3.91	64.50	6.33	26.63
C-104	7.6E-03	0.58	14.67	366.72	196.92	354.02
C-105	4.5E-04	0.40	2.01	41.04	39.67	47.98
C-106	4.5E-04	0.08	1.65	40.82	2.05	3.52
C-107	6.8E-04	0.53	12.98	492.82	667.33	129.76
C-108	4.3E-05	0.20	7.54	283.94	510.05	4.97
C-109	5.0E-05	0.82	2.98	307.61	453.86	102.55
C-110	2.7E-05	0.79	10.45	162.70	2440.87	49.22
C-111	4.7E-05	0.06	1.99	221.74	404.22	99.51
C-112	9.0E-05	1.28	2.93	585.43	783.38	508.88
C-201	2.2E-05	0.01	1.83	33.44	181.58	0.91
C-202	2.3E-05	0.01	1.91	171.18	511.14	0.95
C-203	1.5E-05	0.01	1.22	65.33	223.44	0.60
C-204	9.4E-06	0.00	0.79	42.13	144.25	0.39
Total	9.8E-03	4.96	76.10	3120.74	7879.43	1510.80

HTWOS = Hanford Tank Waste Operations Simulator.

[1]Not included in HTWOS estimate, but calculated from isotopic uranium, which is included in HTWOS estimate.

Table 11. Inventory for an 20,000 Gallon Retrieval Leak.

Tank	Iodine-129	Technetium-99	Chromium	Nitrite	Nitrate	Uranium (Total)[1]
	Ci/L	Ci/L	g/L	g/L	g/L	g/L
C-101	4.2E-05	2.2E-02	9.3E+00	2.9E+02	1.9E+03	3.0E+02
C-102	5.1E-05	2.5E-02	1.4E+01	3.2E+02	1.4E+03	1.5E+02
C-103	7.5E-04	3.9E-01	9.8E+00	1.6E+02	1.6E+01	6.7E+01
C-104	1.9E-02	1.5E+00	3.7E+01	9.2E+02	4.9E+02	8.9E+02
C-105	1.1E-03	9.9E-01	5.0E+00	1.0E+02	9.9E+01	1.2E+02
C-106	1.1E-03	2.1E-01	4.1E+00	1.0E+02	5.1E+00	8.8E+00
C-107	1.7E-03	1.3E+00	3.2E+01	1.2E+03	1.7E+03	3.2E+02
C-108	1.1E-04	5.0E-01	1.9E+01	7.1E+02	1.3E+03	1.2E+01
C-109	1.3E-04	2.0E+00	7.4E+00	7.7E+02	1.1E+03	2.6E+02
C-110	6.9E-05	2.0E+00	2.6E+01	4.1E+02	6.1E+03	1.2E+02
C-111	1.2E-04	1.6E-01	5.0E+00	5.5E+02	1.0E+03	2.5E+02
C-112	2.2E-04	3.2E+00	7.3E+00	1.5E+03	2.0E+03	1.3E+03
C-201	5.5E-05	2.8E-02	4.6E+00	8.4E+01	4.5E+02	2.3E+00
C-202	5.7E-05	2.9E-02	4.8E+00	4.3E+02	1.3E+03	2.4E+00
C-203	3.6E-05	1.9E-02	3.0E+00	1.6E+02	5.6E+02	1.5E+00
C-204	2.3E-05	1.2E-02	2.0E+00	1.1E+02	3.6E+02	9.7E-01
Total	2.5E-02	12.40	190.26	7801.85	19698.57	3777.00

HTWOS = Hanford Tank Waste Operations Simulator.

[1]Not included in HTWOS estimate, but calculated from isotopic uranium, which is included in HTWOS estimate.

Table 12. Assumed Inventory for Ancillary Equipment.

Equipment	Total Volume	Current Waste Volume	Assumed Residual Volume	Iodine-129	Technetium -99	Chromium	Nitrite	Nitrate	Uranium (Total)
	gal[a]	gal	ft^3	Ci	Ci	kg	kg	kg	kg
Average Inventory per ft^3				3.60 E-06	0.001707	0.026859	0.87173	1.88964	0.493243
CR-244[b] TK-CR-001	50,000	2,000 (s)	27	9.73 E-05	0.046	0.725	23.54	51.0	13.32
CR-244[b] TK-CR-002	15,000	1,500 (s)	8	2.88 E-05	0.014	0.215	6.97	15.1	3.95
CR-244[b] TK-CR-003	15,000	4,200 (s)	8	2.88 E-05	0.014	0.215	6.97	15.1	3.95
CR-244[b] TK-CR-011	50,000	35,000 (l)	27	9.73 E-05	0.046	0.725	23.54	51.0	13.32
C-301[c]	35,000	9,016 (s) 1,470 (l)	19	6.85 E-05	0.032	0.510	16.56	35.9	9.37
Totals				3.21 E-04	0.152	2.390	77.580	168.100	43.910
Pipes Layers 1-3	1,000 ft^3	NA	250	0.0009	0.43	6.7	217.9	472.4	123.3

[a] Units are in gallons for tanks, and in cubic feet for pipes.

[b] CR-244 current waste volume from waste information data systems report, http://www.bhi-erc.com/eisdata/wids/.

[c] Tank C-301 current waste volume from *Engineering Study of 50 Miscellaneous Inactive Underground Radioactive Waste Tanks Located at the Hanford Site, Washington* (WHC-SD-EN-ES-040).

s = solids.

l = liquids.

NA = not applicable.

The post-retrieval tank waste residuals, also known as retrieved to HFFACO goal of 1%, are also given in DOE/ORP-2003-02. However, three sets of residual tank inventory values are given in DOE/ORP-2003-02. The three different sets use different assumptions to derive the post-retrieval inventory. The complete assumptions for the residual inventory are given in DOE/ORP-2003-02 and are briefly summarized here:

- Simple volume ratio (Table 8a). Multiply the existing total tank inventory by a ratio of the final tank volume to the current tank volume (not including retained gas).

- Volume ratio based on Selected Phase Removal (SPR) (Table 8b). This is similar to the simple volume ratio, but modified to take into account removal of selected phases (sludge, supernatant, etc.) of waste during retrieval.

- Hanford Tank Waste Operations Simulator (HTWOS) model output (*Single-Shell Tank Retrieval Sequence and Double-Shell Tank Space Evaluation* [RPP-8554]) (Table 8c) adjusted to the same final volume as the other two methods. This method represents HTWOS assumptions for water additions and incorporates wash/leach factors. The residual inventory is generally lower because of leaching of mobile constituents.

Comparing the inventory for the COCs for the tanks within WMA C shows there is very little difference between the simple volume ratio and the selected phase removal. The largest differences were for iodine-129 and chromium, with the total inventory for those constituents being 21%, and 28% higher for selected phase removal, respectively. However, comparing the residual inventory between selected phase removal and the HTWOS model, shows the HTWOS modeled total residual inventory for WMA C to be four to six times less for all COCs

Because the residual inventory is uncertain, the inventory chosen (simple volume, selected phase removal, or HTWOS) for this risk assessment is based on the estimate associated with the selected waste retrieval technology (sluicing or dry). It is expected that as the tank waste is retrieved, the tank waste residuals will be sampled and analyzed with the resulting residual inventory and risk estimates being updated as necessary.

Retrieval leak inventory can be calculated by multiplying the concentration in the leaked fluid by the amount that leaked. The concentration of the leaked fluid has been provided from the HTWOS run described in *Hanford Tank Waste Operations Simulator (HTWOS) Model Run Results for the Integrated Mission Acceleration Plan (IMAP) Unconstrained Case* (RPP-14302). The concentrations for the contaminants of concern, which are given in Table 9, are multiplied by a hypothetical retrieval leak volume (8,000 gal and 20,000 gal). The resulting inventories from that calculation are provided in Tables 10 (8,000 gal leak) and 11 (20,000 gal leak).

Preliminary WMA C risk assessment results were presented to the Ecology during a joint workshop on May 12, 2003. The preliminary risk assessment results did not include residuals left in ancillary equipment because the nature and amount of waste left in ancillary equipment is unknown. However, during the workshop, it was decided to include an assumed inventory for the waste left in the ancillary equipment to show the expected relative contribution of the tank ancillary equipment. The assumed inventory was calculated using the following methodology:

- The present waste volume in ancillary equipment is given in Table 12. It is assumed that the waste in ancillary equipment tanks (244-CR vault tanks and the C-301 catch tank) will be retrieved. Because these tanks are smaller than the 200-series tanks, the ancillary tank residual was calculated by multiplying the residual of the 200-series tanks by the ratio of the volume of the ancillary equipment tank to the 200-series tanks.

- The volume of pipes within the WMA was estimated by scaling off the drawings presented in *Historical Vadose Zone Contamination from A, AX, and C Tank Farms* (RPP-7494). A total of four layers of pipe have been added to the WMA. The first layer of pipe was installed between from 1943 to 1945 and was gravity fed to sup-port filling the tanks. The second layer was added to support bismuth phosphate and uranium recovery operations and was installed from 1946 to 1957. The third layer was in-stalled for waste fractionation operations from 1961 to 1978. The last layer was installed from 1975 to 2001 to support interim stabilization and isolation. For the residual volume estimate, it is assumed that none of the piping in the last layer is blocked because this piping is still being used. For the previous three layers of pipe, the total estimated length of pipe is approximately 20,000 ft. The typical diameter of pipe used in the WMA is 3 inches. The total volume of pipe that may contain blockages is

$$20{,}000 \text{ ft (length)} \times 0.05 \text{ ft}^2 \text{ (cross-sectional area)} = 1{,}000 \text{ ft}^3.$$

  It is further assumed that of the 1,000 ft^3 of piping only 25% is blocked or has residual waste left in it. The pipelines in WMA C were drained and flushed after use; therefore, the amount of residual remaining in the pipelines is expected to be much smaller the 25% used in this estimate.

- The material left in the 244-CR vault tanks, C-301 catch tank, and pipelines is assumed to be similar in nature to what is left in the 100- and 200-series tanks. Therefore, to estimate the inventory left in the 244-CR vaults tanks, the C-301 catch tank, and the pipelines, the total residual inventory for each COC (selected phase BBI) was divided by the total residual volume (12×360 ft^3 [100-series tanks] + 4×30 ft^3 [200-series tanks] = 4,400 ft^3) to come up with an average inventory per cubic foot. The expected residual volume for the ancillary equipment was then multiplied by the average inventory per cubic foot. Table 12 provides the assumed inventory using these calculations.

The ancillary equipment inventory estimate is very conservative. Even using this estimate, the modeling results indicated that the risk associated with residual piping is minimal compared to the risk posed from other sources.

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4.0 LONG-TERM HUMAN HEALTH RISK ASSESSMENT MODELING RESULTS FOR WASTE MANAGEMENT AREA C

The results of the long-term human health risk assessment analysis for WMA C are discussed in this section. Fourteen cases (containing seven distribution coefficients) were simulated representing the four types of contaminant sources and two types of release mechanisms for residual wastes. The four types of contaminant sources and the numerous release mechanisms previously identified. In particular, three hypothetical release models were identified:

- Diffusion-dominated release: a stabilized waste form covered with grout*
- Advection-dominated release: an unstabilized waste form covered with backfill sand and gravel or a failed grout (i.e., the grout has cracked)
- Solubility-dominated release: a waste form bound in a material that releases risk-driving contaminants congruently with the dissolution of the material.

Salt cake releases are often simulated under the solubility-controlled release mechanism. The suite of modeling cases is intended to identify and demonstrate the relative importance of the input parameters upon the results (especially those parameters considered manageable), and provides a quantitative estimate of the expected impact.

In summary, results indicate that the primary long-term human health risk driver is the inventory associated with the past leak sources. The only parameter to affect the past and hypothetical waste retrieval leak results is the surface barrier efficiency. The modeling assumed a 500-year design life for the barrier

Results and Conclusions

- The primary contributors to groundwater contamination are contaminants contained in past leaks from tanks and ancillary equipment, and predicted leaks from tanks during waste retrieval.
- The placement of the surface barrier greatly reduces recharge through vadose zone contamination, which results in a decrease in the predicted peak concentration until the barrier degrades.
- Key parameters affecting the predicted groundwater contaminant concentrations resulting from tank residual waste releases are release rate (but only if the release extends beyond 3,000 years), contaminant mobility, and inventory.
- During the first 120 years after waste retrieval, technetium-99 concentration associated with past leaks is 497 pCi/L at the WMA C fenceline. The peak concentration of technetium-99 resulting from tank residual diffusion-dominated releases after waste retrieval is 60.4 pCi/L.
- During the first 120 years after waste retrieval, peak iodine-129 concentration associated with past leaks is 0.96 pCi/L at the WMA C fenceline. The peak concentration of iodine-129 resulting from tank residual diffusion releases after retrieval is 0.11 pCi/L.
- Contaminants with a $K_d \geq 0.6$ mL/g do not contribute appreciably to groundwater contamination over the 10,000-year simulation.
- Contaminants with a $K_d \geq 0.6$ mL/g exhibit increasing concentrations at the end of the 10,000-year simulation.
- If retrieved to the HFFACO goal of 1%, all peak concentrations for the COCs at calculation points downgradient of the WMA (200 Area core zone boundary and Columbia River) occur at levels below the contaminant's MCL.

* See Preface in *SST System Closure Plan* (RPP-13774).

with immediate resumption of shrub-steppe environment recharge upon barrier degradation. Key parameters affecting the predicted groundwater concentrations resulting from tank residual waste are the inventory, release rate mechanism for the residual waste, the hydraulic conductivity of the unconfined aquifer, and the mobility of the individual contaminants.

A number of the models examined the impacts to groundwater from different release rates for the residuals and the results were somewhat unexpected. When all of the mass was released in less time than it takes for water to move through the vadose zone and into the aquifer, approximately 2000 years, the peak concentration for those releases did not vary by much. For example, the difference between case 10, all of the mass was released in 5 years, and case 7, all of the mass was released in 1000 years, was approximately 37 pCi/L or 13.5 %. However, if the release rate was over 10,000 years instead of 10 years the difference was approximately an order of magnitude. However, the impacts continued for the entire period of the simulation; thus, measures taken to limit future releases from tank residuals must be effective over periods longer than 2,000 years to have a significant impact on groundwater.

The following specific aspects of the analyses are presented in subsequent sections:

- Overview of constituent transport simulations
- Unit inventory results
- Cumulative inventory results
- Sensitivity analysis.

4.1 OVERVIEW OF CONSTITUENT TRANSPORT SIMULATIONS

Estimated impacts to the groundwater resource have been simulated for the following four types of contaminant sources within WMA C:

- Past leaks from tanks
- Past leaks from tank ancillary equipment (i.e., past pipe leaks)
- Potential leaks during waste retrieval
- Residual waste in both tanks and tank ancillary equipment.

These sources were defined in the modeling data package (RPP-13310) and a series of numerical simulations were performed using the STOMP code (Section 3.3). A total of 14 individual simulation cases were prepared to provide a basis for evaluating the sensitivity of various closure decisions. Each case describes the behavior of seven surrogate contaminants of varying distribution coefficients under variable waste release modes for the selected sources at a unit inventory (inventory = 1.0 unit). The simulation cases are summarized in Table 4.

The potential contaminant sources associated with WMA C have been identified and cataloged to associate them with appropriate transport simulation cases. The conceptual physical model of WMA C (Figure 4) indicates how the major features within the WMA are organized into rows

and cross sections. This arrangement allows application of the principle of superposition as a method of calculating impacts from each source location on the basis of simulation of a single source within a cross section.

An estimate of the impact to groundwater posed by a waste inventory contained in a particular source can be calculated by multiplying the simulated unit-source result by the specific source inventory and then making an appropriate distribution of the resulting concentration along the fenceline. For all of the WMA C estimates presented in this section, the cumulative cross-sectional concentrations for the sources in the WMA are distributed uniformly along the length of the downgradient WMA C boundary, a length of approximately 233 m. Impact can be evaluated for individual sources or as cumulative impact for multiple sources.

The conceptual model for WMA C incorporates multiple sources within the WMA, including the primary waste storage tanks, as well as major (244-CR vault, C-301 catch tank, diversion boxes) and minor (piping systems) ancillary equipment and past leaks from components. Inventories were identified for all of the 100- and 200-series tanks in the WMA, one past tank leak, and three ancillary equipment leaks. Other potentially important sources within the WMA (such as waste tanks within the 244-CR vault, C-301 catch tank, and pipelines) currently do not have reliable inventory estimates; however, an assumption of the inventory associated with this ancillary equipment was made and applied to the ancillary equipment (see Section 3.5).

The risk assessment approach provides for analysis of sensitivities in risk estimates arising from uncertainties in waste constituent inventory, waste release scenarios, and waste retrieval efficacy. The results of the risk assessment provide a basis for evaluation of the following sensitivities:

- Residual waste inventory in tanks (range from [theoretical] zero residual to current BBI)
- Residual waste inventory constituents (individual or cumulative impacts for 239 constituents)
- Potential tank retrieval leaks (none, 8,000 gal, 20,000 gal)
- Residual tank waste inventory release mechanisms (arbitrary 5-, 10-, 100-, 1,000-, or 10,000-year release duration; advection-dominated, diffusion-dominated, and solubility-limited release models)
- Presence/absence of past leaks
- Presence/absence of residual inventory in ancillary equipment.

The primary radionuclides that contribute to long-term human health risk are those with relatively long half-lives that are also completely mobile.

4.2 UNIT INVENTORY RESULTS

A discussion of the results for the simulation cases, using unit inventory, is presented in this section. A unit inventory source term was used for the following reasons:

- Except for model runs assuming solubility release controls, model results (contaminant BTCs) can be scaled to inventories identified for contaminant source by multiplying the model results by the source's mass (non-radionuclides units are kg for source term) or activity estimate and decay rate (radionuclides units are curies for source term) for COCs.

- Model results from individual contaminant sources can be added using the principle of superposition to evaluate the impacts of multiple sources for a composite analysis for the entire WMA C.

- When additional information becomes available (updated or new inventory data) the impacts of the new data can quickly be assessed.

- The unit inventory method also provides a relative evaluation of parameter and release mechanism sensitivity independent of source inventory.

The resulting contaminant breakthrough curves for a mobile contaminant ($K_d = 0$), including simulated peak concentrations and arrival times, for each of the different source models given in Table 4, are presented in Figure 6.

4.2.1 Release Models

In examining the results shown in Figure 6 in terms of release models, the results can be broken into the following three categories:

- **Retrieval losses and past leaks.** As shown in Figure 6(a), the contaminant BTCs show a dual peak trend for Cases 1 through 4. The first concentration peak is the result of the leak occurring before the emplacement of a barrier and some, but not all, of the contaminant traveling through the vadose zone before the barrier becomes effective. Once the barrier becomes effective, the contaminant movement slows limiting release from the vadose until the barrier degrades 500 years into the future and the recharge changes from 0.5 to 3.5 mm/yr. Once the recharge rate increases, the remaining contaminant in the vadose zone is released, causing a second peak approximately 1,100 years after the first peak, with all of the contaminant being released from the vadose zone approximately 4,500 years after the initial release.

- **Fast Releases from Residual Waste.** The results for this category, which includes Cases 5, 6, 7, 9, and 10, are shown in Figure 6(b). For Cases 5, 6, 7, and 9, the release for the unit inventory was arbitrarily set to occur over a specified number of years; the residual waste release duration was less than 1,000 years for all four cases. Case 10 is the advection-dominated case and represents release from an unstabilized waste form covered with backfill sand and gravel or failed grout (RPP-13310). In all of these cases, the release duration is shorter than the vadose zone travel time (approximately 2,000 years), resulting in similar BTCs. For Case 7, the peak is a little broader because of the much longer release duration (1,000 years versus 100 years for Case 6).

- **Slow Releases from Residual Waste.** The results for this category are shown in Figure 6(c). The results correspond to Case 8 and Cases 11 through 14. For Case 8, the release rate was arbitrarily set to the length of the simulation time period (10,000 years).

Cases 11, 13, and 14 represent diffusion-dominated release from stabilized, grouted waste form for both the residual tank waste (Cases 11 and 14) and ancillary equipment (Case 13). The differences shown in this figure between Cases 11 and 14 are the result of the use of a different distribution coefficient; the distribution coefficient for Case 11 is 6×10^{-7} cm^2/s, whereas Case 14 has a distribution coefficient of 5×10^{-8} cm^2/s. The differences in results for Cases 11 and 13 are because of the assumed footprint of the source inventory, which for Case 11 is the diameter of the tank (22 m) and for Case 13 is a diameter of 7 m between tanks. The solubility-controlled release model (Case 12) assumed congruent release of various contaminants, with the major constituent in the waste (sodium nitrate) controlling the release of all constituents. As the major constituent dissolves, all other constituents within the tank are released in proportion. The solubility of sodium nitrate was assumed to be 72 g/L in the tank solution. In all of these cases, the release duration is much longer than the travel time to groundwater. The fact that the actual solubility of the waste is currently unknown (WMA C tank wastes are not predominantly nitrate salts) is a major uncertainty of the solubility-controlled release model. Results are likely to vary depending on the actual release rate.

The simulation results suggest the following:

- Past leaks potentially have the largest impact (depending on inventory); however, a barrier emplacement can mitigate the impacts from leaks.

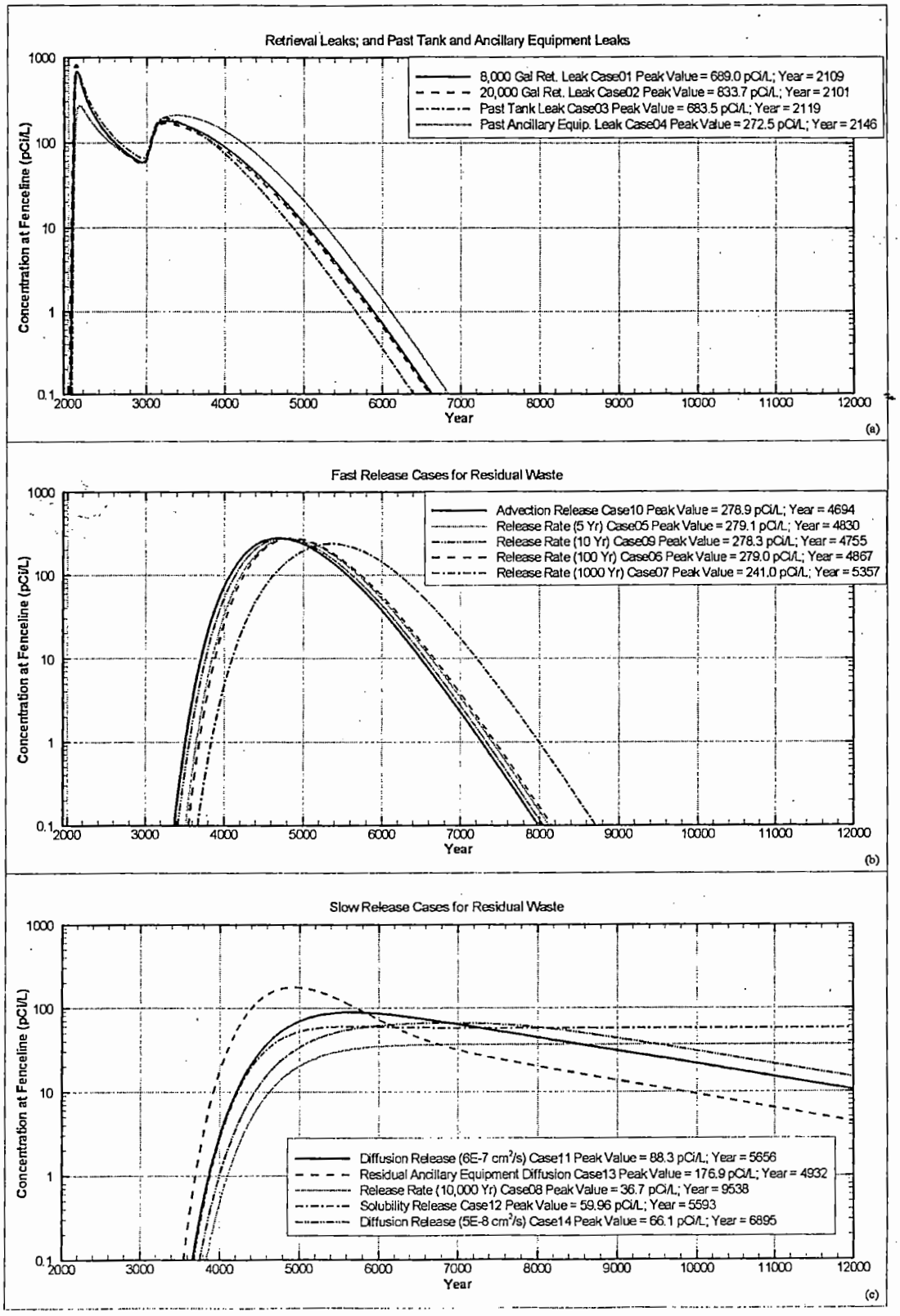
- The release duration from the tanks, if it is fast and occurs completely before any of the contaminants reach the groundwater, does not change the estimated peak groundwater concentration.

- The factors with the greatest impact on the results are the longevity of the closure barrier and the release duration of the residual waste if it is slow (takes longer than the vadose zone travel time).

- Which release model is appropriate for the tank residual waste is unknown at this time. Further laboratory work addressing residual waste release models is needed; however, to simulate the impact of a grout* fill material, the diffusional release model is considered.

* See Preface in *SST System Closure Plan* (RPP-13774).

Figure 6. Contaminant Breakthrough Curves for all Cases Using Unit Inventory ($K_d = 0.0$).



4.2.2 Bulk Distribution Coefficients

The contaminants simulated represent seven different measures of contaminant mobility through the use of distribution coefficients (K_d = 0, 0.01, 0.03, 0.1, 0.3, 0.6 and 1.0 mL/g). By using a range of distribution coefficients, a wide variety of contaminants can be examined by applying the appropriate inventory and decay rate to the unit results for the contaminant of interest. Figure 7 was prepared to illustrate how a small change in the mobility (K_d = 0.0 vs. K_d = 0.1 mL/g) can dramatically change the results especially for waste retrieval leaks (Figure 7a) and past leaks (Figure 7b). The second peak value for K_d = 0.1 mL/g dropped approximately by a factor of 2 over that for K_d = 0 mL/g, with the arrival of the peak delayed by approximately 2,800 years. Additionally, the peak for the less mobile contaminant is broader and appears to be very similar to the peak caused by a slow release mechanism for the residual waste.

The cross-sectional views in Figure 8, based on the tank row center-line concentrations, illustrate how the contaminants are predicted to move through the vadose zone. The figure shows the location of the plumes resulting from 8,000-gal waste retrieval leaks after 100 years for contaminants (K_d = 0.0 mL/g in Figure 8a, K_d = 0.1 mL/g in Figure 8b). The waste retrieval leaks from all tanks are released simultaneously. While the likelihood of all of the tanks failing simultaneously during waste retrieval may be remote, the results from the advection-dominated release sensitivity cases indicated that the resultant concentration at the fenceline is virtually unaffected by the release rate or timing, when the release is completed within about 100 years of closure. The plumes emanating from the tanks appear to be almost identical. The plumes from the four tanks co-mingle, although the areas of highest concentration remain distinct as the plumes migrate into groundwater. The plumes enter the aquifer almost simultaneously, and contaminant transport through the aquifer to the fenceline occurs almost instantaneously. The simultaneous release, co-mingling of the plumes, and instantaneous transport of the contaminants through the aquifer to the fenceline result in the concentration at the fenceline being essentially cumulative for different sources.

Figure 7. Comparison of Breakthrough Curves between a Mobile Contaminant ($K_d = 0.0$) and a Slightly Mobile Contaminant ($K_d = 0.1$) for Waste Retrieval Leaks and Past Leaks.

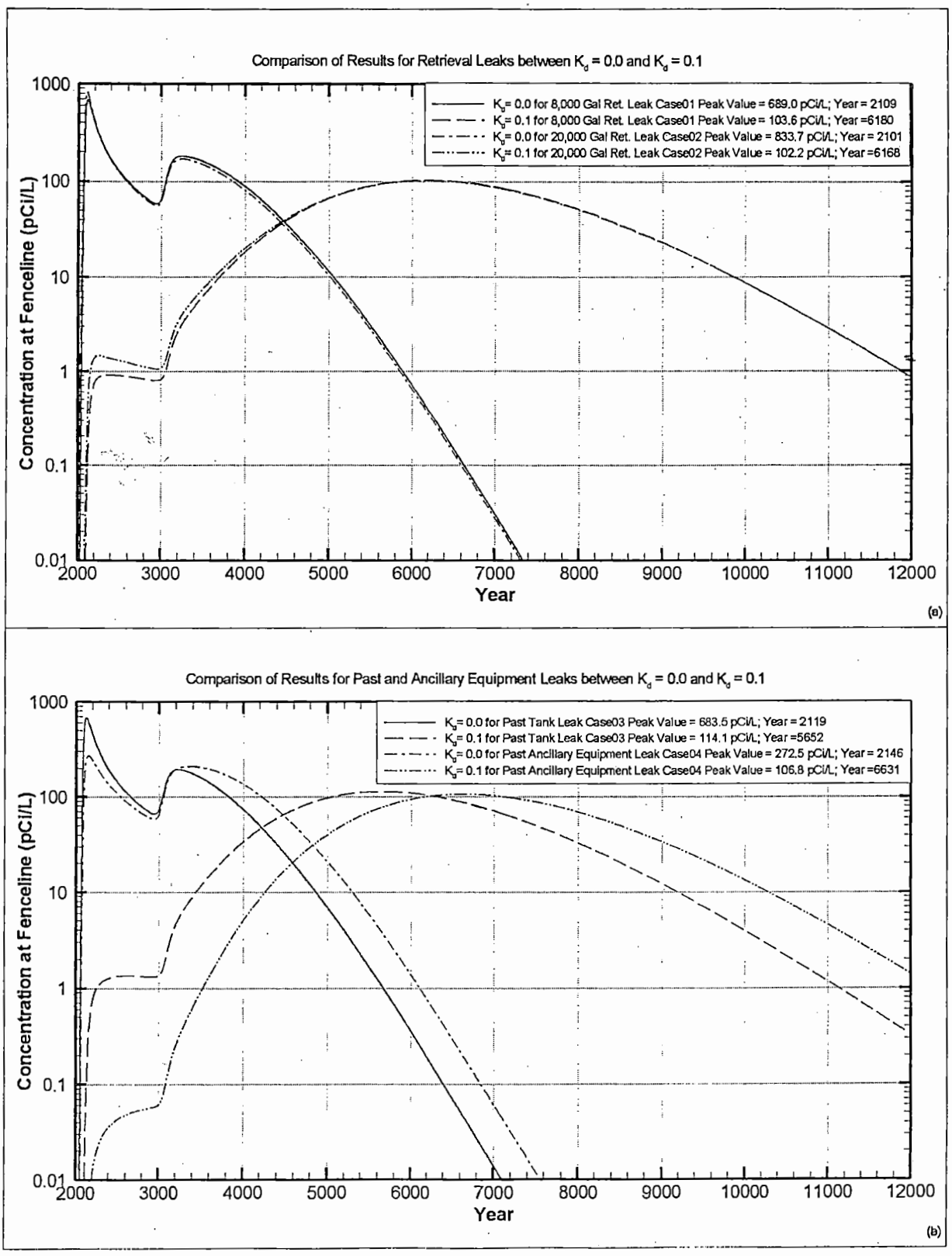
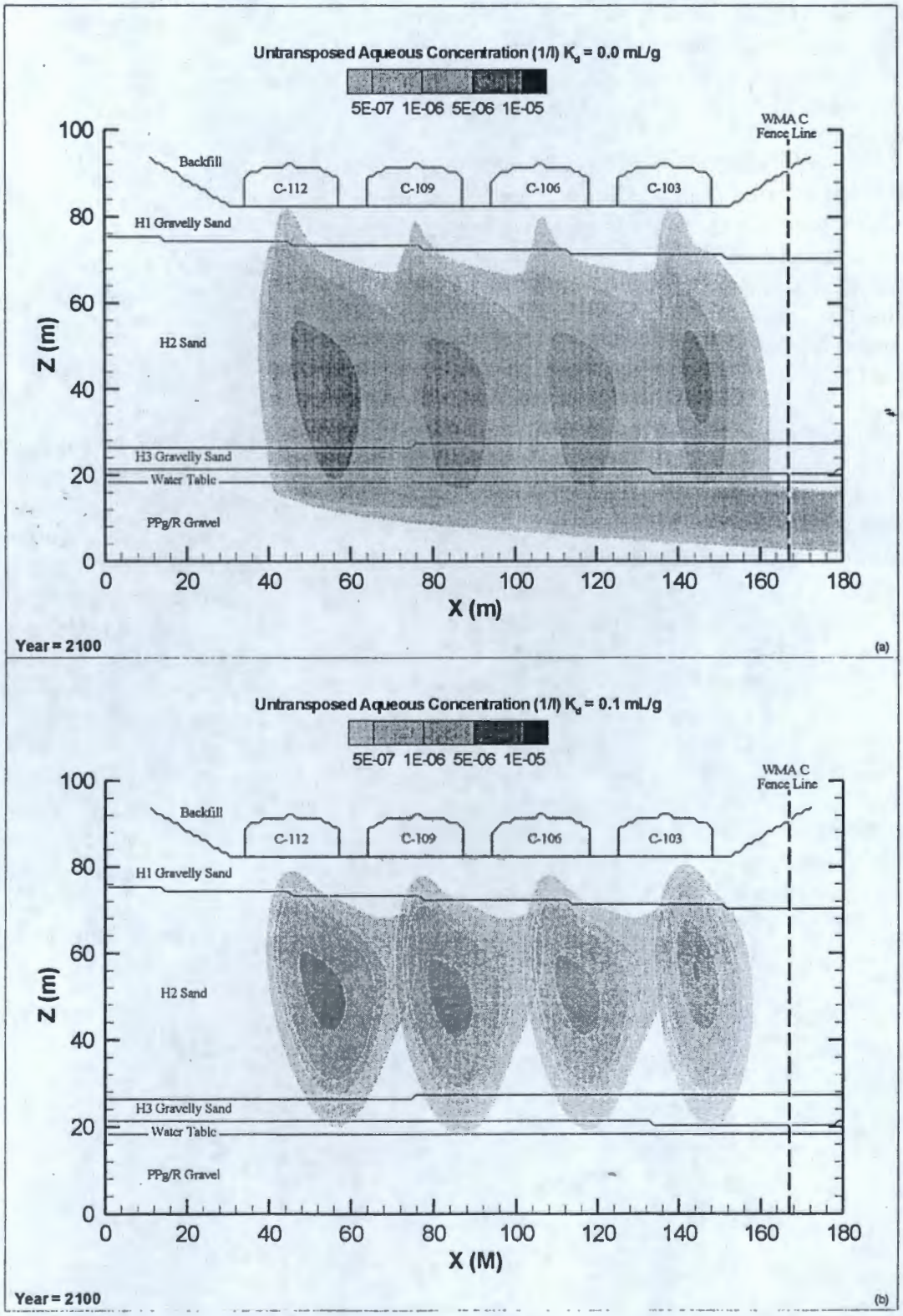


Figure 8. Untransposed Model Contaminant Transport Results for an 8,000-gal Waste Retrieval Leak for K_d = 0.0 mL/g and K_d = 0.1 mL/g.



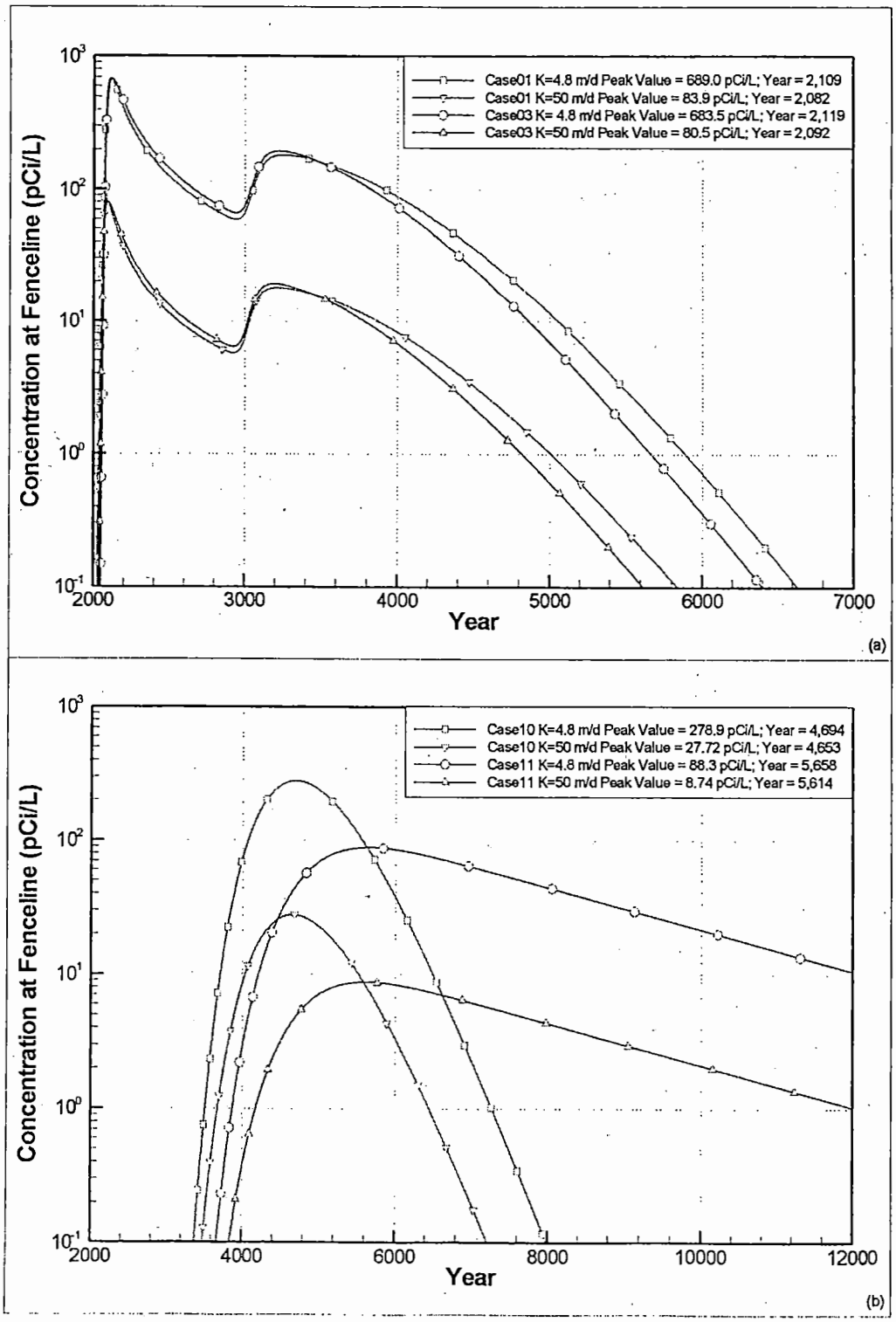
4.2.3 Hydraulic Conductivity of the Unconfined Aquifer

The results for all 14 cases were provided with the hydraulic conductivity of the unconfined aquifer set to 4.8 m/day. Although this laboratory-measured hydraulic conductivity value is consistent with undifferentiated Plio-Pleistocene/Ringold gravels, it is inconsistent with the large-scale hydraulic conductivities for the unconfined aquifer reported within the 200 East Area, which are typically higher by at least factor of 10.

Presently, all wells in the vicinity of WMA C are completed at the water table and the underlying geology is inferred from wells further away. As part of the RCRA Groundwater Monitoring Program, four additional wells are being drilled in the vicinity of WMA C in the summer of 2003. For one of these wells, drilling is scheduled to penetrate to the base of the aquifer, thereby providing additional geologic information. Following drilling, the well will be developed. During the development cycle, a more representative number for the hydraulic conductivity of the unconfined aquifer in the vicinity of WMA C will be obtained. This proposed new well is located northeast of C-204 just outside of WMA C.

To address the uncertainty in hydraulic conductivity values until additional data is obtained, Cases 1, 3, 4, 10, and 11 were also simulated with a hydraulic conductivity of 50 m/day. Figure 9 shows the comparison between the two hydraulic conductivities for these cases. Figure 9(a) compares the results between the different hydraulic conductivities for Cases 1 (8,000-gal leak) and 3 (tank leak), while Figure 9(b) compares the results between the different hydraulic conductivities for Cases 10 (advection-dominated release) and 11 (diffusion-dominated release). For Cases 1 and 3, the results indicate that increasing the hydraulic conductivity by an order of magnitude decreases the concentration by a factor of approximately 8.5 and decreases the travel time to the fenceline by 27 years. For Cases 10 and 11, reducing the hydraulic conductivity by a factor of 10 decreases the concentration at the fenceline by approximately the same amount and decreases the travel time to the fenceline by approximately 41 and 44 years, respectively. The difference between the factor of 8.5 and the factor of 10 for the leak cases compared to the residual cases is because of a different hydraulic gradient present at the time the contaminants reach the groundwater. The leak cases occur when the recharge rate is 100 mm/yr, which causes a slightly higher hydraulic gradient in the unconfined aquifer. For the residual cases, release occurs far enough into the future that recharge reverts back to pre-Hanford values (3.5 mm/yr) and the hydraulic gradient at that time reverts back to pre-Hanford conditions and remains constant.

Figure 9. Comparison of Results using Hydraulic Conductivity of 4.8 m/day and 50.0 m/day for the Unconfined Aquifer. (Upper figure presents the results for retrieval leaks and past tank leaks. Lower figure presents the results for advection- and diffusion-dominated release from residuals.)



4.3 CUMULATIVE INVENTORY RESULTS

The preceding results are based on unit source inventory. In this section, the impacts of the COCs (Section 3.5) are assessed. To estimate the predicated impacts for the COCs, BTCs for the unit source inventory are multiplied by a contaminant inventory to obtain a BTC for each of the identified sources shown on Figure 2. The BTCs for each individual source were then summed to produce a composite BTC for WMA C. Before applying the contaminant inventories, a base case must be defined for WMA C. The base case describes the assumed post-retrieval conditions, which are based on current waste retrieval plans. Table 13 provides a listing of the selected conditions, constituents, and source terms. When a cumulative total is given for WMA C, the base case condition is used.

Table 13. Features of Waste Management Area C Base Case (2 Pages).

Hydraulic conductivity of unconfined aquifer	50 m/day
Release model for residual waste	Diffusion (coefficient 6 E-07 cm^2/s)
COCs and distribution coefficients	Technetium-99, iodine-129, chromium, nitrate, nitrate, and uranium Uranium = 0.6 mL/g; All other COCs = 0.0 mL/g

Inventory and Source Terms

Tank Sources	Retrieval Method[a]	Residual Volume/ Inventory Used	Vadose Zone Contamination associated with Past Tank Leak[b]	Hypothetical Retrieval Leak	Inventory[c]		
					Residual	Past Tank Leak	Retrieval Leak
C-101	Sluicing	360 ft^3/SPR[d]	No	Yes	Table 8b		Tables 10 and 11
C-102	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-103	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-104	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-105	Sluicing	360 ft^3/SPR	Yes	Yes	Table 8b	Table 6	Tables 10 and 11
C-106	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-107	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-108	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-109	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-110	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-111	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-112	Sluicing	360 ft^3/SPR	No	Yes	Table 8b		Tables 10 and 11
C-201	Vacuum	30 ft^3/SPR	No		Table 8b		
C-202	Vacuum	30 ft^3/SPR	No		Table 8b		
C-203	Vacuum	30 ft^3/SPR	No		Table 8b		
C-204	Vacuum	30 ft^3/SPR	No		Table 8b		

Table 13. Features of Waste Management Area C Base Case (2 Pages).

Past UPR Sources[f]	Inventory[c]	
UPR-200-E-81	see Table 6	
UPR-200-E-82	see Table 6	
UPR-200-E-86	see Table 6	
Ancillary Equipment Sources	**Residual Vol./Type**	**Inventory [c]**
244-CR TK-CR-001	27 ft^3/SPR	see Table 12
244-CR TK-CR-002	8 ft^3/SPR	see Table 12
244-CR TK-CR-003	8 ft^3/SPR	see Table 12
244-CR TK-CR-011	27 ft^3/SPR	see Table 12
C-301	19 ft^3/SPR	see Table 12
Piping	250 ft^3/SPR	see Table 12

[a] Retrieval Method from RPP-15588 *Hanford Tank Waste Operations Simulator (HWTOS) Model Run Results for the Proposed Baseline Change Request (BCR) Case* (Table A-1E) Vacuum and Crawlers are considered dry retrieval technologies. Minimal water will be used with these technologies as opposed to sluicing which uses large volumes of water to retrieve.

[b] Past Tank Leaks,only tanks with verfied vadose zone contamination were included in the model. Vadose contamination was either verified by either by borehole sampling or geophysical logging.

[c] Inventory Tables are from Section 3.6 of this document

[d] SPR = Selected Phase Removal inventory after the retrieval of tank wastes as reported in *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA: Inventory and Source Term Data Package.*

[e] HTWOS = Hanford Tank Waste Operation Simulator (HTWOS) Model Output *Single-Shell Tank Retrieval Sequence and Double-Shell Tank Space Evaluation* (RPP-8554), modeled inventory after retrieval simulating differential dissolution of waste constituents in high volume retrieval (Please note after this risk analysis was completed, the retrieval technology selected for C-106 was changed from modified sluicing to acid dissolution. An inventory analysis has not been completed for tank residuals using acid dissolution) Subsequent risk assessments will address acid-dissolution for this tank.

[f] Past leaks and hypothetical retrieval leaks are simulated using advective transport through the vadose zone.

4.3.1 Results for Technetium-99

The results of the WMA C composite analysis for technetium-99, representing all sources, are given in Table 14 and Figure 10. In this figure, the following six BTCs are shown:

- **Source – Hypothetical Retrieval Leaks** (Figure 10): Hypothetical retrieval leaks were modeled for all C-100 Series tanks, since the expected retrieval methodology is thought to be sluicing. The retrieval methodology for the C-200 series tanks is a dry vacuum. A retrieval leak was not applied to these tanks.

  The total estimated inventory for retrieval leaks is 5.0 Ci. The inventory from waste retrieval leaks was applied to simulation Case 1 (Table 4) with the higher hydraulic conductivity for the unconfined aquifer and then summed to estimate impacts of waste retrieval leaks from all C-100 series tanks. Although retrieval leaks are included in the cumulative curve, it is unrealistic to assume all tanks will leak 8,000 gal. The waste retrieval leaks peak breakthrough occurs approximately 80 years after retrieval with a peak concentration of 430 pCi/L, which is below the MCL derived constituent concentration of 900 pCi/L. The Hanford Advisory Board (HAB) Consensus Advice #132 states that the core zone will have an industrial scenario for 150 years after site closure. At that time the concentration will have dropped to approximately175 pCi/L. Following the emplacement of a barrier, contaminant levels would drop until the barrier degrades. After the barrier degrades, a second peak arrives approximately 1,135 years after the first peak with a peak value of 88 pCi/L.

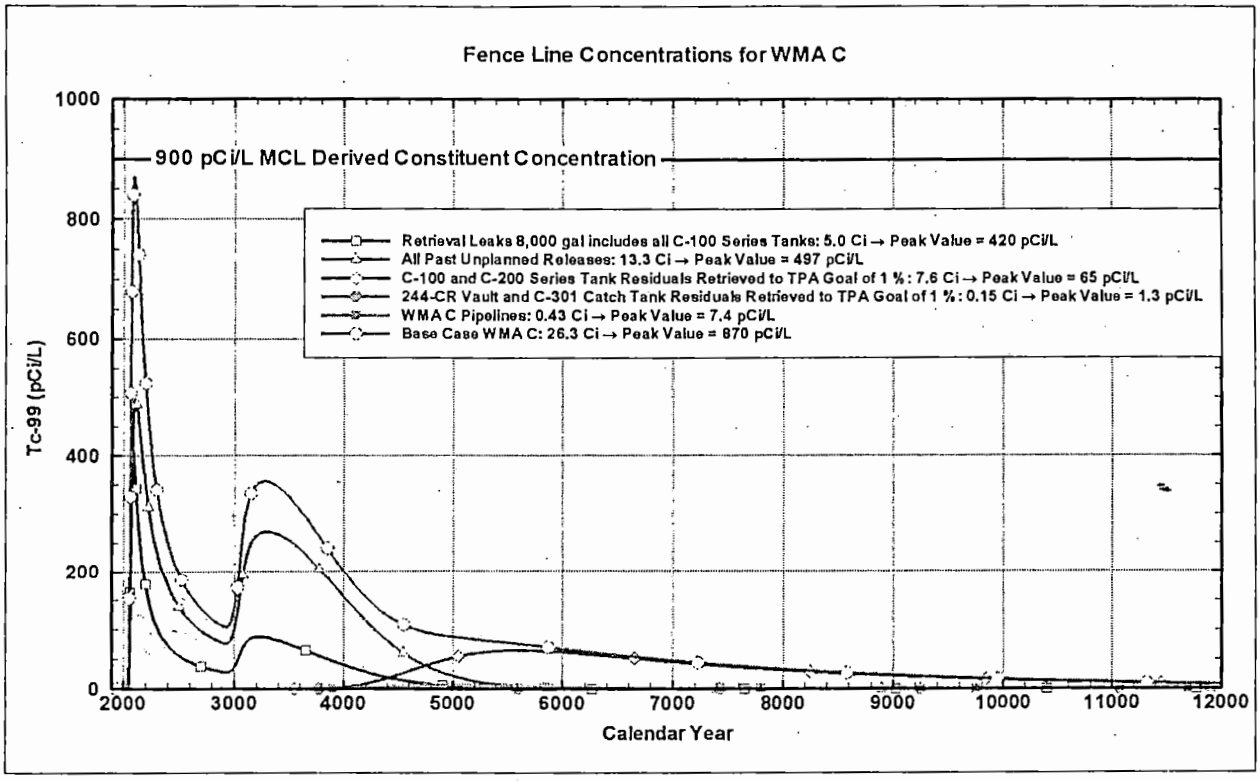
- **Source – Unplanned Releases** (Figure 10): Estimated inventory for technetium-99 from past leaks from C-105 and the ancillary equipment is 1.9 Ci and 11.3, respectively (total 13.26 Ci). This inventory was applied to the simulation Case 3 (Table 4, tank C-105 past tank leaks) and Case 4 (Table 4, ancillary equipment leaks) with the higher hydraulic conductivity for the unconfined aquifer. The simulations were then summed to estimate the concentrations for both tank ancillary equipment leaks. The simulated peak concentration from these sources is 497 pCi/L occurring approximately 110 years after the leak. This is slightly under the MCL derived constituent concentration of 900 pCi/L. Like the waste retrieval leaks, concentrations decrease following the emplacement of a barrier. After the barrier degrades, concentrations rise reaching a peak approximately 1,180 years after the first peak, with a peak value of 270 pCi/L.

Table 14. Simulated Peak Concentrations [a] (pCi/L) and Arrival Times (year) for Technetium-99 at Various Boundaries.

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved Tank Waste Advection-dominated release [simulation case 10] [b]	4653	9639	4676	1520	4883	560
Unretrieved Tank Waste Diffusion-dominated release [simulation case 11]	5614	3030	5637	480	5839	178
Base Case Post-Retrieval [b]						
Retrieved Tank Residuals Advection-dominated release[simulation case 10] [b]	4653	208	4676	32	4883	12
Retrieval leak (8,000 gal) [simulation case 1]	2082	420	2107	67	2324	22
Past tank leaks [simulation case 3]	2092	156	2117	25	2333	9
Past ancillary equipment leaks (UPR) [simulation case 4]	2117	353	2141	56	2355	20
Retrieved Tank Residuals Diffusion-dominated release [simulation case 11]	5614	65	5637	10	5839	4
Residuals in 244-CR vault and catch-tank release limited to diffusion [simulation case 11]	5614	1	5637	0.2	5839	0.08
Residuals in ancillary pipeline release limited to diffusion [scaled simulation case 13]	4891	7.4	4925	1.2	5130	0.4

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.
[b] Not part of the base case; only added for comparison purposes between release models.
UPR = unplanned release
WMA = waste management area

Figure 10. Technetium-99 Results for Hypothetical Retrieval Leaks, Past Unplanned Releases, and Tank and Ancillary Equipment Residuals (Diffusion-Dominated Release).



- **Source – C Farm 100- and C-200-Series Tank Residual Waste Releases** (Figure 10): Total technetium-99 inventory left in the residual waste within the tanks is 7.6 Ci using selected phase removal for all tanks. The inventory from these sources was applied to Case 11 (Table 4) with the higher hydraulic conductivity for the unconfined aquifer. The diffusion-dominated release model results for residuals are presented. Again, such a release model represents release from a stabilized waste form covered with grout* or cementitious grout*. If diffusion is the correct release mechanism, the release of contaminants from the tank residuals is not expected to exceed the MCL derived constituent concentration. The simulated peak for residual waste in all tanks is 65 pCi/L occurring approximately 3,500 years after closure.

- **Source – Ancillary Equipment CR-Vaults and C-301 Catch Tank Residual Releases** (Figure 10): This assumes the waste in the CR-vaults and C-301 catch tank will be retrieved to approximately the HFFACO goal. Assumed inventory for technetium-99 for this ancillary equipment is 0.15 Ci. The inventory from these sources was applied to Case 11 (Table 4) with the higher hydraulic conductivity for the unconfined aquifer. These sources were modeled the same as the C farm 100- and 200-series tanks, with a

* See Preface in *SST System Closure Plan* (RPP-13774).

diffusion-dominated release model (a waste form covered with grout*). The simulated peak for residual waste in these tanks is 1.3 pCi/L occurring 3,500 years after closure.

- **Source – Ancillary Equipment: Pipeline Residual Release** (Figure 10): This assumes an ancillary equipment inventory of 0.43 Ci for technetium-99. The inventory from this source was applied to a scaled Case 13 (Table 4), Case 13 was modeled with a diffusion-dominated release model assuming a waste form in which the pipelines are filled with grout*. With the assumed inventory for residual in pipelines, the simulated peak is 7.5 pCi/L. The arrival time for the peak occurs approximately 2,850 years after closure. The residual in the pipeline represents approximately 12% of cumulative impacts at the peak arrival time for release from the pipeline, which occurs 700 years before the impacts due to tank residual waste.

- **Source – Cumulative Impacts from all Sources within WMA C** (Figure 10): The BTCs for the five sources listed above were summed to calculate a total technetium-99 concentration at the fenceline. The total technetium-99 inventory for the release to the surrounding environment would be 26.3 Ci. The peak simulated technetium-99 concentration for the composite WMA C is 870 pCi/L occurring approximately 100 years into the future. This peak is slightly under the 900 pCi/L MCL derived constituent concentration for technetium-99. The principal driver for the peak concentration is from the past leaks and hypothetical retrieval leaks which occurs during the time in which the core zone use is considered industrial. Once the barrier is emplaced, the concentrations drop to 105 pCi/L. Once the barrier degrades, concentrations rise to a second peak value of 356 pCi/L approximately 1,180 years after the first peak.

The results of the WMA C cumulative analysis indicate the following:

- The primary contributors to groundwater contamination are contaminants contained in past leaks from tanks and ancillary equipment and the hypothetical retrieval leaks.

- The highest contaminant concentration in groundwater occurs within 100 years of retrieval, and within the time periode in which the core zone is considered industrial.

- The placement of the surface barrier greatly reduces recharge through vadose zone contamination, which results in a decrease in the predicted groundwater concentration until the barrier degrades.

- During the first 120 years after waste retrieval, technetium-99 concentration associated with past leaks is 497 pCi/L, which is approximately half of the MCL derived constituent concentration, followed by hypothetical retrieval leaks at 420 pCi/L The peak concentration of technetium-99 resulting from tank residual diffusion releases after waste retrieval is 65 pCi/L which occurs approximately 3500 years after site closure.

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* See Preface in *SST System Closure Plan* (RPP-13774).

No-Action and Post-Retrieval Residual Technetium-99 Results: Figure 11 shows the simulated fenceline concentrations for technetium-99 for both no-action and post-retrieval. Figure 11(a) presents the no-action technetium-99 results for the WMA C 100- and 200-series tanks. The total technetium inventory for these tanks before retrieval is 350.8 Ci. Figure 11(b) shows simulated post-retrieval technetium-99 results (note the vertical scale has been increased by a factor of two over the upper figure). The total technetium inventory for these tanks after retrieval is 7.6 Ci. Included in each of the figures is a comparison between the advection- and diffusion-dominated release mechanisms.

- If the release is advection-dominated (from a sand or gravel fill material for the tank), the peak concentration at the fenceline is approximately 9,640 pCi/L for the present day BBI. However, if the tank is filled with a stabilizing agent (grout or concrete) and the release is diffusion-dominated, the resulting concentration drops by approximately 70% to 3,030 pCi/L.

- Retrieving to HFFACO goals reduces the technetium-99 concentration from 9,640 to 192 pCi/L for the advection-dominated release model. However, if the release is diffusion-dominated, the concentration at the fenceline is reduced from 3,030 to 65 pCi/L.

Comparison of no-action tank waste inventory and post-retrieval inventory results for a fast release model (advection-dominated) versus a slow release model (diffusion-dominated) shows the following:

- Retrieval of tank residual waste to HFFACO goals can reduce fenceline concentrations to below the MCL.

- Work to establish the type of release from residual tank waste is important in direct proportion to the amount of waste that remains in the tank after waste retrieval. The more waste left behind, the more important the release model becomes.

Individual Tanks: Evaluation of the tanks individually (Figure 12 for advection-dominated release, Figure 13 for diffusion-dominated release) indicates that when the wastes are retrieved to the HFFACO goal, none of the tanks are projected to contain a residual inventory capable of resulting in a peak concentration greater than the MCL, regardless of the release mechanism.

Figure 11. Advection- and Diffusion-Dominated Technetium-99 Release Model Results for all C Farm 100- and 200-Series Tanks using both Pre- and Post-Retrieval Inventories.

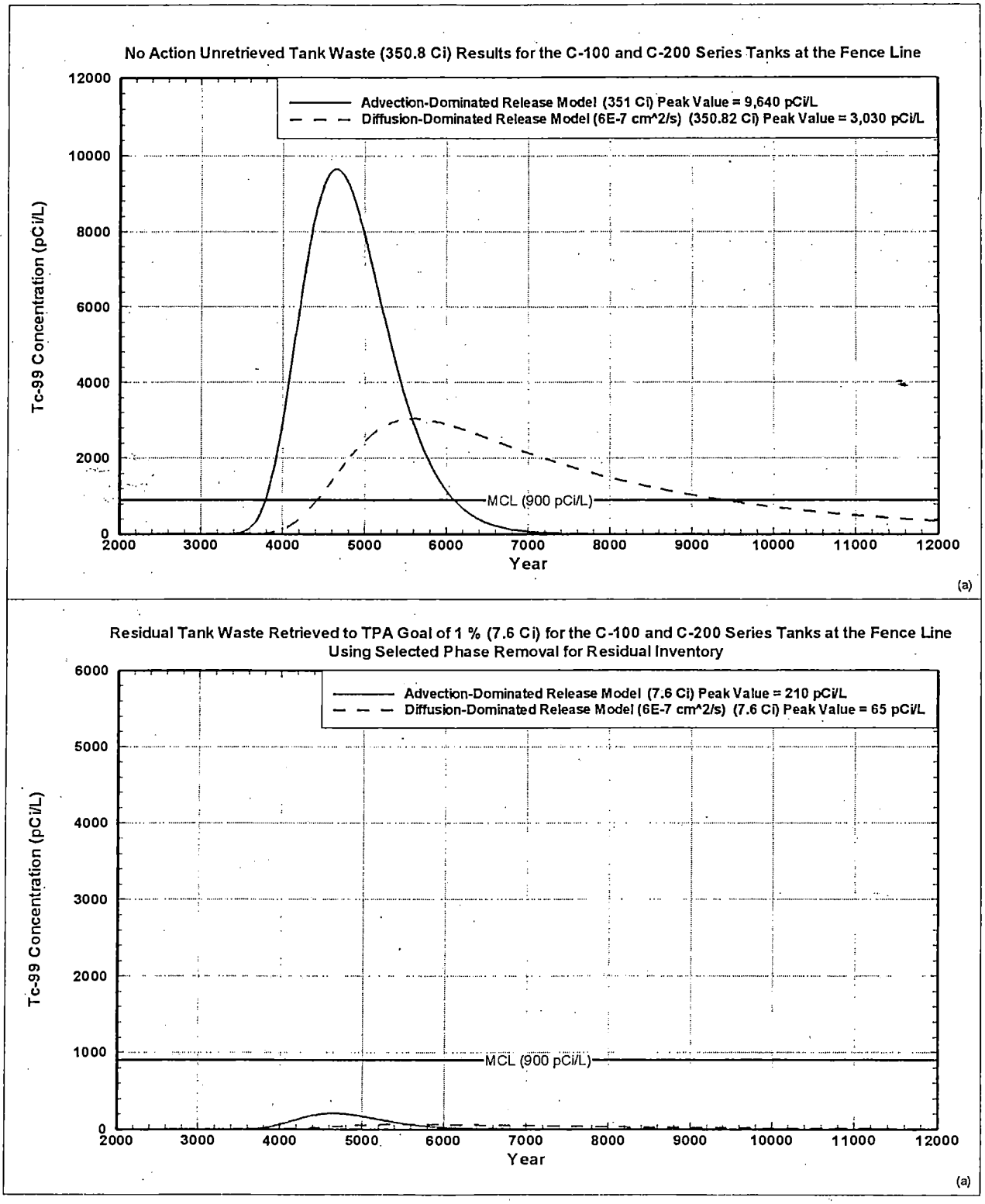


Figure 12. Post-Retrieval Technetium-99 Advection-Dominated Release Model Results for Individual C Farm 100-Series Tanks.

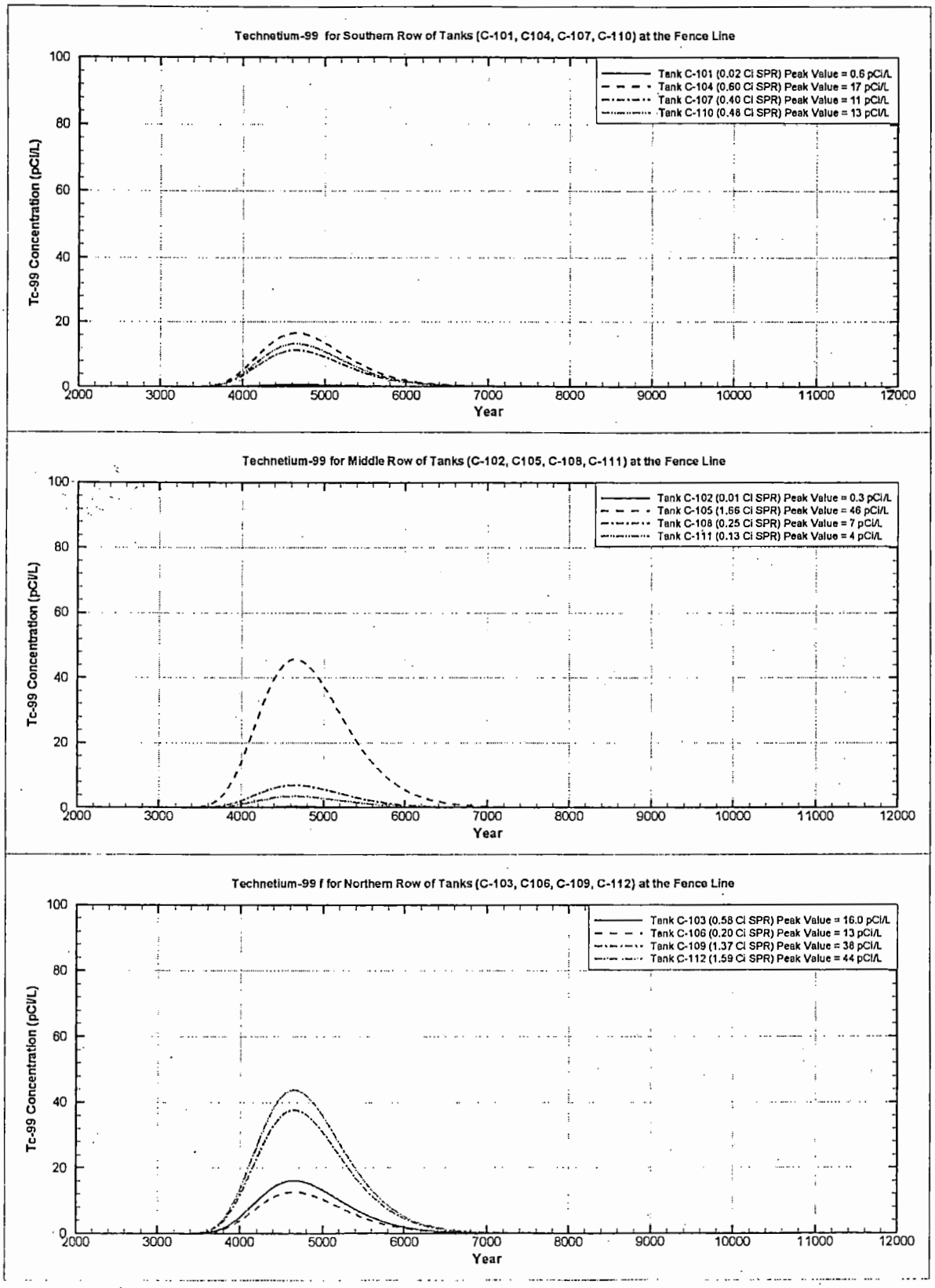
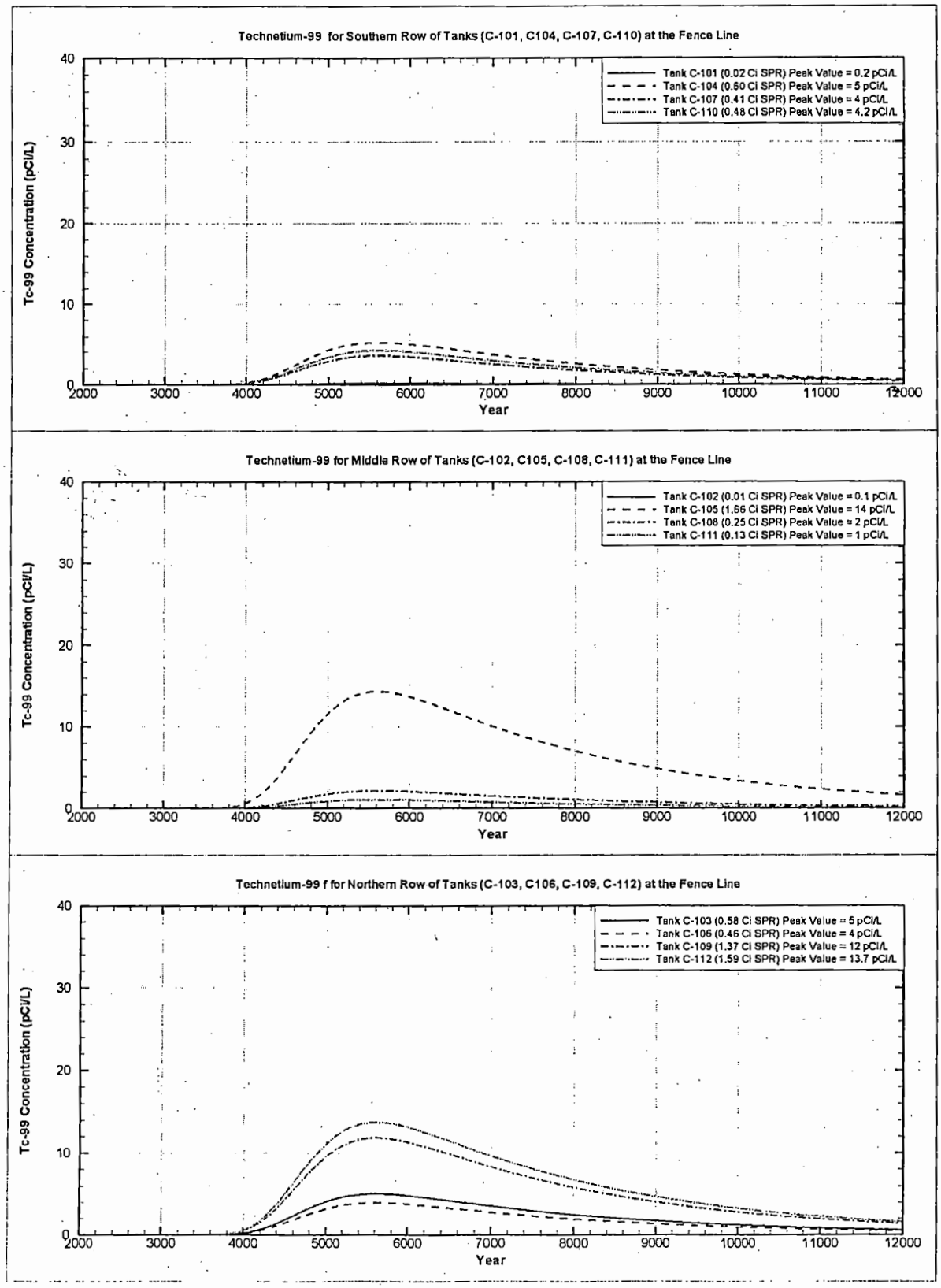


Figure 13. Post-Retrieval Technetium-99 Diffusion-Dominated Release Model Results for Individual C Farm 100-Series Tanks.



Hypothetical Retrieval Leaks: Three types of retrieval technologies have been identified for WMA C (RPP-15588). *Waste Retrieval and Storage Data Package* (DOE/ORP-2003-06) provides detailed descriptions of the retrieval methodologies. For all 200-series tanks, a vacuum system is used to retrieve waste. All 100 series tanks will be sluiced. This is essentially a dry technology in which a crawler moves the waste to a riser from which it will be vacuumed out. The crawler may spray some water onto the waste to help move it, but the amount of water used for waste retrieval is minimized. Modified sluicing was originally identified as the retrieval technology for C-106[5] however, the most recent waste retrieval technology for this tank is an acid wash. Because a post-retrieval inventory has not been associated with an acid wash, for this analysis C-106 will be treated as if its waste were being retrieved with modified sluicing. Sluicing requires the introduction of water under pressure to remove the waste. A waste retrieval leak could occur when waste material is being sluiced. Figure 14 presents the results for a hypothetical retrieval leak of 8,000 gal from all C-100 series tanks. Breakthrough Curves for C-112; C-109 and C-110 show the highest peak concentrations (108 pCi/L, 69 pCi/L and 66 pCi/L, respectively). The arrival time for the peak concentration occurs 82 years after waste retrieval. Results from unit source analysis (Figure 6), indicate that if a 20,000 gal leak were to occur, the resulting peak concentration would be approximately 20% higher.

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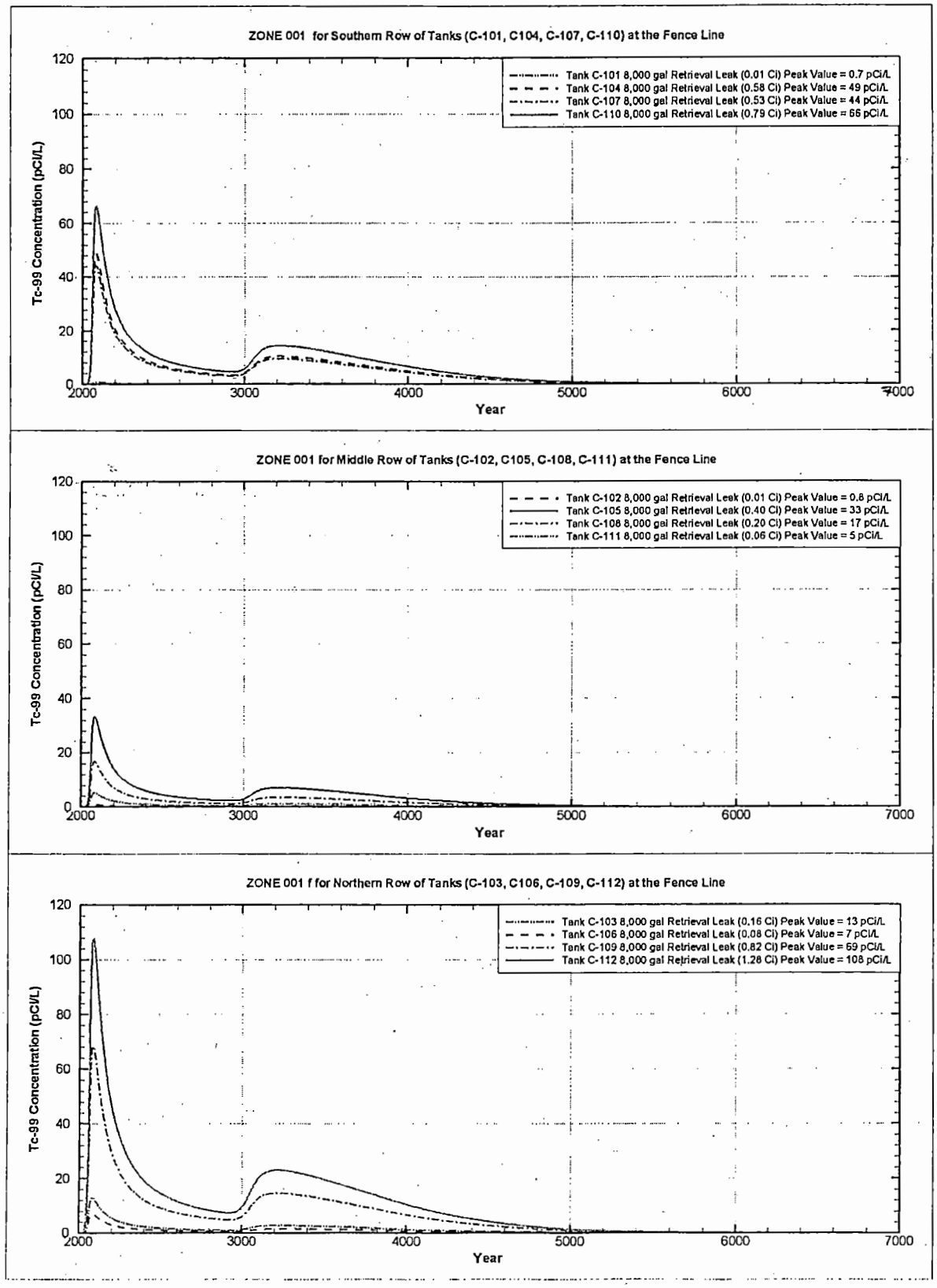
[5]Oxalic acid will be neutralized by the carbonate minerals naturally present in the soil and, given the amount and concentration of acid in an 8,000 gallon leak of 1M oxalic acid and the percent level of carbonate minerals in the soil, it is likely that the soil will neutralize the acid a short vertical distance (tens of feet or less) below the leak. The neutralized pH will likely be in the range of 7 to 8. Oxalic acid is fully deprotonated at a pH of about 4; therefore, above this pH all of the oxalate will be present in solution as the oxalate anion ($C_2O_4^{2-}$). This anion will complex with uranium (uranium oxalate stability constant → log K = +6.36 (*NIST Critically Selected Stability Constants of Metal Complexes Database,*[Smith and Martell 2003]), although no where near as strongly as with other organic complexes such as EDTA (uranium EDTA stability constant → Log K = 9.28 [Smith and Martell (2003]). PNNL found that the formation of the uranium oxalate complex did not reduce the adsorption of uranium onto Hanford soils compared to an oxalate-free solution. However, PNNL was not using 1M oxalate solutions so the results are not directly comparable; however, it is possible that the presence of oxalate will not significantly increase the mobility of uranium through the vadose zone.

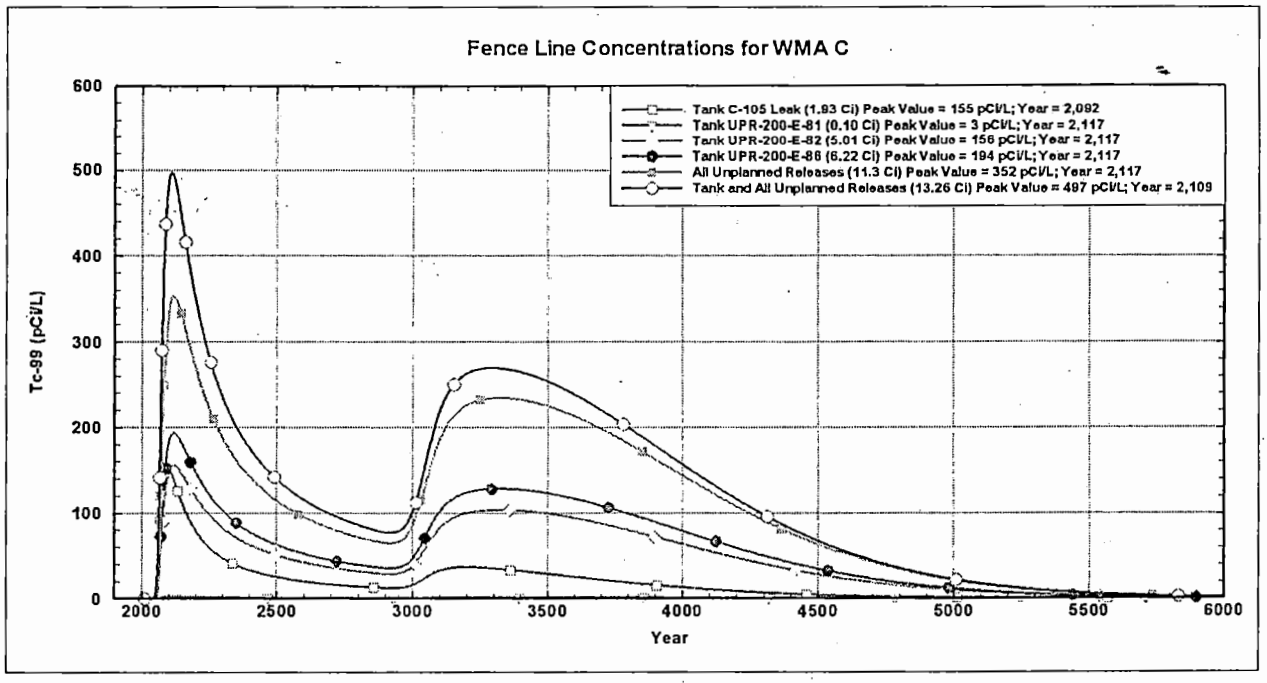
Additionally, no specific contaminants were used in the fate and transport model. Instead specific contaminants are modeled by assigning it to a sorption coefficient (K_d) bin. Contaminants like iodine-129 and technetium-99 were assigned a K_d of 0.0 ml/g, while uranium was assigned a K_d of 0.6 ml/g. If appropriate, the K_d for uranium could be adjusted.

Figure 14. Results for a Waste Retrieval Leak of 8,000 gal for C-100 Series Tanks.



Past Leaks: Figure 15 presents the results for all past leaks. The tank leak is simulated by the placement of the leak deeper in the vadose zone (Case 3, Table 4), compared to ancillary equipment releases (Case 4, Table 4); hence, the higher impact for a leak from tank C-105 per curie of inventory than the ancillary equipment releases. The tank C-105 leak released 1.93 Ci with a resulting peak concentration of 155 pCi/L. There are three unplanned releases from tank ancillary equipment (pipelines). UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86 released 0.1, 5.01, and 6.22 Ci of technetium-99, respectively, with resulting peak concentrations of 3 pCi/L, 156 pCi/L, and 197 pCi/L. A dual peak is observed on all of these curves because of the installation of a barrier, which effectively limits the movement and the contaminants remain in the vadose zone until the barrier degrades. Once the barrier degrades, a smaller second peak is observed.

Figure 15. Results for All Past Unplanned Releases.



4.3.2 Results for Other Contaminants of Concern

The results presented thus far were for the long-lived mobile radionuclide technetium-99. The transport of other highly mobile contaminants (such as iodine-129, nitrate, nitrite, and hexavalent chromium) is expected to be similar to that for technetium-99, with the resulting risk contribution to the overall cumulative risk dependent upon the contaminant inventory. Tables 15 through 19 illustrate the simulated peak concentrations and arrival times for all COCs and all sources. Included in these tables are the results for residuals at BBI and retrieved to HFFACO goals with both advection- and diffusion-dominated release models. Solubility-limited release model results are not presented here because of considerable uncertainty about its applicability to tank waste releases and appropriate solubility values to use in contaminant migration analyses. The WMA fenceline results for other selected COCs are summarized below:

- **Iodine-129** (Table 15 and Figure 16). For retrieval leaks of 8,000 gal at C-106 and C-107, previous tank leaks, and previous unplanned releases, the simulated peak concentrations are 0.82, 0.30, and 0.68 pCi/L, respectively, which are under the MCL derived constituent concentration of 1 pCi/L. For pre-retrieval residuals, both the advection- and diffusion-dominated release models have peak concentrations well over the MCL derived constituent concentration. For retrieval to HFFACO goals, the peak concentration for the advection-dominated release is 0.43 pCi/L; however, if the release mechanism is diffusion, the peak concentration is 0.14 pCi/L. For the base-case composite analysis of the WMA (Figure 16), the concentration (1.7 pCi/L) is higher than the MCL derived constituent concentration. However, this peak concentration is due to past leaks (tanks and operational) and hypothetical retrieval leaks. Peaks due to the residuals in tanks and pipelines are observed at 3,500 and 2,900 years past closure, respectively, and are approximately one (tank residuals) and two (pipeline residuals) orders of magnitude less than those for past leaks and hypothetical retrieval leaks.

Table 15. Simulated Peak Concentrations[a] (pCi/L) and Arrival Times (year) for Iodine-129 at Various Boundaries.

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved Tank Waste Advection-dominated release [simulation case 10][b]	4653	27	4676	4.3	4883	1.6
Unretrieved Tank Waste Diffusion-dominated release [simulation case 11]	5614	8.7	5637	1.4	5839	0.50
Base Case Post-Retrieval [b]						
Retrieved Tank Residuals Advection-dominated release [simulation case 10][b]	4653	0.43	4676	0.05	4883	0.025
Retrieval leak (8,000 gal) [simulation case 1]	2082	0..82	2107	0.11	2324	0.055
Past tank leaks [simulation case 3]	2092	0.30	2117	0.05	2333	0.02
Past ancillary equipment leaks (UPR) [simulation case 4]	2117	0.68	2141	0.11	2355	0.04
Retrieved Tank Residuals Diffusion-dominated release [simulation case 11]	5614	0.14	5637	0.025	5839	0.012
Residuals in 244-CR vault and catch-tank release limited to diffusion [simulation case 11]	5614	0.003	5637	4.4 E-04	5839	1.6 E-04
Residuals in ancillary pipeline release limited to diffusion [Scaled simulation case 13]	4891	0.015	4925	2.5 E-03	5130	9E-04

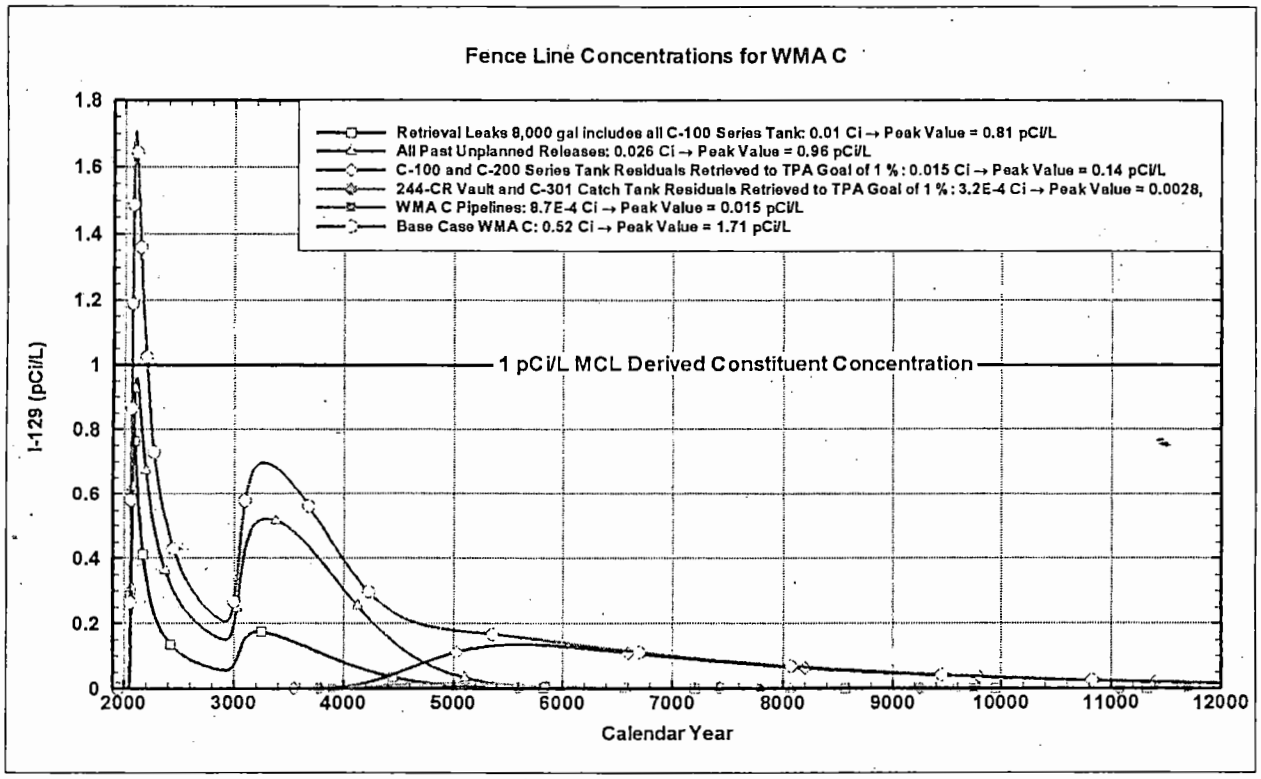
[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.

[b] Not part of the base case; only added for comparison purposes between release models.

UPR = unplanned release

WMA = waste management area

Figure 16. Iodine-129 Composite Waste Management Area C Fenceline Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks.



- **Nitrate** (Table 16 and Figure 17). For all sources and release models, the simulated peak concentration is below the MCL (45 mg/L, nitrate as nitrate). For the base-case composite analysis (Figure 17), the peak (0.8 mg/L) is approximately a factor of 50 less than the MCL with the hypothetical retrieval leaks contributing 80 % of the peak concentration. It should be noted that no sources came close to exceeding the MCL.

Table 16. Simulated Peak Concentrations[a] (mg/L) and Arrival Times (year) for Nitrate at Various Boundaries.

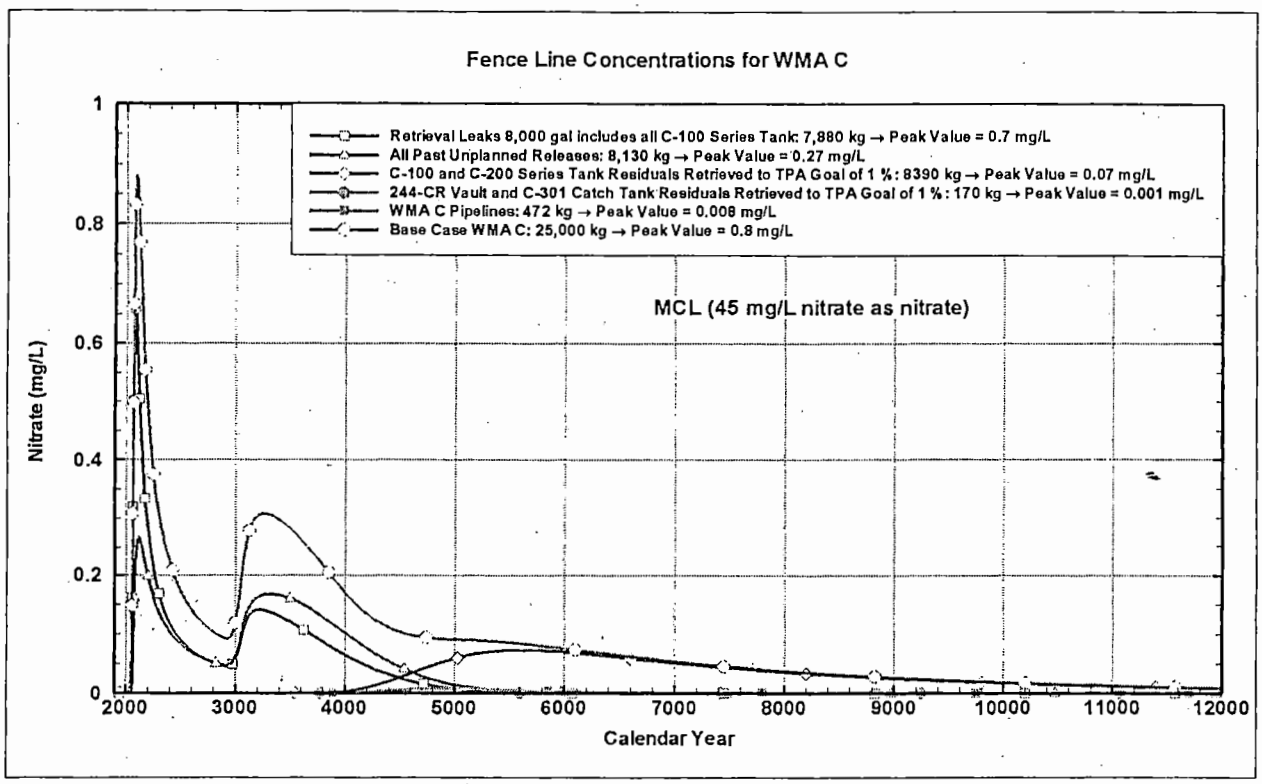
Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved Tank Waste Advection-dominated release [simulation case 10][b]	4653	11	4676	1.7	4883	0.64
Unretrieved Tank Waste Diffusion-dominated release [simulation case 11]	5614	3.5	5637	0.55	5839	0.20
Base Case Post-Retrieval[b]						
Retrieved Tank Residuals Advection-dominated release [simulation case 10][b]	4653	0.22	4676	0.03	4883	0.01
Retrieval leak (8,000 gal) [simulation case 1]	2082	0.66	2107	0.1	2324	0.05
Past tank leaks [simulation case 3]	2092	0.03	2117	4E-03	2333	1.4 E-03
Past ancillary equipment leaks (UPR) [simulation case 4]	2117	0.24	2141	0.04	2355	0.01
Retrieved Tank Residuals Diffusion-dominated release [simulation case 11]	5614	0.07	5637	0.01	5839	4E-03
Residuals in 244-CR vault and catch-tank release limited to diffusion [simulation case 11]	5614	0.0015	5637	2E-04	5839	8E-05
Residuals in ancillary pipeline release limited to diffusion [Scaled simulation case 13]	4891	0.008	4925	0.0013	~5130	~5E-04

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.

[b] Not part of the base case; only added for comparison purposes between release models.

~ = approximately
UPR = unplanned release
WMA = waste management area

Figure 17. Nitrate Composite Waste Management Area C Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks



- **Nitrite** (Table 17 and Figure 18). For all sources and release models, the simulated peak concentration is below the MCL (3.3 mg/L, nitrite as nitrite). For the base-case composite analysis (Figure 18), the peak (0.36 mg/L) is approximately one order of magnitude less than the MCL with hypothetical retrieval leaks account for approximately 60 % of the peak and ancillary equipment accounting for 30 % of the peak.

- **Chromium** (Table 18 and Figure 19). For the base-case composite analysis, the peak concentration (0.009 mg/L) is one order of magnitude less than the MCL (0.1 mg/L). For pre-retrieval residual waste, the advection-dominated release model has a peak concentration of 0.16 mg/L (Table 18), approximately a factor of 1.5 over the MCL; and diffusion-dominated release model has a peak concentration of 0.05 mg/L, which is at 0.5 of the MCL.

- **Uranium** (Table 19 and Figure 20). For all sources and releases (simulated with K_d = 0.6 mL/g, [*Hanford Contaminant Distribution Coefficient Database and Users Guide*, {PNNL-13895, Rev.1}]), did not result in concentrations above the MCL (0.03 mg/L) over the simulation time period regardless of the release mechanism or initial inventory. The source provides the greatest contribution to the total concentration is the hypothetical retrieval leak by the end of the simulation, and that concentration is a factor of 250 below the MCL. The next largest contributor is the unplanned releases which are a factor of approximately 3500 below the MCL. Uranium, primarily due to past leaks and retrieval leaks, does not arrive at the fenceline until approximately 8,000 years into the future. Future revisions of this document or will examine the sensitivity of the results to lower K_ds for uranium.

Table 17. Simulated Peak Concentrations[a] (mg/L) and Arrival Times (Year) for Nitrite at Various Boundaries.

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved Tank Waste Advection-dominated release [simulation case 10][b]	4653	5.3	4676	0.82	4883	0.3
Unretrieved Tank Waste Diffusion-dominated release [simulation case 11]	5614	1.7	5637	0.26	5839	0.1
Base Case Post-Retrieval [b]						
Retrieved Tank Residuals Advection-dominated release [simulation case 10][b]	4653	0.11	4676	0.02	4883	0.006
Retrieval leak (8,000 gal) [simulation case 1]	2082	0.26	2107	0.05	2324	0.01
Past tank leaks [simulation case 3]	2092	0.02	2117	0.0034	2333	0.0012
Past ancillary equipment leaks (UPR) [simulation case 4]	2117	0.12	2141	0.02	2355	0.0070
Retrieved Tank Residuals Diffusion-dominated release [simulation case 11]	5614	0.03	5637	0.005	5839	0.002
Residuals in 244-CR vault and catch-tank release limited to diffusion [simulation case 11]	5614	7E-04	5637	1E-04	5839	4E-05
Residuals in ancillary pipeline release limited to diffusion [Scaled simulation case 13][c]	4891	0.004	4925	6E-04	5130	2E-04

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.

[b] Not part of the base case; only added for comparison purposes between release models.

UPR = unplanned release
WMA = waste management area

Figure 18. Nitrite Composite Waste Management Area C Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks.

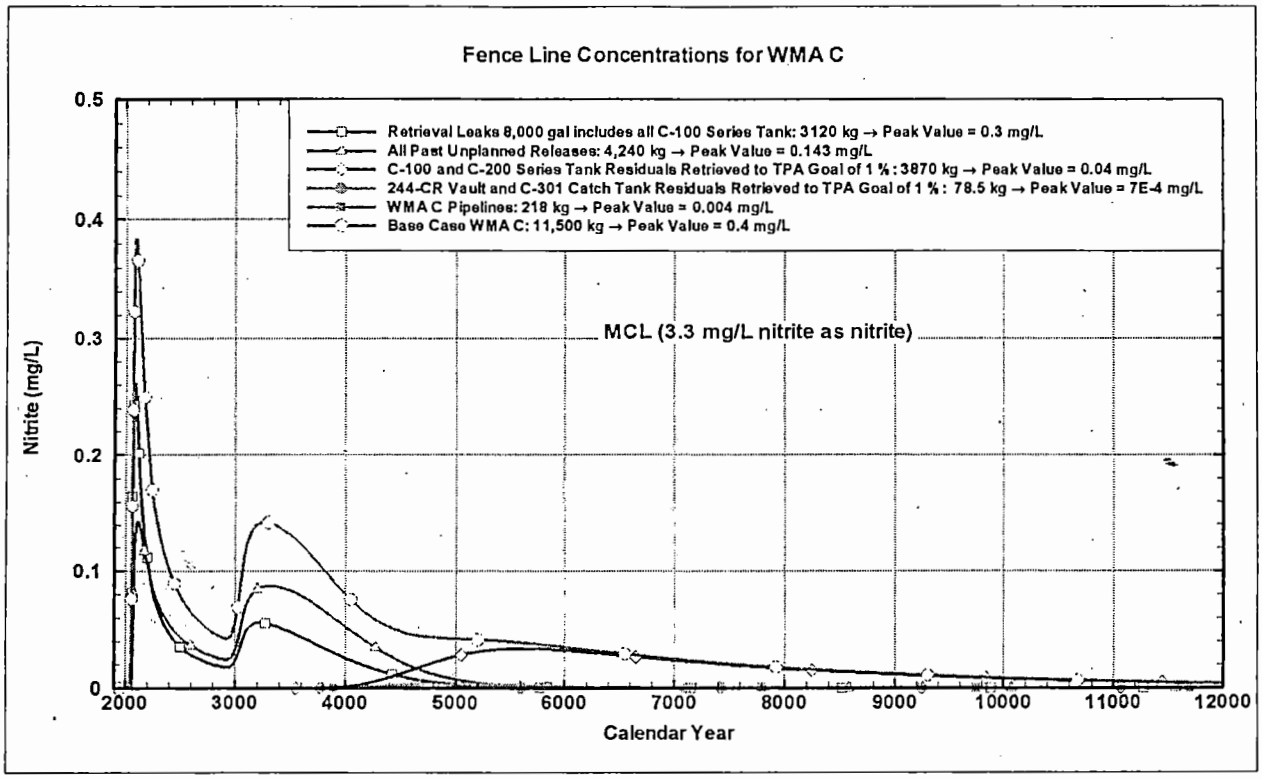


Table 18. Simulated Peak Concentrations a (mg/L) and Arrival Times (Year) for Chromium+6 at Various Boundaries. (2 Pages)

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
Pre-Retrieval Cases						
Unretrieved Tank Waste Advection-dominated release [simulation case 10] [b]	4653	0.16	4676	0.02	4883	0.009
Unretrieved Tank Waste Diffusion-dominated release [simulation case 11]	5614	0.05	5637	0.008	5839	0.003
Base Case Post-Retrieval [b]						
Retrieved Tank Residuals Advection-dominated release [simulation case 10] [b]	4653	0.003	4676	4E-04	4883	1E-04
Retrieval leak (8,000 gal) [simulation case 1]	2082	0.0064	2107	1E-03	2324	3E-04
Past tank leaks [simulation case 3]	2092	8E-04	2117	1E-04	2333	4E-05
Past ancillary equipment leaks (UPR) [simulation case 4]	2117	0.003	2141	5E-04	2355	2E-04

Table 18. Simulated Peak Concentrations a (mg/L) and Arrival Times (Year) for Chromium+6 at Various Boundaries. (2 Pages)

Simulation	WMA C Fenceline Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
Retrieved Tank Residuals Diffusion-dominated release [simulation case 11]	5614	0.001	5637	1.6E-04	5839	6E-05
Residuals in 244-CR vault and catch-tank release limited to diffusion [simulation case 11]	5614	2E-05	5637	3E-06	5839	1E-06
Residuals in ancillary pipeline release limited to diffusion [Scaled simulation case 13] [c]	4891	1E-04	~4925	2E-05	~5130	7E-06

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.
[b] Not part of the base case; only added for comparison purposes between release models.
[c] Scaled results are approximate; see discussion in text for scaling methodology.
~ = approximately
UPR = unplanned release
WMA = waste management area

Figure 19. Chromium Composite Waste Management Area C Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks.

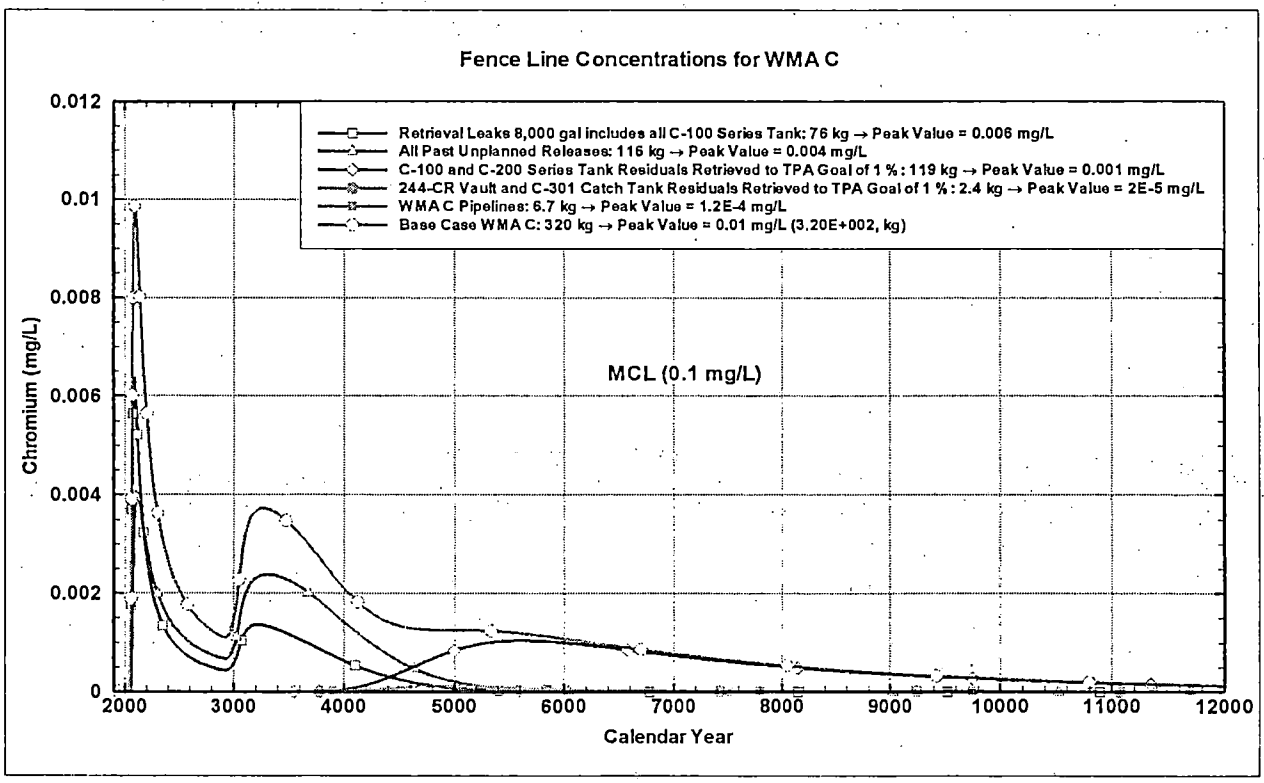
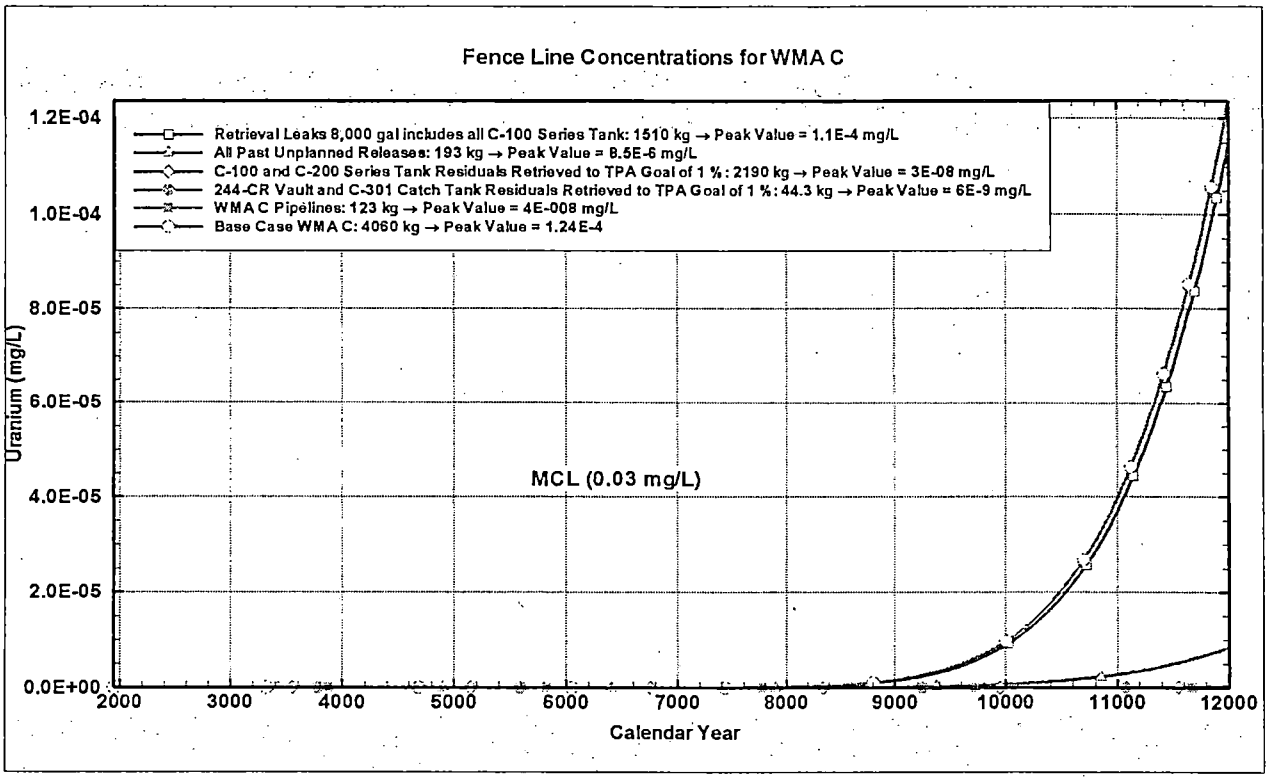


Table 19. Simulated Peak Concentrations[a] (mg/L) and Arrival Times (Year) for Uranium at Various Boundaries.

Simulation	WMA C Fence Line Boundary		Proposed Core Zone Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.
No-Action (i.e., no retrieval) Tank Residuals						
Unretrieved Tank Waste Advection-dominated release[b]	12000	3E-04	12000	1.6E-04	12000	<1 E-05
Unretrieved Tank Waste Diffusion-dominated release	12000	1.5E-05	12000	<1E-05	12000	<1 E-05
Base Case Post-Retrieval [b]						
Retrieved Tank Residuals Advection-dominated release[b]	12000	<1 E-05	12000	<1 E-05	12000	<1 E-05
Retrieval leak (8,000 gal)	12000	1.2E-05	12000	8E-05	12000	<1 E-05
Past tank leaks	12000	<1 E-05	12000	<1 E-05	12000	<1 E-05
Past ancillary equipment leaks (UPR)	12000	<1 E-05	12000	<1 E-05	12000	<1 E-05
Retrieved Tank Residuals Diffusion-dominated release	12000	<1 E-05	12000	<1 E-05	12000	<1 E-05
Residuals in 244-CR vault and catch-tank release limited to diffusion	12000	<1 E-05	12000	<1 E-05	12000	<1 E-05
Residuals in ancillary pipeline release limited to diffusion	12000	<1 E-05	12000	<1 E-05	12000	<1 E-05

[a] Solubility-limited release model results are not presented here because of considerable uncertainty about the applicability of this particular release model.
[b] Not part of the base case; only added for comparison purposes between release models.
UPR = unplanned release
WMA = waste management area

Figure 20. Total Uranium Composite Waste Management Area C Results for Past Unplanned Releases, Tank Residuals (Diffusion-Dominated Release Model) and Retrieval Leaks.



4.3.3 Downgradient Concentrations

As contaminants move through an aquifer, the concentration decreases because of adsorption, dispersion, and diffusion processes. Adsorption refers to the process of contaminants binding to soil particles rather than continuing to travel in the groundwater. Dispersion and diffusion refer to the processes of contaminants spreading in the aquifer and consequently becoming more dilute. Dispersion occurs because the contaminants travel along different paths and at different velocities in the aquifer. The different paths and velocities, often referred to as the aquifer tortuosity, result from the structure of the porous media comprising the aquifer deflecting and diverting the water from a straight line. Diffusion occurs across concentration gradients as contaminants move from areas of high to low concentration. To estimate the concentration of contaminants at locations downgradient from a source, Domenico and Schwartz (1990) developed a three-dimensional analytical equation. The contaminant transport properties required to estimate the concentration of a plume through an aquifer include contaminant-specific distribution coefficients, which describe a contaminant's affinity to adsorb to soil particles, and soil bulk density, effective porosity, and longitudinal and transverse dispersivity coefficients. A description of the model equation and the properties used to simulate the transport of the contaminants through the aquifer is contained in *2003 Initial Assessments of Closure for the C Tank Farm: Numerical Simulations* (PNNL-14334).

In addition to the BTCs presented in Sections 4.3.1 and 4.3.2, the analytical stream tube solution (Domenico and Schwartz 1990) was used to model groundwater flow and transport to various

points of calculation downgradient from the WMA. The results from the stream tube model are summarized in Tables 14 through 19. The concentrations in groundwater are expected to attenuate as the contaminants move from the WMA C fenceline. For the base case model (Table 13), the results indicated that none of the COCs are expected to be found at concentrations exceeding their respective MCL or MCL derived constituent concentration at the proposed core boundary (2,900 m from the WMA C fenceline) or at the Columbia River (14,300 m from the WMA C fenceline), regardless of the inventory or release mechanism.

At the currently proposed core zone boundary for the 200 Areas, only the concentration of iodine-129 resulting from the advection- and diffusion-dominated releases without retrieval (4.3 pCi/L and 1.4 pCi/L, respectively [Table 15]) and the concentration of technetium-99 resulting from the advection-dominated release case without waste retrieval (1,520 pCi/L [Table 14]) may exceed the MCL derived constituent concentration. Including the effects of inventory reduction associated with retrieval to the HFFACO limits for the advection- and diffusion- dominated releases reduce the predicted iodine-129 concentrations to 0.05 pCi/L and 0.025 pCi/L (Table 15), respectively. For technetium-99, concentration for the advection-dominated release is reduced to 32 pCi/L. When calculations are extended to the river, the calculated concentrations of all of the contaminants for all of the release and inventory cases decrease to levels below their respective MCL and MCL derived constituent concentration levels, except for iodine-129 (1.6 pCi/L, pre-retrieval inventory with advection-dominated release [Table 15]). As the uranium releases did not result in concentrations above the MCL at the fenceline, uranium is not expected to impact more distant points.

4.4 SENSITIVITY RESULTS

Selected variables were analyzed to identify the degree of sensitivity in WMA C fenceline groundwater concentration estimates to variations in input values. Sensitivity refers to the relative incremental change in the result of the estimate caused by an incremental change in a given input value for a selected system element. System elements are considered to be sensitive if variations in input values (within the range of realistic possibility) result in substantial variation in the estimated result. System elements that exhibit small changes in results when input values vary over the range of possible inputs are considered to be nonsensitive. The following variable inputs were identified for sensitivity analysis:

- Residual waste inventory in tanks (current BBI or retrieval to 360 ft^3 [30 ft^3 for 200-series tanks])
- Residual waste release mode (advection- or diffusion-dominated release)
- Past leak contribution to cumulative effects (presence and absence of past leaks)
- Ancillary equipment residual waste inventory (presence/absence of residual waste volume with estimated inventory)
- Computational approach (use of simulated unit source results from a single source location, tank C-112, as a surrogate to represent all source locations in WMA C)
- Aquifer hydraulic conductivity and resultant groundwater flow velocity
- Distribution coefficient of waste constituents in the vadose zone and aquifer system.

The effect of these input variations on groundwater constituent concentrations was selected for the sensitivity analysis because all of the long-term human health risk metrics are derived from the constituent concentration in groundwater downgradient of the WMA. The results of selected sensitivity analyses are shown in Figures 21 and 22. The sensitivities analyzed and their relative magnitudes are presented in Table 20.

Figure 21. Waste Management Area C Simulated Groundwater Technetium-99 Concentration Resulting from Residual Tank Waste as Modified by Variations in Inventory (Retrieval) and Waste Release Mode.

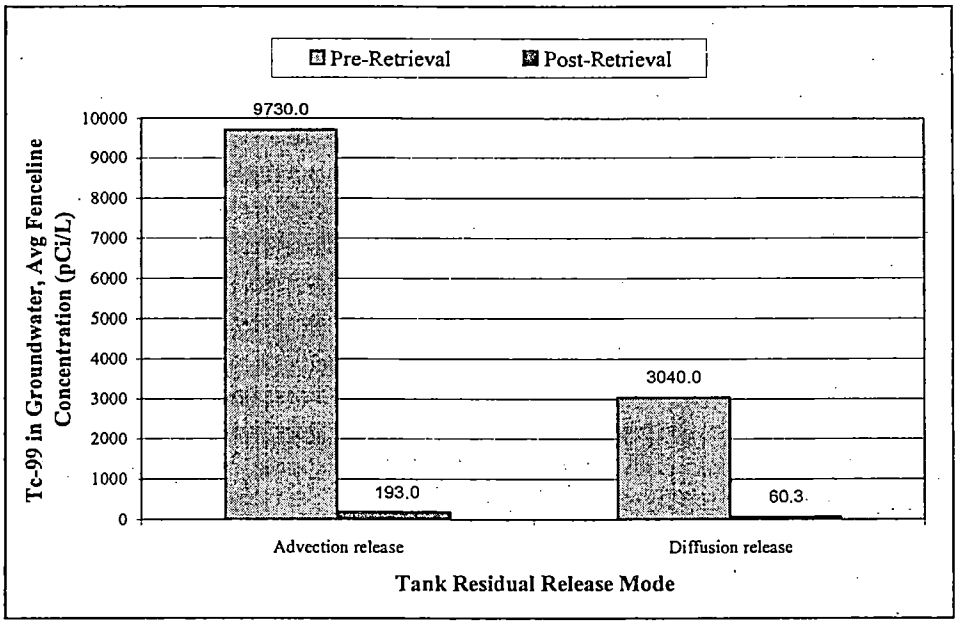


Figure 22. Waste Management Area C Simulated Technetium-99 in Groundwater Resulting from Addition of Past Releases to Residual Tank Waste as Modified by Variations in Tank Residual Release Mode for Unretrieved and Post-Retrieval Inventory.

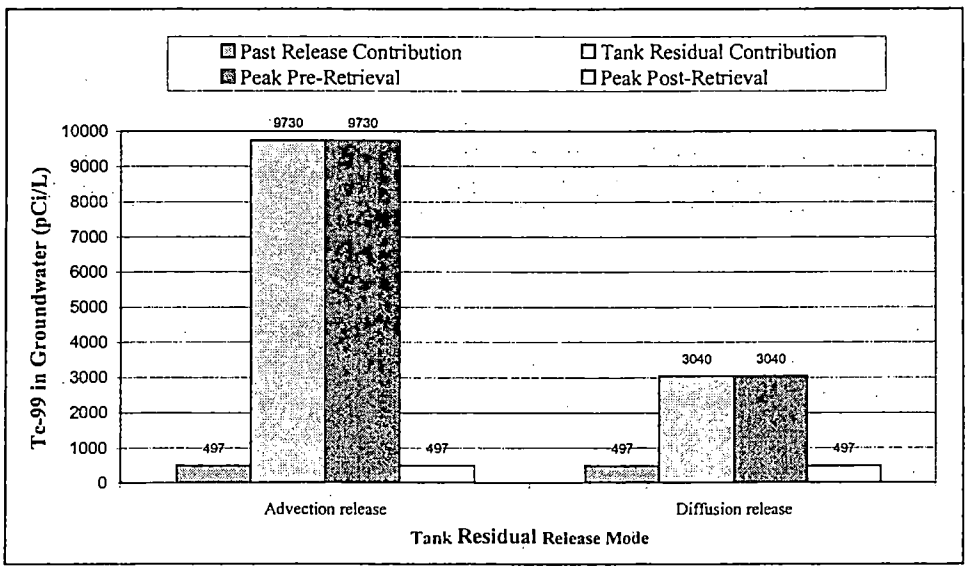


Table 20. Summary of Sensitivity Analysis of Impacts of Selected Input Parameters on Resultant Base Case WMA C Fenceline Groundwater Concentrations.

Parameter Analyzed	Type of Sensitivity [a]	Approximate Magnitude of Sensitivity	Apparent Conservatism of Approach Presented
Residual tank inventory after retrieval	Direct relationship	Retrieval to HFFACO maximum goal reduces concentration by factor of about 50.	Conservative if retrieval exceeds goal, nonconservative if retrieval does not meet goal.
Time to release waste constituents from residual tank waste	Direct relationship	Diffusion-dominated release from waste form reduces concentration by factor of about 3 over advection-dominated release.	Conservative if actual waste release is slower than diffusion-limited case, nonconservative if actual release is faster than diffusion case.
Contribution of past leaks in WMA C	Direct relationship	Past leaks account for approximately half of the concentration after retrieval of tank waste.	Conservative. Estimated major past leak inventory is included in quantitative risk estimates.
Contribution of ancillary equipment residual inventory	Direct relationship	Magnitude of sensitivity depends on waste inventory. Currently there is no sound basis to estimate inventory located in major ancillary equipment components.	Estimated ancillary equipment inventory included in quantitative risk estimates. No basis to assess conservatism due to lack of inventory data for ancillary equipment.
Computational extrapolation of a single unit source location to represent all sources in WMA C	Not sensitive	Not sensitive	Not sensitive: Approach appears representative.
Aquifer gradient and hydraulic conductivity	Inverse relationship	As aquifer gradient or hydraulic conductivity increase, fenceline concentration decreases at a rate of approximately 1 to 1 (e.g., 10x increase in gradient yields 10x decrease in concentration.	Conservative. Aquifer hydraulic conductivity may be as much as one order of magnitude higher than estimated.
Waste constituent Bulk Distribution Coefficient	Inverse relationship	As K_d increases from 0.0, fenceline peak concentrations decrease by about 5% for each 0.01 increase in K_d within a small range of values near zero.	Conservative. Low K_d values were selected for constituents of interest from ranges of measured and/or estimated values.

[a] Direct = resultant concentration increases as input parameter value increases.
Inverse = resultant concentration decreases as input parameter value increases.

HFFACO = *Hanford Federal Facility Agreement and Consent Order*.

K_d = distribution coefficient.

WMA = waste management area

Waste Retrieval and Post-Retrieval Tank Inventory: The inventory of target waste constituents contained in residual waste in the tanks is a highly-sensitive parameter. As shown in Figure 11, a substantial reduction in resultant groundwater concentration for technetium-99 (approximately two orders of magnitude) is attained by retrieving waste to the HFFACO goal of 1 % (i.e., achieve a maximum residual of 360 ft^3 in the 100-series tanks and 30 ft^3 in the 200-series tanks). This reduction is apparent for each of the three selected tank residual release modes. The magnitude of reduction in resultant groundwater concentration is a function of both the volume of waste in each tank and the concentration of constituents in the tank waste.

Residual Tank Waste Release Mechanism: The mode of release of the tank residual waste constituents is the second most sensitive input parameter. Within a wide range of relatively rapid release scenarios, the peak concentration is not sensitive when release occurs within 1,000 years of site closure. As shown in Figure 21, the resultant peak concentration is reduced by approximately a factor of three (before and after waste retrieval) by a diffusion-limited release mode compared with the advection-dominated release.

Past Leaks, Unplanned Releases: Based on evaluation of the four past releases for which preliminary inventory estimates were established, the resultant groundwater concentration of technetium-99 following retrieval of tank wastes to 360 ft^3 residual was found to be highly sensitive to the effects of past leaks. As shown in Figure 22, the past leak element contributed to the majority of the cumulative resultant concentration for technetium-99 in groundwater for both tank residual release modes.

Residual Waste in Ancillary Equipment: As discussed in Sections 4.4.1 and 4.4.2, long-term groundwater impacts are highly sensitive to the waste inventory remaining in the WMA. Estimates for residual ancillary equipment waste inventory contain substantial uncertainty because retrieval of waste from ancillary equipment, such as the C-301 catch tank, which is currently classified as a miscellaneous underground storage tank (MUST), is not yet formally linked to tank waste retrieval and WMA closure.

Detailed inventory data are unavailable for ancillary equipment components. A sensitivity analysis of potential contribution to long-term groundwater impacts from ancillary equipment residues used the following set of assumptions for selected component inventory:

- 244-CR vault tanks are assumed to be retrieved to residual volumes similar to those required for the 100- and 200-series tanks. The residual inventories are calculated as the product of the residual volume and the averaged contaminant-specific contribution from the combined contents of the 100- and 200-series tank solids.

- C-301 catch tank is assumed to be retrieved to a residual volume similar to that of the 200-series tanks. The residual inventories are calculated as the product of the residual volume and the averaged contaminant-specific contribution from the combined contents of the 100- and 200-series tank solids.

- WMA C piping system comprises multiple layers of waste transfer piping that were installed within WMA C with new piping being installed as old pipes were found to leak, became plugged, or otherwise became unserviceable. An estimated total volume of

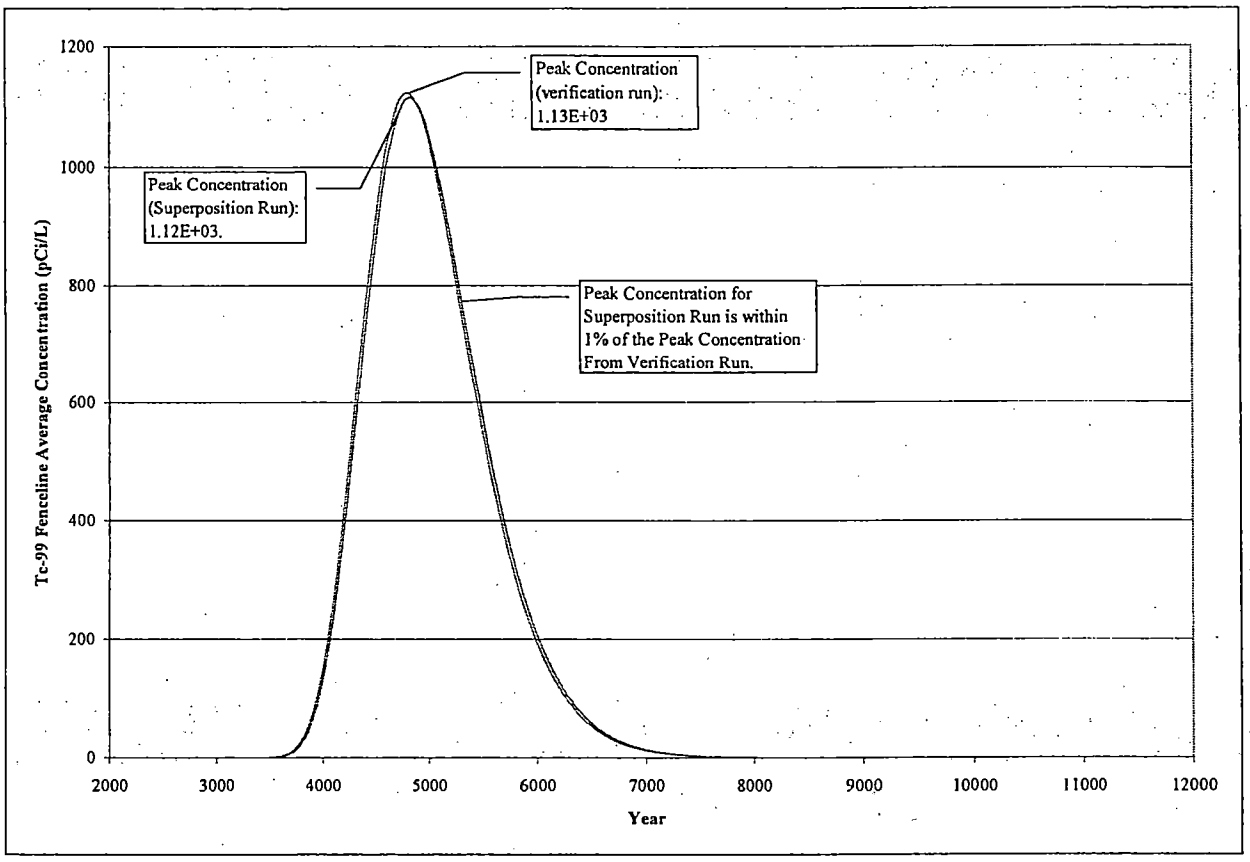
1,000 ft^3 of waste transfer pipe was assumed for this analysis. To estimate a residual waste inventory related to the piping system, 25% of the pipe (250 ft^3) was assumed to be plugged and filled with residual solids whose contaminant concentrations were calculated from the combined contents of the 100- and 200-series tank waste solids. The ancillary equipment inventory estimate is very conservative. Even using this estimate, the modeling results indicated that the risk associated with residual piping is minimal compared to the risk posed from other sources.

- WMA C diversion boxes were designed to drain to waste storage tanks; spill and leaks within the diversion boxes were routed to the C-301 catch tank. Although substantial surface contamination is expected to remain in the diversion boxes, no substantial quantity of residual waste is attributed to them for this analysis.

Under the defined simulation conditions, tank ancillary equipment effects on groundwater are observed at the same time as the 100- and 200-series residual tank waste. Pipeline ancillary equipment impacts on groundwater are observed approximately 600 years before the 100- and 200-series residual tank waste. Including the estimated retrieved waste volume in ancillary equipment results in approximately 10% increase in the peak concentration after 4500 AD.

Extrapolation of Single Unit Source to Multiple Sources (Superposition Approach): Sensitivity impacts of a fundamental computational approach used in estimation of cumulative impacts of multiple sources in the WMA were evaluated. The initial approach to extrapolation of simulated fate and transport results was based on the concept of super-positioning. This involves performing transport simulations using unit sources loaded into only one source location in the WMA conceptual model. The source location selected initially was tank C-112, located in the most upgradient row of tanks in the WMA. Applying the simulation from a single location to multiple locations via super-positioning provides for increased computational efficiency in the simulations, thus providing the project with latitude to perform additional simulation cases for sensitivity and uncertainty analysis. Verification tests for all 14 cases were performed in which sources were present at all four tank locations in one cross-section (i.e., the row containing tanks C-112, C-109, C-106, and C-103) and compared against the case with source for tank C-112 only. The verification tests included simulations for $K_d = 0$ and 0.03. The results for $K_d = 0$ are presented below. Comparison of the results of resultant fenceline concentrations of technetium-99 in groundwater using the superposition and verification runs for WMA C indicate a difference of less than 1% in peak arrival time and peak concentration. The results of the comparison are shown in Figure 23.

Figure 23. Cumulative Waste Management Area C Fenceline Average Technetium-99 Concentration Comparison Between Verification Run and Superposition (C-112) Run (Case 05, Post-Retrieval Inventory, $K_d = 0.0$)



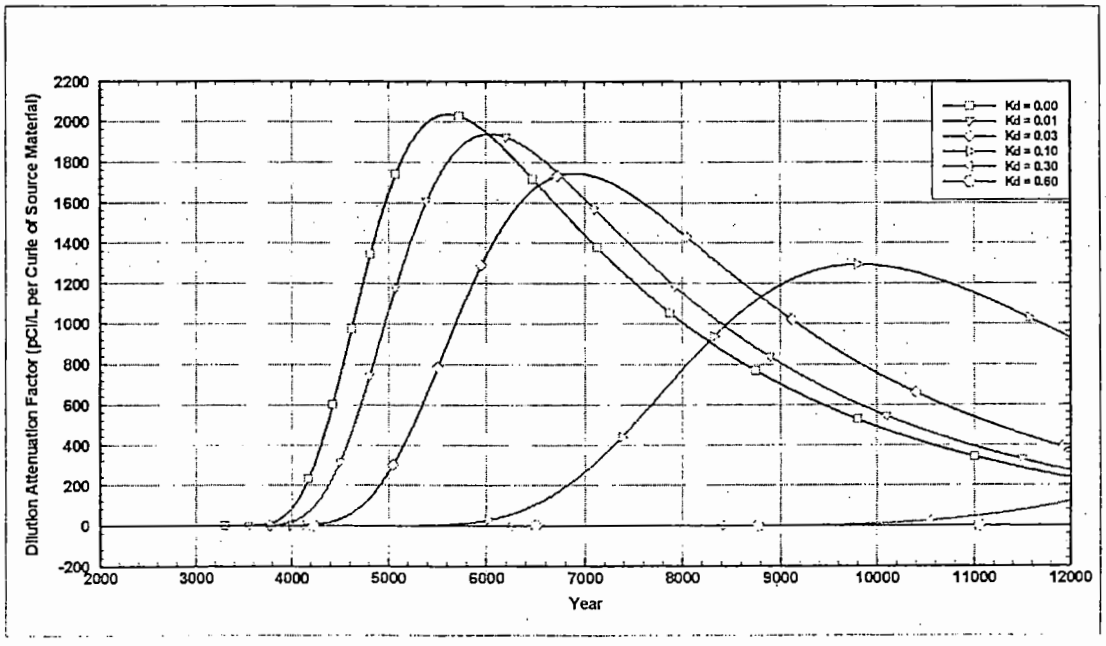
Aquifer Saturated Hydraulic Conductivity: The concentration of constituents in groundwater projected to the WMA C fenceline is also sensitive to the velocity of groundwater flowing beneath the WMA. Under the site's arid conditions, the rate at which constituents migrate from near-surface source terms to the aquifer at the water table is much slower that the rate at which those constituents travel from the point of aquifer entry to the downgradient fenceline. The groundwater velocity is a function of the hydraulic gradient and hydraulic conductivity of the underlying aquifer. The aquifer gradient (i.e., 4.5×10^{-4} m/min.) selected for use in the transport simulations presented in this document was extrapolated from Hindcast water table calculations and was selected to represent expected post-Hanford groundwater conditions at WMA C. The current gradient is very flat as a result of the dissipation of the historical groundwater mound from B Pond.

The aquifer hydraulic conductivity value used in the simulations was selected from typical formation values at the Hanford Site. The actual hydraulic conductivity of the aquifer underlying WMA C is not defined. Existing groundwater monitoring wells were not extended through the full thickness of the aquifer, so description of the formation below the water table is not available. Aquifer hydraulic conductivity may be as much as one order of magnitude higher that the estimate used in the simulations.

The estimated groundwater concentration beneath the WMA is inversely proportional to the groundwater gradient and hydraulic conductivity if other inputs are fixed (i.e., as resultant groundwater velocity increases, fluid volume through the aquifer system increases, and the resultant constituent concentration decreases). Comparative simulation runs indicate that calculated fenceline groundwater concentrations at WMA C will decrease by nearly an order of magnitude for each order of magnitude increase in aquifer hydraulic conductivity. The comparison simulations were done using saturated hydraulic conductivity values of 4.8 and 50 m/day. The 50 m/day value was selected for use in the quantitative risk estimates for this risk assessment. Measured hydraulic conductivity of the aquifer at other locations in the 200 East Area are as high as 500 m/day. The estimated WMA C fenceline concentrations, and resultant performance metrics, are, therefore, expected to be conservative (i.e., biased high) by the application of the selected hydraulic conductivity over the course of the simulation period.

Constituent K_d Assignment. The K_d is used to describe the relative interaction of constituents with the geologic materials through which the constituents are transported from the point of release to the point of measurement. The movement of constituents with higher K_d values is more highly retarded than constituents with relatively lower K_ds. Highly mobile constituents exhibit K_d values near zero for the geologic formations in the simulation domain. As K_d values for constituents increase in the current simulations, the resultant peak concentration in groundwater at the fenceline decreases in magnitude and occurs later in time relative to the peak of non-retarded (i.e., $K_d = 0$) constituents. The relative effect of varying K_d of constituents is shown in Figure 24. This figure displays the relative peak effects in terms of dilution-attenuation factors derived from the transport simulations using unit sources (i.e., source of 1 Ci) for surrogate constituents with K_d ranging from zero to one. Note that constituents with K_d greater than 1.0 for the geologic materials in the conceptual model do not appear at the fenceline during the 10,000-year simulation period.

Figure 24. Relative Effects of Variations in Distribution Coefficient on Resultant Constituent Peak Groundwater Concentration and Arrival Time for Residual Waste Constituents.



Constituents of interest for this risk assessment exhibit a range of K_ds under varying chemical conditions. The results of the risk assessment quantitative estimates is sensitive to assignment of K_d to COCs for the following reasons:

- As the K_d for a single constituent increases, the resultant peak groundwater concentration decreases.
- Multiple constituents with the same, or similar, K_ds produce additive effects during the time period that they are present in mixtures in the groundwater.

The magnitude of effects of change in peak concentration effects and peak arrival time are shown in Table 21.

Table 21. Summary of Relative Effects of Variability in Constituent Distribution Coefficient.

Constituent K_d (mL/g)	Peak DAF[a] ([pCi/L]/Ci)	First Arrival Time (year AD)	Peak Arrival Time (year AD)	Relative Change in Peak DAF from $K_d = 0$
0.00	2105	3199	5614	0
0.01	2005	3299	6042	- 5%
0.03	1804	3496	6896	-14%
0.10	1337	4199	9819	-35%
0.30	124[a]	6283	12000[a]	-94%
0.60	0.03[a]	9499	12000[a]	-99.9%
1.00	0.00[a]	Does not appear	Does not appear	Not applicable

[a] Simulated DAFs for constituents with K_ds of 0.30 and greater are still increasing at the end of the 10,000-year simulation period. Constituents with K_ds of 1.00 and greater do not arrive in the groundwater at the WMA C fenceline during the simulation period. Individual Dilution Attenuation Factors (DAF) represent the ratio between the initial concentration of the contaminant in the tank or vadose and the resulting concentration in the aquifer at some groundwater assessment point. As contaminants move through the vadose zone or an aquifer, the concentration decreases because of adsorption, dispersion, and diffusion processes, as well as (in some cases) environmental and radioactive decay.

DAF = dilution-attenuation factor
K_d = distribution coefficient
WMA = waste management area

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5.0 HUMAN HEALTH AND DOSE ESTIMATION

A variety of human health and dose estimates will be completed as part of this risk evaluation. Specific exposure scenarios, summarized below and described in greater detail in HNF-SD-WM-TI-707 Rev. 3, are constructed to estimate human health impacts from exposure to radionuclides and harmful chemicals present at a waste site that allows comparison with specific regulatory requirements (e.g., performance objectives in Table 2). These scenarios have been evaluated in numerous performance and risk assessment activities completed previously at the Hanford Site and have been extensively reviewed by the Hanford Site regulatory community. Quantitative risk and dose estimates for selected exposure scenarios are presented in Section 7.0 based on the simulated constituent concentrations presented in Section 4.3

Exposure scenarios are organized as a function of water infiltration and receptor location. Water infiltration is divided into two basic categories. The first category assumes very limited contact between water and waste, thereby preventing groundwater contamination from the waste source in question (e.g., the no-water infiltration case). Typically, an engineered barrier system is assumed to limit waste/water interactions. The second category assumes sufficient water infiltration to leach waste and drive contaminants into the underlying aquifer. In this analysis, infiltration from natural sources is assumed and effective infiltration rates are determined from the combination of average precipitation rates mitigated by engineered cover infiltration controls (e.g., the low water infiltration case). Potential receptors are either at the waste site (i.e., an onsite receptor) or at least 100 m away from the waste site (i.e., an offsite receptor). The onsite receptor is an inadvertent intruder who is deterred from entering the site for at least 100 years and is exposed primarily by contact with the waste. The offsite receptor can be exposed anytime after site closure and is exposed primarily by using contaminated groundwater.

Table 22 is a general summary of exposure scenarios that have been analyzed in Hanford Site risk and performance assessments in terms of onsite versus offsite receptors. Table 23 summarizes exposure scenarios for no-water infiltration cases. The first two receptors do not directly exhume waste but are exposed in various ways to radionuclides that reach the surface by vapor migration. The second two receptors are exposed when they exhume waste. Table 24 summarizes exposure scenarios for low-water infiltration cases. Only offsite receptors are considered and all exposures stem from the use of contaminated groundwater. Both individuals and area populations can be considered in offsite receptor calculations.

Depending on the scenario, up to three types of health impacts are calculated. These include dose from radionuclide exposure, ILCR from radionuclide, ILCR from carcinogenic chemical exposure, or toxic health effects (quantified as Hazard Index) from exposure to noncarcinogenic chemicals. Dose from radionuclide exposure (mrem/yr) is compared to performance objectives defined in DOE O 435.1[6]. ILCR from radionuclide and carcinogenic chemicals and the Hazard Index from noncarcinogenic chemicals are compared to the health standards (cancer risk of 10^{-5} and a unit value of 1, respectively) in WAC 173-340. Dose, ILCR, and Hazard Index are

[6] *Implementation Guide* for use with DOE M 435.1-1, July 9, 1999, Chapter IV, Section IV.P.(1) through IV.P.(4).

calculated as the product of waste concentrations in soil, air, or water (as appropriate) and the appropriate unit conversion factor (e.g., mrem per pCi/L for dose).

To provide a comprehensive estimate of potential human health effects that addresses all performance objectives in Table 2, a total of eight scenarios have been considered in this analysis. The scenarios and type of human health effects considered include the following:

- **Onsite Receptors (i.e., within the WMA)** – Two scenarios are considered, the well driller and the post-intrusion resident. Both are exposed to contaminated soils resulting from drilling a well within the WMA. Dose by radionuclide exposure is calculated for comparison with DOE O 435.1[7] inadvertent intruder performance objectives. Intruder scenarios were not considered in this document. However, in the future, DOE Order 435.1 based intruder calculations will be provided to Ecology as part of a performance assessment. Based on preliminary discussions on implementing the recently proposed TPA Closure Process, performance assessments will replace risk assessments. The performance assessments will be designed to meet DOE, Ecology, and EPA's needs in this area. The performance assessment will become a central document in the effective integration of each agencies regulations and guidelines. The performance assessment document's contents will generally follow the DOE Order 435.1 but with modifications based on local discussions among Ecology, EPA, and DOE.

- **Offsite Receptors (i.e., outside the WMA)** – Six scenarios are considered. The all pathways farmer lives 100 m downstream of the waste site and uses contaminated well water. Dose by radionuclide exposure is calculated for comparison with general public protection performance objectives in DOE O 435.1[8]. The Native American uses contaminated well water at the WMA C fenceline or Columbia River water and additional cultural activities increase exposure for the same amount of environmental contamination compared to the non Native American resident. Dose, ILCR, and Hazard Index are calculated for comparison with general public protection performance objectives in DOE O 435.1[9] and WAC-173-340. The final four scenarios are defined in DOE/RL-91-45, *Hanford Site Risk Assessment Methodology*, and include the industrial worker (industrial scenario), the recreational shoreline user (the recreational scenario), the resident (the resident scenario), and the subsistence farmer (the agricultural scenario). Of these, risk calculations are not presented in this analysis for the recreational user. Dose, ILCR, and Hazard Index to the receptor are calculated for radionuclides and chemicals that contaminate groundwater.

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[7] *Implementation Guide* for use with DOE M 435.1-1, July 9, 1999, Chapter IV, Section IV.P.(1) through IV.P.(4).

[8] See footnote 6

[9] See footnote 6.

Table 22. General Features of Performance Assessment Exposure Scenarios.

Feature	Onsite Receptor	Offsite Receptor
Time delay following site closure	No less than 100 years	Any time after site closure
Receptor location	Directly over the waste disposal site	No closer than 100 m from the edge of the buried waste
Sources of exposure	Gases and vapors that migrate upward from the waste Direct radiation exposure Well water Exhumed waste	Gases and vapors carried by the wind to the offsite location Well water
Exposure scenarios	Well driller – person actually drilling through the waste Residential – person living near the well spreads soil cuttings from well into a small garden Farmer with rural pasture for dairy spreads soil cuttings from well into a pasture Commercial farmer spreads soil cuttings from well into a field for growing a food crop	Industrial – people working at some commercial enterprise Recreational – people who spend time near the site doing typical recreational activities Residential – person living near the well Farmer – subsistence farming operation that provides a portion of the individual diet (includes All-Pathways Farmer) Native American Indian

Table 23. Exposure Scenarios for the No-Water Infiltration Case

Offsite Farmer – Gas/vapor emanations from the disposal site are carried downwind to a subsistence farm
▸ Inhalation of plume ▸ Ingestion (plants and animals) ▸ External radiation exposure from plume ▸ Dermal absorption from air
Onsite Resident – Gas/vapor emanations into the basement of a residence located over the disposal site
▸ Inhalation (higher concentrations in a dwelling) ▸ External radiation exposure (from buried waste and air) ▸ Dermal absorption (from air)
Intruder – Individual present while a well is being drilled through the waste disposal site
▸ Inhalation (resuspended dust and gaseous emissions) ▸ Ingestion (trace amounts of soil) ▸ External radiation exposure ▸ Dermal absorption (contact with soil)
Post-Intrusion Resident – Spreads the exhumed waste into a vegetable garden
▸ Inhalation (resuspended dust and gaseous emissions) ▸ Ingestion (trace amounts of soil and garden produce) ▸ External radiation exposure (working in garden) ▸ Dermal absorption (contact with soil)

Notes: "Dermal absorption" refers to materials on the skin being absorbed into the body by passage through the skin. The first scenario applies any time after site closure, while the other 3 require a delay of at least 100 years before they can occur.

Table 24. Exposure Pathways for the Low-Water Infiltration Case

(1) Drinking the well water (also cooking with it)
▸ Ingestion
(2) Showering and bathing with the well water
▸ Inhalation (sprays) ▸ Ingestion (small amounts) ▸ External radiation exposure (immersion) ▸ Skin absorption (contact with water)
(3) Irrigating a garden
▸ Inhalation (sprays and resuspended dust) ▸ Ingestion (produce and trace amounts of soil) ▸ External radiation exposure (while in garden) ▸ Skin absorption (contact with soil)
(4) Drinking water for house pets and livestock
▸ Ingestion (eggs, poultry, milk) ▸ External radiation exposure (proximity to animal)
(5) Irrigating livestock pastures
▸ Inhalation (sprays and resuspended dust) ▸ Ingestion (beef and milk) ▸ External radiation exposure (while in pasture)
(6) Sweat lodge/wet sauna
▸ Inhalation (steam) ▸ Skin absorption (contact with steam) ▸ External radiation exposure (soil, walls, steam)

5.1 EXPOSURE SCENARIOS, MEDIA, AND PATHWAYS

The exposure scenarios, media, and pathways selected for the Hanford tank waste risk assessments given in HNF-SD-WM-TI-707 Rev. 3 are shown in Tables 25 and 26. Table 25 summarizes the exposure pathways for the typical performance assessment scenarios. There are eight scenarios presented in Table 25. The first four are the waste intruder cases, namely, the well driller and the post-intrusion residents. The next four are individuals exposed to a contaminated water source, either a well to groundwater or the Columbia River.

The intruder scenarios (the Well Driller, Suburban Garden, Rural Pasture, and Commercial Farm) consider only the impact of radionuclides. For the Well Driller, the total effective dose equivalent (TEDE) is calculated based on a unit concentration averaged over all the material removed from the well hole. For the other post-intrusion cases, the TEDE is calculated during the first year after the well is drilled. The dose is based on a unit quantity of activity removed from the well and spread on the ground in either a garden, a cow pasture, or an agricultural field.

The next two exposure scenarios have individuals who are users of contaminated water. The contaminated water may be obtained from either a well or the Columbia River. When the Columbia River is the source of contaminated water, the risk calculations include the fish pathway and exposure to shoreline sediments. Otherwise, they are identical. This situation occurs long in the future, when the hazardous materials have migrated into the groundwater and the Columbia River. The two individuals are the All Pathways Farmer and the Native American. The All Pathways Farmer is a representative average individual who grows much of his own food. His intakes of food and water, for example, are population averages. The Native American represents a bounding individual, particularly with regard to fish consumption.

Table 26 summarizes the exposure scenarios, and media and exposure pathways for the HSRAM scenarios (DOE/RL-91-45 Rev 3) used to assess human health risks associated with specific waste disposal options. The scenarios are consistent with EPA guidance and the Tri-Party Agreement. The final two columns in Table 26 also shows the exposure pathways used for the State of Washington groundwater and surface water cleanup calculations (WAC 173-340 Part VII -- Cleanup Standards). Method B is a residential setting, while Method C uses an occupational setting.

Table 25. Exposure Pathway Summary for Standard Performance Assessment Scenarios.

←Media	Exposure Scenarios →	Standard Performance Assessment Exposure Scenarios							
		Waste Intruders				All Pathways Farmer		Native American	
	Exposure Pathways ↓	Driller	Suburban Garden	Rural Pasture	Com-mercial Farm	GW	River	GW	River
Water	Ingestion					●	●	●	●
	Vapor Inhalation					●	●	●	●
	Shower, dermal					●	●	●	●
	Swimming, dermal								●
	Sweat Lodge, inhalation							●	●
Shore Sediments	Ingestion						●		●
	Inhalation								
	Dermal Contact						●		●
	External Radiation Dose						●		●
Soil	Ingestion	●	●	●	●	●	●	●	●
	Inhalation	●	●	●	●	●	●	●	●
	Dermal Contact					●	●	●	●
	External Radiation Dose	●	●	●	●	●	●	●	●
	Tritium Vapor Inhalation		●			●	●	●	●
Food Chain	Garden Produce		●			●	●	●	●
	Grains								
	Beef & Milk			milk only		●	●	●	●
	Poultry & Egg					●	●	●	●
	Fish						●		●
	Wild Game								●

The annual total effective dose equivalent (TEDE) (in mrem) is calculated for all of the exposure scenarios shown on this table. Radiological dose is the only risk metric used for the waste intruders. The other exposure scenarios (All-Pathways and Native American) also include ILCR from a lifetime exposure to both radionuclides and chemicals, and Hazard Index for non-radioactive chemicals.

Table 26. Exposure Pathway Summary for HSRAM and MTCA Scenarios.

←Media	Exposure Scenarios →	Hanford Site Risk Assessment Methodology (HSRAM)							WAC 173-340	
		Industrial	Recreational		Residential		Agricultural		MTCA B & C	
	Exposure Pathways↓		GW	River	GW	River	GW	River	GW	River
Water	Ingestion	•	•	•	•	•	•	•	•	•
	Vapor Inhalation	•	•	•	•	•	•	•		
	Shower, dermal	•	•	•	•	•	•	•		
	Swimming, dermal			•		•		•		
	Sweat Lodge, inhalation									
Shore Sediments	Ingestion			•		•		•		
	Inhalation									
	Dermal Contact			•		•		•		
	External Radiation Dose			•		•		•		
Soil	Ingestion	•	•	•	•	•	•	•		
	Inhalation	•	•	•	•	•	•	•		
	Dermal Contact	•	•	•	•	•	•	•		
	External Radiation Dose	•	•	•	•	•	•	•		
	Tritium Vapor Inhalation	•	•	•	•	•	•	•		
Food Chain	Garden Produce				•	•	•	•		
	Grains									
	Beef & Milk						•	•		
	Poultry & Egg									
	Fish			•		•		•		•
	Wild Game			•				•		

The annual TEDE (in mrem) is not calculated for the exposure scenarios shown on this table. The risk quantifiers for these scenarios are incremental cancer risk from a lifetime exposure to both radionuclides and chemicals, and hazard index for non-radioactive chemicals.

6.0 LIMITATIONS AND UNCERTAINTIES

This risk assessment was developed to show our present understanding of the risks associated closure of WMA C as a landfill. However, significant limitations and uncertainties exist in this preliminary risk assessment of WMA C. Figure 4-2 of the *Framework Plan for Single Shell System Closure Plan* (RPP-13774) conceptually shows how this uncertainty is addressed through a series of circles that represent uncertainty with the circles becoming smaller as more data is collect and the uncertainty about a parameter is reduced. Since this is a preliminary risk assessment, an understanding of this uncertainty is necessary before proceeding to Section 7.0 which compares the results of the risk assessment against the performance objectives. To deal with the uncertainty in this first iteration of the risk assessment, the parameters, for the most part, have been biased to yield higher risk numbers. It is expected, that as retrieval progresses, new information will become available that can potentially lower the risk. Table 27 lists the uncertainties associated with this risk assessment and how this uncertainty could impact the results.

Table 27. Uncertainties Associated with the Preliminary Risk Assessment Results

Uncertainty		Uncertainty Description	Impact on Results (if known)
Inventory Uncertainty	Best Basis Inventory	All results are based on some derivation of the best basis inventory. It does not contain all contaminants of concern and it is based on process knowledge with limited sampling.	**UKNOWN** until post-retrieval sampling results confirm BBI. Additional contaminants of potential concern will be analyzed[1]
	No Retrieval	Risk assessment examined using existing Best Basis Inventory instead of Selected Phase Removal inventory without any retrieval	**INCREASE** → The residential ILCR for residual tank waste will increase by a factor of approximately 50.
	Simple Volume Ratio	Risk assessment uses retrieved inventory based on simple volume ratio (Section 3.6.1) instead of Selected Phase Removal (i.e. inventory for technetium-99 is slightly lower for simple volume)	**DECREASE** → The residential ILCR risk for residual tank waste will decrease by 5 %
	Selected Phase Removal	Risk assessment used residual inventory based on Selected Phase Removal. This is conservative because if sluicing is used for the C-100 Series tanks, the HTWOS residual inventory would be more appropriate	**NO CHANGE**
	HTWOS	Risk assessment uses retrieved inventory based on HTWOS projected inventory (Section 3.6.1) instead of Selected Phase Removal (i.e. inventory for technetium-99 is a factor of 5 greater for Select Phase Removal)	**DECREASE** → The residential ILCR for residual tank waste will decrease by a factor of approximately 5
	Pipeline Residuals	Risk assessment estimated the amount inventory left in pipelines by calculating the number of linear feet of pipe and assumed that approximately 25 % of it was blocked by waste (Section 3.6.1).	**UNKNOWN**, but as part of the RFI/CMS process pipelines will be examined for residual waste[1].

Table 27. Uncertainties Associated with the Preliminary Risk Assessment Results

Uncertainty		Uncertainty Description	Impact on Results (if known)
Inventory Uncertainty	8,000 gal Retrieval Leaks	Inventory used for retrieval leaks is calculated from concentrations supplied by HTWOS model runs based on either 5 molar sodium nitrate solution or 10 wt % solids (Section 3.6.1)	**UNKNOWN**, because it is dependent upon leak volume and leak concentration. Model uses constant 8,000 gal retrieval for all C-100 Series tanks. However, present results are believed to be highly conservative. In reality, some tanks may not leak at all and some tanks may leak more than 8,000 gal. It is expected that a number of the tanks will be equipped with a Leak Detection Monitoring system, from which leak volume estimates will be made[1]
	20,000 gal Retrieval Leak	Risk assessment uses a 20,000 gal leak for all C-100 Series tanks instead of 8,000 gal leak	**INCREASE →** The residential ILCR for retrieval leaks will increase by a factor of approximately 3
	Unplanned Releases	This risk assessment made estimates about the amount of contaminants lost through unplanned releases (either from tanks or ancillary equipment. These estimates are documented in Section 3.6.1 and in RPP-15317. However, the estimates are only as good as the available data (processed records, borehole sampling and logging, etc.) Some unplanned releases have excellent records, but others do not. For those that have good records the inventory is probably correct; for those that do not, the inventory could be an order of magnitude off.	**UNKNOWN**, however additional wells are being drilled in WMA C to determine the characteristics of past unplanned releases[1].
Release Mechanism Uncertainty	Advection-Dominated Release Rate Model	In absence of characterization data for release models, an advection-dominated release model was used to simulate unstablized waste form covered with backfill and gravel, this would also cover a grout that fails.	**INCREASE →** The residential ILCR for residual tank waste will INCREASE by a factor of approximately 3
	Diffusion-Dominated Release Rate Model	In absence of characterization data for release models, an diffusion-dominated release model was used to simulate a stabilized waste form covered with grout. It used a relatively high diffusion coefficient 6E-7 cm^2/s.	**DECREASE →**, however, additional work is being done on evaluating diffusion-dominated release of grout. It is expected the diffusion coefficient will go decrease with additional testing of grout. Reducing diffusion coefficient by a factor of 10 decreases ILCR by 20 %[1]

Table 27. Uncertainties Associated with the Preliminary Risk Assessment Results

Uncertainty		Uncertainty Description	Impact on Results (if known)
Release Mechanism Uncertainty	Steel Liner	Risk assessment for conservative purposes assumes the steel liner instantaneously fails in the year 3050. In reality, the steel liner would probably last much longer.	**UNKNOWN,** if deemed necessary, work needs to be developed that addresses the decomposition of the steel liner for residual waste
Release Mechanism Uncertainty	Release Mechanism for Contaminants from Residual Waste	The risk assessment assumes the waste is not strongly bound to the solid matrix and all of it is available for transport	Waste constituent studies have been started on sludge from tank AY-102 (sludge originally from C-106). Preliminary results indicate the release of technetium to groundwater flow is much slower than previously believed. Work is on-going and will cover additional contaminants of concern[1]
Modified RCRA Subtitle C Barrier		This barriers design life is 500 years (see section 3.2.1) at which time it instantaneously fails. In reality barrier would degrade slowly over time	**UNKNOWN** → Barrier could either degrade faster or last longer than the design life. Sensitivity runs will be made to show the impacts of barrier degradation or increased design life
Recharge Rates		The model used recharge rates of 3.5 mm/yr (pre-Hanford) 100 mm/yr (Hanford Operational Period), 0.5 mm/yr (barrier design life for 500 years), 3.5 mm/yr (post-barrier). However in *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (PNNL-13033) should be 0.9 mm/yr (pre-Hanford) 60 mm/yr (Hanford Operational Period), 0.1 mm/yr (barrier design life for 500 years), 0.9 mm/yr (post-barrier). Recharge estimates were made higher than recommended for this area bias the results to higher risk estimates	**DECREASE** → similar analysis for the B/BX/BY Field Investigation report indicates lowering the recharge rate by ½ reduces the risk by 1/2. Additional, sensitivity cases will be made show the impact of varying recharge rates[1]
Hydraulic Conductivity of the Unconfined Aquifer		Reported results use a hydraulic conductivity of 50 m/day, but 5 m/day and 1,000 m/day were also examined. Recent RCRA drilling just to the north outside the WMA C found open framework gravels to basalt and oscillatory place the hydraulic conductivity in this region to between 1,000 to 6,000 m/day for two test intervals.	**DECREASE** → increasing the hydraulic conductivity by a factor of 10 decreases the concentrations by almost but not quite the same amount (i.e going from 50 to 1,000 m/d decrease the concentration by a factor of 18.5)[1].
2-D Modeling vs. 3-D Modeling		To account for the three-dimensional aspects, the calculated 2-D fenceline concentration was scaled by dividing by the length of the WMA C fenceline perpendicular to the flow direction.	**INCREASE** → recent sensitivity results a 3D S/SX model indicates the 2-D to 3-D dilution factor used here is factor of 5 to 7 higher than it should be.

Table 27. Uncertainties Associated with the Preliminary Risk Assessment Results

Uncertainty		Uncertainty Description	Impact on Results (if known)
Chemical Uncertainty	Bulk Distribution Coefficients	Bulk distribution coefficient determine how well a contaminant adsorbs onto the soil. This risk assessment used a bulk distribution coefficient of 0.0 mL/g for all contaminants except uranium for uranium it used 0.6 mL/g	**DECREASE** → since all contaminants except uranium were modeled with a K_d = 0.0 mL/g would reduce the impact for those contaminants **INCREASE/DECREASE** → for uranium *Hanford Contaminant Distribution Coefficient Database and User's Guide* (PNNL-13985), recommends using a range from 0.2 to 4. Therefore, the impacts due to uranium could increase if a lower K_d is used. Future iterations of this risk assessment will examine different K_d for uranium[(1)]
	Chromium	This risk assessment assumed all chromium was chromium^{+6}. Chromium^{+6} was analyzed because it provides the greatest risk for ILCR. However, only the slope factors for inhalation are available, chromium is assumed to be inhaled through shower, sprinklers, and/or dust contaminated with it.	**DECREASE** → If all chromium is chromium^{III}, then the ILCR for non-radionuclide chemicals goes down by several orders of magnitude
Exposure Scenario Uncertainty	Risk parameters	Inputs for overall risk prediction per exposure scenario are also uncertain and potentially sensitive. These other inputs might include various models (e.g., food chain model, toxicokinetic model) and model parameters (e.g., food chain transfer factors, exposure factors, dose factors, risk factors)	**UNKNOWN** →These inputs are applied after prediction of groundwater concentrations and are not trivial.
	Exposure Scenarios	The Section 6.0 describes the various exposure scenarios. All Pathways Farmer are representative (average) individuals. The Native American represents a bounding individual. Numerous variations of these basic exposure scenarios are possible.	**VARIES GREATLY**→ The radionuclide ILCR for resident scenario for tank residual waste is factor of 22 higher than the industrial scenario, while the Native American scenario is a factor of 15 over the residential scenario

(1) Indicates ongoing work either laboratory, modeling or field analysis to reduce the radius of uncertainty given in Figure 4-2 of the *Framework Plan for Single Shell System Closure Plan* (RPP-13774).

7.0 QUANTITATIVE PERFORMANCE METRIC ESTIMATES FOR WASTE MANAGEMENT AREA C CLOSURE SCENARIO

Dose and risk estimates are provided in this section for various exposure scenarios. In these scenarios a human receptor is exposed when that receptor uses groundwater contaminated by tank waste sources in WMA C. In Section 4.3 a series of quantitative estimates for technetium-99, iodine-129, nitrate, nitrite, and chromium(VI) groundwater concentrations over time were generated assuming different waste sources and their associated release and migration characteristics. However, technetium-99 was chosen as a representative contaminant to evaluate because it is highly mobile in the subsurface and is a primary risk-generating constituent in tank waste. Using the technetium-99 results as a template, additional mobile constituents were also considered as contributors to dose and risk estimates. To calculate dose and risk values for a given waste source and exposure scenario, the peak groundwater concentration from the corresponding waste source analysis was multiplied by the appropriate dose and/or risk conversion factor appropriate for the specific type of exposed individual. The appropriate dose and/or risk conversion factor is provided in HNF-SD-WM-TI-707.

Section 6.1 and 6.2 describe the selected constituents of potential concern and selected points of calculation for evaluation of possible groundwater contamination resulting from closure conditions at WMA C.

Dose and Risk Estimates Conclusions

- The DOE/RL-91-45 industrial and residential exposure scenarios were selected for detailed analysis.
- The primary contributors to long-term radiological dose due to groundwater contamination by residual tank waste, past leaks, and hypothetical retrieval leaks are technetium-99 and iodine-129.
- The major contributors to long-term incremental cancer risk are technetium-99 and iodine-129. The major contributors to cumulative Hazard Index are nitrate, nitrite, and hexavalent chromium.
- Following retrieval of tank waste to meet the maximum residual specified in the HFFACO, known past leaks are responsible for the largest peak values for dose, cancer risk, and Hazard Index, followed by hypothetical retrieval leaks.
- Cumulative Radiological dose (effective dose equivalent) resulting did not exceed the performance objective of 25 mrem/yr at the WMA C fenceline.
- For the Industrial Scenario, cumulative (i.e. all source terms) radiological ILCR exceeded the target value of 1.0 E-05 at the WMA fenceline (Figure 25). This is due to hypothetical retrieval leaks, if hypothetical retrieval leaks are not included, ILCR falls below the target value. For residual tank waste, total radiological ILCR exceeded the 1.0 E-05 for the residential scenario at the fenceline, but not at the core zone boundary. While for past leaks and hypothetical retrieval leaks, total radiological ILCR exceeded the 1.0 E-05 for the residential scenario at the fenceline and core zone boundary. Corresponding risks were not exceeded for the industrial scenario. Technetium-99 accounts for most of the risk.
- Hazard Index was not exceeded (< 1.0) at the WMA C fenceline for any of the sources.
- Dose-based primary drinking water standards (MCL) are exceeded for cumulative iodine-129 but not for technetium-99 although it is very close to the MCL. The past leak and hypothetical retrieval leaks cause exceedence of the dose MCL for iodine-129 at the fenceline.

Sections 6.3, 6.4, and 6.5 describe the relative impacts to groundwater from the following source terms:

- Residual tank waste following retrieval to a maximum of 360 ft^3 in each 100-series tank (30 ft^3 in each 200-series tank)
- Estimated inventory of past leaks from tanks and ancillary equipment
- Hypothetical releases of retrieval solutions during water-based waste retrieval.

These resultant groundwater effects of these source terms are evaluated at the following locations:

- The downgradient WMA C fenceline (average concentration)
- Nearest boundary of the proposed 200 Area Plateau core zone (2,900 m from the WMA C fenceline)
- Downgradient groundwater immediately before discharge of the aquifer into the Columbia River (14,300 m east of the WMA C fenceline).

Radiological dose from groundwater contaminants is presented in terms of effective dose equivalent (EDE) in Sections 6.3, 6.4, 6.5, and 6.6, along with estimated ILCR and non-carcinogenic Hazard Index. The calculation of dose using the EDE method is consistent with previous work prepared for the immobilized low-activity waste disposal facility.

A graphical illustration of the cumulative effects of multiple source terms on the ICLR is presented in Section 6.7. This evaluation indicates the high sensitivity of the risk estimate to the impacts of hypothetical retrieval solution releases and past leaks. The estimated impacts of the hypothetical retrieval leaks is extremely conservative due to the assumptions that (1) all of the tanks selected for sluicing retrieval methods will leak the same quantity of material during retrieval (i.e., 8,000 gal), and (2) all of the most-soluble constituents in the tanks (e.g., technetium-99, iodine-129, nitrate) dissolve in a given volume of retrieval solution and subsequently 8,000 gal of that solution is released during retrieval. Actually, only tanks that are considered to be structurally sound are considered for the high-volume wet retrieval systems.

The national primary drinking water standards, as codified in "National Primary Drinking Water Regulations" (40 CFR 141), were also identified as performance objective metrics for assessment of tank closure. Section 7.8 presents a summary comparing the estimated groundwater impacts to the respective numerical (i.e., MCLs) standards for the selected preliminary contaminants of potential concern. Although meeting the primary drinking water standards in groundwater at WMA C is expected to be protective, the standards are not strictly applicable to WMA C groundwater because it cannot be used as a source of drinking water until the existing plumes have either been remediated or have naturally attenuated. Use of WMA C groundwater as a drinking water source (i.e. existing plumes have been remediated or naturally attenuated) most likely will not occur before the peak concentration from past unplanned releases or hypothetical retrieval leaks arrive at the groundwater, but should occur before contaminants from tank residuals arrive at the groundwater.

Comparison of dose and risk estimates with performance objectives show that performance objectives are satisfied in many, but not all cases. Larger groundwater concentrations are associated with source terms containing the largest inventories of mobile constituents (e.g., past leaks) and for groundwater evaluated closest to the source (i.e., at the WMA C fenceline).

7.1 PRELIMINARY CONTAMINANTS OF POTENTIAL CONCERN

In the analyses presented in the following sections, an engineered cover, or cap, is assumed to be placed over the entire WMA at the time of facility closure. The cover is assumed to retain its effectiveness in controlling infiltration through the site for 500 years, after which infiltration control is degraded. The contributions from three discrete types of source terms (residual tank waste, past leaks, and hypothetical retrieval leaks) were evaluated because differences in release behavior of constituents are assumed for each source. Residual tank waste will likely be present after retrieval and inventory estimates were based on the target residual volume. To gauge sensitivity to variable residual volume, the effects of pre-retrieval inventories on dose/risk estimates were also evaluated. The diffusion-limited waste release case (simulation Case 11) was used to describe the residual waste releases. To estimate the impact of the retrieval leak source, a hypothetical leak of 8,000 gal was assumed for the two tanks in WMA C that will be retrieved using high-volume wet methods.

Table 10 of Section 4.3 provides the base case conditions for this risk assessment. Note the following conditions:

- Residual tank waste volume is assumed to be present at a maximum of 360 ft^3 for the 100-series tanks and 30 ft^3 for the 200-series tanks.
- Hypothetical retrieval leaks are applied only to tanks that are scheduled for waste retrieval using past-practice or modified sluicing techniques. Tanks being retrieved by dry (e.g., vacuum) methods, or using the mobile retrieval system do not have a retrieval leak source term applied.
- Quantitative source terms are not included for individual WMA components for which no basis has been identified to support a preliminary inventory.
- Quantitative source terms are not included for past leaks and areas of known or suspected vadose zone contamination for which no basis has been identified to support a preliminary inventory.

Dose and risk estimates were calculated for the following constituents identified as preliminary contaminants of potential concern at post-retrieval inventories:

- Technetium-99
- Iodine-129
- Total Uranium
- Nitrate
- Nitrite

- Chromium.

The evaluation of simulation results is given in Table 28 indicates that these constituents will provide the majority of the long-term risk and dose impacts related to WMA C. Table 28 does not include hypothetical retrieval leaks, because the results for hypothetical retrieval leaks would be similar to residuals, since the inventory used to calculate the residuals and the hypothetical retrieval leaks is the same. Table 27 provides the individual contaminant's contribution to the particular exposure scenario and the percentage of that contaminant's contribution to the total for the exposure scenario. The total for the exposure scenario includes all contaminants presently given in *Inventory and Source Term Data Package* (DOE/ORP-2003-02). The inventory for these constituents is variable between sources, and is uncertain due to the variety of approaches used to derive the inventories (e.g., sampling and analysis, process evaluations). This inventory uncertainty will be systematically reduced through sampling and analysis of residual waste following retrieval. Final selection of COCs will be performed after completion of residual waste sampling and analysis and the DQO process.

Table 28. Percentage of Individual Contaminant to Total for Exposure Scenario.

	ILCR Industrial		ILCR Residential		HI Industrial		HI Residential		All-Pathways Farmer	
COPC	ILCR	Percentage of ILCR	ILCR	Percentage of ILCR	HI	Percentage of HI	HI	Percentage of HI	Dose mrem/y	Percentage of Dose
	Tank Residuals									
Tc-99	9.0E-07	90.0%	2.2E-05	95.6%	N/A	N/A	N/A	N/A	0.115	59.3%
I-129	1.0E-07	9.9%	5.2E-07	2.3%	N/A	N/A	N/A	N/A	0.071	36.7%
Nitrite	N/A	N/A	N/A	N/A	3.4E-03	35.6%	2.2E-02	37.7%	N/A	N/A
Nitrate	N/A	N/A	N/A	N/A	4.5E-04	4.8%	2.9E-03	5.1%	N/A	N/A
Chromium^{+6}	2.8E-08	100%	6.3E-08	100%	4.5E-03	47.8%	2.5E-02	43.7%	N/A	N/A
Uranium	N/A	N/A	N/A	N/A	4.8E-06	0.1%	3.4E-05	0.1%	N/A	N/A
Total Radionuclides	1.0E-06		2.3E-05		N/A		N/A		0.194	
Total Non Radionuclides	2.8E-08		6.4E-08		9.4E-03		5.7E-02		N/A	
	All Past Unplanned Releases									
Tc-99	6.9E-06	84.6%	1.7E-04	95.4%	N/A	N/A	N/A	N/A	0.87	50.6%
I-129	7.1E-07	8.8%	3.7E-06	2.1%	N/A	N/A	N/A	N/A	0.51	29.7%
Nitrite	N/A	N/A	N/A	N/A	1.4E-02	42.8%	9.1E-02	45.8%	N/A	N/A
Nitrate	N/A	N/A	N/A	N/A	1.7E-03	5.0%	1.1E-02	5.3%	N/A	N/A
Chromium^{+6}	1.1E-07	100%	2.4E-07	100%	1.7E-02	52.4%	9.7E-02	48.5%	N/A	N/A
Uranium	N/A	N/A	N/A	N/A	1.4E-04	0.4%	9.8E-04	0.5%	N/A	N/A
Total Radionuclides	8.1E-06		1.8E-04		N/A		N/A		1.72	
Total Non Radionuclides	1.1E-07		2.4E-07		3.3E-02		2.0E-01		N/A	

7.2 SELECTED EXPOSURE SCENARIOS AND POINTS OF CALCULATION

Two receptor scenarios were selected for the following analysis of ILCR and Hazard Index: industrial worker scenario and residential scenario. Both scenarios are developed from scenarios described in DOE/RL-91-45. For information, additional exposure scenarios were evaluated, including Native American receptors and receptors exposed to a surface water source. The industrial and residential scenarios are summarized in the following sections.

The analysis presented in this section includes extrapolation of groundwater concentrations to selected distances downgradient from the WMA C fenceline. These estimates assume that groundwater will ultimately assume a pre-Hanford flow direction and that groundwater from beneath WMA C will flow generally east from the site toward the Columbia River. These distances were selected as follows:

- The proposed core zone boundary surrounding the 200 Areas. This boundary is not yet fully defined and is subject to negotiation in terms of its actual location and also its applicability to any particular groundwater metric. The boundary location selected for this preliminary analysis is located 2,900 m east of WMA C.

- The Columbia River east of the 200 Areas was also selected as a point of calculation. The distance from WMA C to the Columbia River to the east is approximately 14,300 m. This calculation point is reported as Columbia River (groundwater) and the concentration of groundwater is evaluated just before it enters the Columbia River. Another scenario would actually include the Columbia River surface water, which includes such activities as swimming and eating fish from the river. This scenario is being evaluated as part of the composite analysis (which includes a Columbia River model), described in Section 4.0 of the *Framework Plan for Single Shell Tank System Closure* (RPP-13774).

An analytical model was applied to the results of the numerical simulations at the WMA C fenceline to estimate reduction in concentration with distance downgradient from the WMA. These estimated downgradient concentrations were then used to estimate risk and dose metrics at distance.

The industrial scenario was chosen because Hanford Advisory Board Advice recommends the industrial scenario for the 200 Core Zone Boundary for the next 150 years. This also makes sense in light of the results. The highest contamination from WMA C occurs within the next 150 years and is due to past leaks and hypothetical retrieval leaks. The groundwater within the 200 Area Core Zone boundary cannot be used as a drinking water source until the existing plumes have either been remediated or have naturally attenuated. The residential scenario is presented because it is unrealistic to assume that an industrial scenario is appropriate once the existing plumes have been remediated or have naturally attenuated, which is expected to occur before contamination from residuals left in the tanks arrive at groundwater. Therefore a residential scenario should be used for tank residuals. The WMA C results of the analyses for both of the selected scenarios and the supplemental exposure scenarios are presented in this section and in Addendum C2.

7.3 RESIDUAL TANK WASTE SOURCE TERM IMPACTS

The residual waste remaining in tanks at the time of WMA closure is an important element for two primary reasons: (1) it represents a potentially high mass of constituents at the highest possible concentration, and (2) it is subject to management of mass and/or modification of final characteristics through implementation of selected in-tank treatment and stabilization technologies.

The base case scenario presented in this section incorporates the impacts of the preliminary constituents of potential concern present in residual waste at concentrations derived from the BBI. For all tanks,, the post-retrieval waste volume is estimated by removing the liquid, or supernate, fraction of the BBI and then reducing the volume of the remaining solid fraction to the maximum volume allowable under the HFFACO (i.e., 360 ft^3 for 100-series tanks and 30 ft^3 for 200-series tanks). This estimated inventory is representative of the residual waste remaining after retrieval by dry, or low water volume, methods such as the mobile retrieval system. .

In addition to the twelve 100-series tanks and four 200-series tanks in WMA C, residual waste impacts were evaluated for the C-301 catch tank and 244-CR vault. Currently there is no BBI inventory associated with these ancillary tanks. For evaluation purposes, these tanks were assigned inventories based on the average BBI minus liquids inventory for the entire WMA C. See Section 3.5 for the description of how residual waste volumes and inventories were estimated for the C-301 catch tank and 244-CR vault.

The constituents in the residual waste are assumed to release from the tank through a diffusion-controlled process. This process is simulated by applying the results of simulation Case 11. The diffusion-controlled release presents a representative result based on the assumption that the waste is released by diffusion through a monolithic waste form (e.g., cement grout*). Release from a grouted mass* is realistic based on the existence of the current concrete tank structure and preliminary plans to utilize cement grout* as part of the final tank fill.

The residual tank waste contributions to estimated dose, cancer risk, and Hazard Index values are presented in Tables 29, 30, and 31, respectively. These values are calculated as cumulative fenceline average concentrations over the entire length of the downgradient fenceline of WMA C. The concentration of constituents related to the residual tank waste source term peaks at approximately 5614 AD, in the middle range of the 10,000-year simulation period. The constituent concentration exhibits a very slow decline over time, consistent with the diffusion release scenario.

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* See Preface in *SST System Closure Plan* (RPP-13774).

Table 29. Residual Tank Waste Contribution to Radiological Dose from Exposure to Groundwater and Drinking Water for Technetium-99 and Iodine-129.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)[a]	
	Time (yr AD)	Dose (mrem/yr)	Time (yr AD)	Dose (mrem/yr)	Time (yr AD)	Dose (mrem/yr)
All Pathways Farmer (compare to <25 mrem/yr target)						
Technetium-99	5610	1.2 E-01	5637	1.8 E-02	5839	6.8 E-03
Iodine-129	5614	7.1 E-02	5637	1.1 E-02	5839	4.2 E-03
Cumulative[a]		1.9 E-01		3.0 E-02		1.1 E-02
Native American Groundwater (compare to <25 mrem/yr target)						
Technetium-99	5610	2.8 E-01	5637	4.3 E-02	5839	1.6 E-02
Iodine-129	5614	1.7 E-01	5637	2.6 E-02	5839	9.8 E-03
Cumulative[a]		4.6 E-01		7.1 E-02		2.7 E-02
Residential -- Drinking Water (compare to <4 mrem/yr EDE target)[b]						
Technetium-99	5610	6.9 E-02	5637	1.1 E-02	5839	3.8 E-03
Iodine-129	5614	2.6 E-02	5637	4.0 E-03	5839	1.4 E-03
Cumulative[a]		9.7 E-02		1.5 E-02		5.3 E-03

NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a] Cumulative includes all COPCs from *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).
[b] Based on 2L/day ingestion

Table 30. Residual Tank Waste Contribution to Incremental Lifetime Cancer Risk from Exposure to Groundwater for Selected Constituents.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (GW)	
	Time (yr AD)	Risk	Time (yr AD)	Risk	Time (yr AD)	Risk
HSRAM Industrial Scenario – Risk (compare to <1.0 E-05 target)						
Technetium-99	5610	9.0 E-07	5637	1.4 E-07	5839	5.2 E-08
Iodine-129	5614	1.0 E-07	5637	1.6 E-08	5839	5.8 E-09
RAD TOTAL[a]		1.0 E-06		1.6 E-07		6.0 E-08
Chromium^{+6} [b]	5614	2.8 E-08	5637	4.4 E-09	5839	1.6 E-09
Nitrate	NA		NA		NA	
Nitrite	NA		NA		NA	
Uranium	NA		NA		NA	
Non-RAD Total[a]	5614	2.8 E-08	5637	4.4 E-09	5839	1.7 E-09
HSRAM Residential Scenario – Risk (compare to <1.0 E-05 target)						
Technetium-99	5610	2.2 E-05	5637	3.4 E-06	5839	1.3 E-06
Iodine-129	5614	5.2 E-07	5637	8.2 E-08	5839	3.0 E-08
RAD TOTAL[a]		2.3 E-05		3.5 E-06		1.3 E-06
Chromium^{+6} [b]	5614	6.3 E-08	5637	9.8 E-09	5839	3.6 E-09
Nitrate	NA		NA		NA	
Nitrite	NA		NA		NA	
Uranium	NA		NA		NA	
Non-RAD Total[a]	5614	6.3 E-08	5637	9.8 E-09	5839	3.6 E-09

HSRAM = Hanford Site Risk Assessment Methodology (DOE/RL-91-45).
NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a] Cumulative includes all COPCs from *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).

[b] For conservative purposes, all chromium is assumed to be in the +6 valence state. Additionally, when calculating ILCR, only the slope factors for inhalation are available, hexavalent chromium is assumed to be inhaled through shower, sprinklers, and/or dust contaminated with it

Table 31. Residual Tank Waste Contribution to Hazard Index from Exposure to Groundwater for Selected Constituents.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Hazard Index	Time (yr AD)	Hazard Index	Time (yr AD)	Hazard Index
HSRAM Industrial Scenario – Hazard Index (compare to < 1.00 target)						
Chromium^{+6}	5614	4.5 E-03	5637	7.0 E-04	5839	2.6 E-04
Nitrate	5614	4.5 E-04	5637	7.1 E-05	5839	2.6 E-05
Nitrite	5614	3.4 E-03	5637	5.2 E-04	5839	1.9 E-04
Uranium	12000	4.8 E-06	12000	2.8 E-06	12000	<1E-6
Cumulative[a]		9.4 E-03		1.5 E-03		5.6 E-04
HSRAM Residential – Hazard Index (compare to < 1.00 target)						
Chromium^{+6}	5614	2.5 E-02	5637	3.9 E-03	5839	1.5 E-03
Nitrate	5614	2.9 E-03	5637	4.6 E-04	5839	1.7 E-04
Nitrite	5614	2.2 E-02	5637	3.4 E-03	5839	1.2 E-03
Uranium	12000	3.3 E-05	12000	2.0 E-05	12000	<1E-6
Cumulative[a]		5.7 E-02		8.9 E-03		3.4 E-03

NA = not applicable. Risk metric does not apply to this constituent.
HSRAM = Hanford Risk Assessment Methodology (DOE/RL-91-45).
WMA = waste management area

[a] Cumulative includes all COPCs from *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).

The following key summary points were identified with respect to the residual waste source term:

- Cumulative groundwater dose originating from post-retrieval residual tank waste is below the target maximum value of 25 mrem in a year performance objective for the all pathways farmer and Native American exposure scenarios at all locations evaluated. For the industrial and residential drinking water scenarios, doses were calculated using conversion factor based on a 1 and 2 L/day ingestion rate, respectively. Calculated doses for both scenarios are below the target maximum value of 4 mrem/yr (Table 2). Dose contributions from technetium-99 and iodine-129 are approximately of equal magnitude (Table 29).

- Cumulative risk is below the target maximum value of 1×10^{-5} (Table 2) at all evaluation points for the DOE/RL-91-45 industrial exposure scenario. Target maximum value is exceeded for the residential exposure scenario at the WMA C fenceline only. Risk from technetium-99 accounts for greater than 95% of the total risk (Table 30).

- Cumulative Hazard Index is less than the target maximum value of one (Table 2) for all evaluation points for both exposure scenarios. Contribution from uranium is shown for information only and is not included in the cumulative value as it arrives much later than the other constituents. Hexavalent chromium and nitrite are the primary contributors and are of approximately equal magnitude (Table 31).

7.4 PAST LEAKS SOURCE TERM IMPACTS

A number of past leaks have occurred within WMA C. These include both leaks from a tank (i.e., tank C-105) and from ancillary equipment (i.e., pipes) associated with WMA operations. Past leaks are important to long-term human health risk estimates because of their potential to migrate to groundwater relatively quickly under the current assumed infiltration conditions at the WMA. One tank leak and three ancillary equipment leaks have been populated with estimated inventories at this time. WMA monitoring activities have detected the presence of widespread shallow radionuclide contamination, along with deeper contamination in the eastern portion of the tank farm. However, the expected inventory from these other sources is expected to be much smaller than for the sources analyzed and would provide only a small contribution of the total risk (see Section 3.5). Inventory data for remaining vadose zone contamination in WMA C will be generated as site characterization and closure activities are performed.

The past leak source term was simulated using simulation Cases 3 and 4 to represent past leaks from tanks and from ancillary equipment, respectively. The primary difference in the two simulation cases is the assumed placement of the source in the vadose zone at the start of the simulation (i.e., a past tank leak is assumed to be present deeper in the vadose zone than a release from ancillary equipment). As suggested by the depth of placement at the start of simulation, the past tank leak results in arrival of a peak groundwater concentration slightly faster than a corresponding ancillary equipment leak; however, the peaks are very close in time and are considered to be coincidental for this analysis.

The past leaks source term contribution to estimated dose, cancer risk, and Hazard Index values are presented in Tables 32, 33, and 34, respectively. These values are calculated as cumulative fenceline average concentrations over the entire downgradient length of the fenceline of WMA C. The concentration of constituents related to the past leak source term peaks at approximately 2117 AD, in the early portion of the 10,000-year simulation period. This peak is largely due to the migration of mobile constituents (e.g., technetium-99, iodine-129, nitrate, nitrite, and chromium). Because of the separation in arrival time of peak groundwater concentration, the peak values related to the past leaks source term are not additive to the peak(s) related to the residual tank waste source term. These constituents appear to move through the simulation domain (i.e., they leave the WMA area) within the period of the simulation. A secondary impact due to moderately retarded constituents (e.g., uranium) is observed to begin at about 6900 AD and is still rising at the end of the simulation period.

The following key summary points were identified with respect to the past leak source term:

- Cumulative groundwater dose attributed to past leaks does not exceed the target performance objective of 25 mrem in a year for any scenario at the WMA C fenceline or

any distant evaluation point. Technetium-99 accounts for nearly 65% of the total drinking water dose (Table 32).

- Cumulative risk evaluated exceeds the target maximum value at the WMA C fenceline for the residential exposure scenario. Cumulative risk does not exceed the maximum target value for the Industrial scenario at the fenceline. Cumulative risk is above the target value at the fenceline, 200 Area Core Zone Boundary and at the Columbia River for the Residential Scenario. Technetium-99 accounts for approximately 85% of the total risk for the industrial scenario, and 95 % of the risk for the residential scenario (Table 33).

- Hazard Index values are less than the target value of 1 for both exposure scenarios at all evaluation points. Hexavalent chromium and nitrite are the primary contributors (Table 34).

Table 32. Past Leak Contribution to Radiological Dose from Exposure to Groundwater and Drinking Water for Technetium-99 and Iodine-129.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Dose (mrem/yr)	Time (yr AD)	Dose (mrem/yr)	Time (yr AD)	Dose (mrem/yr)
All Pathways Farmer (compare to <25 mrem/yr target)						
Technetium-99	2117	8.7 E-01	2141	1.4 E-01	2355	5.1 E-02
Iodine-129	2117	5.1 E-01	2141	7.8 E-02	2355	3.0 E-02
Cumulative[a]		1.7 E+00		2.7 E-01		1.0 E-01
Native American Groundwater (compare to <25 mrem/yr target)						
Technetium-99	2117	2.1 E+00	2141	3.3 E-01	2355	1.2 E-01
Iodine-129	2117	1.2 E+00	2141	1.8 E-01	2355	7.0 E-02
Cumulative[a]		4.1 E+00		6.4 E-01		2.4 E-01
Residential Drinking Water Dose (compare to <4 mrem/yr EDE target[b])						
Technetium-99	2117	5.2 E-01	2141	8.2 E-02	2355	2.9 E-02
Iodine-129	2117	1.8 E-01	2141	2.8 E-02	2355	1.0 E-02
Cumulative[a]		8.0 E-01		1.3 E-01		4.4 E-02

NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a] Cumulative includes all COPCs from *241-C Waste Management Area Inventory Data Package* (RPP-15317) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).
[b] Based on 2 L/day ingestion

Table 33. Past Leak Contribution to Incremental Lifetime Cancer Risk from Exposure to Groundwater for Selected Constituents.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Risk	Time (yr AD)	Risk	Time (yr AD)	Risk
HSRAM Industrial Scenario – Risk (compare to <1.0 E-05 target)						
Technetium-99	2117	6.9 E-06	2141	1.1 E-06	2355	3.8 E-07
Iodine-129	2117	7.1 E-07	2141	1.1 E-07	2355	4.0 E-08
RAD TOTAL[a]		8.1 E-06		1,3 E-06		4.5 E-07
Chromium^{+6} [b]	2117	1.1 E-07	2141	1.7 E-08	2355	6.1 E-09
Nitrate	NA		NA		NA	
Nitrite	NA		NA		NA	
Uranium	NA		NA		NA	
Non-RAD Total[a]		1.1 E-07		1.7 E-08		6.1 E-09
HSRAM Residential Scenario – Risk (compare to <1.0 E-05 target)						
Technetium-99	2117	1.7 E-04	2141	2.6 E-05	2355	1.0 E-05
Iodine-129	2117	3.7 E-06	2141	5.7 E-07	2355	2.1 E-07
RAD TOTAL[a]		1.8 E-04		2.8 E-05		1.0 E-05
Chromium^{+6} [b]	2117	2.4 E-07	2141	3.8 E-08	2355	1.5 E-08
Nitrate	NA		NA		NA	
Nitrite	NA		NA		NA	
Uranium	NA		NA		NA	
Non-RAD Total[a]		2.4 E-07		3.8 E-08		1.5 E-08

HSRAM = Hanford Site Risk Assessment Methodology (DOE/RL-91-45).
NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a]Cumulative includes all COPCs from *241-C Waste Management Area Inventory Data Package* (RPP-15317) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).
[b]For conservative purposes, all chromium is assumed to be in the +6 valence state. Additionally, when calculating ILCR, only the slope factors for inhalation are available, hexavalent chromium is assumed to be inhaled through shower, sprinklers, and/or dust contaminated with it.

Table 34. Past Leak Contribution to Hazard Index from Exposure to Groundwater for Selected Constituents[a].

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Hazard Index	Time (yr AD)	Hazard Index	Time (yr AD)	Hazard Index
HSRAM Industrial Scenario - Hazard Index (compare to < 1.00 target)						
Chromium^{+6}	2117	1.7 E-02	2141	2.7 E-03	2355	1.0 E-03
Nitrate	2117	1.7 E-03	2141	2.6 E-04	2355	9.5 E-05
Nitrite	2117	1.4 E-02	2141	2.2 E-03	2355	8.1 E-04
Uranium	12000	1.4 E-04	12000	9.6 E-05	12000	8.0 E-06
Cumulative[b]		3.3 E-02		5.3 E-03		2.0 E-03
HSRAM Residential – Hazard Index (compare to < 1.00 target)						
Chromium^{+6}	2117	9.7 E-02	2141	1.5 E-02	2355	5.5 E-03
Nitrate	2117	1.1 E-02	2141	1.6 E-03	2355	6.1 E-04
Nitrite	2117	9.1 E-02	2141	1.4 E-02	2355	5.3 E-03
Uranium	12000	9.8 E-04	12000	6.7 E-04	12000	5.6 E-05
Cumulative[b]		2.0 E-01		3.2 E-02		1.2 E-02

[a] Contributions from past tank leak (tank C-105) and three unplanned releases are summed and are reported as single peak contribution at a single time. Detailed results of the simulation indicate that the past tank leak contaminants arrive approximately 26 years ahead of the past ancillary equipment leaks.

[b] Cumulative includes all COPCs from *241-C Waste Management Area Inventory Data Package* (RPP-15317) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).

HSRAM = Hanford Site Risk Assessment Methodology (DOE/RL-91-45).
NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

7.5 POTENTIAL RETRIEVAL LEAKS SOURCE TERM IMPACTS

Leaks of residual waste and retrieval solution may occur under some tank waste retrieval scenarios. This could be the case if high-volume water systems are used to retrieve waste (e.g., high-volume sluicing) in tanks with poor structural integrity. Potential impacts from retrieval leaks, as discussed in this section, could be dramatically reduced or eliminated by selection of either low water volume (e.g., simultaneous sluice and pump operations) or dry (e.g., vacuum) waste retrieval technologies. The potential impacts of waste retrieval leaks were evaluated in this risk assessment because the use of water-based systems remains a feasible and very practical method of retrieving tank wastes. The hypothetical waste retrieval leak source term is applied to all C-100 series tanks. It was not applied to the C-200 series tanks because those tanks are using a dry retrieval methodology.

Waste retrieval leaks were simulated using simulation Cases 1 and 2 for hypothetical leaks of 8,000 gal and 20,000 gal, respectively. The 8,000-gal waste retrieval leak case was selected for this analysis. Current awareness of the potential for retrieval leaks and the intent to implement retrieval mechanisms that will minimize the potential for leaks indicates that the 8,000-gal leak scenario is appropriate. Waste retrieval leak inventories will vary according to the pre-retrieval inventory of the tank being retrieved.

The retrieval leaks source term contribution to estimated dose, cancer risk, and Hazard Index values are presented in Tables 35, 36, and 37, respectively. These values are calculated as cumulative fenceline average concentrations over the entire downgradient length of the fenceline of WMA C. The concentration of constituents related to the waste retrieval leak source term peaks at approximately 2082 AD, in the early portion of the 10,000-year simulation period. Because of the separation in arrival time of peak groundwater concentration, the peak values related to the waste retrieval leak source term are not additive to the peak(s) related to the residual tank waste source term. They are, however, additive to the peaks related to the past leaks source term.

The following key summary points were identified with respect to the hypothetical retrieval leak source term:

- Cumulative groundwater dose from technetium-99 and iodine-129 attributed to hypothetical waste retrieval leaks does not exceed the target maximum performance objective of 25 mrem in a year for any of the exposure scenarios at any evaluation point. The dose resulting from a single waste retrieval leak will be uniquely determined by the inventory of the specific tank. The impact of waste retrieval leaks is magnified by the fact that their risk impacts would be largely additive with respect to past leaks (Table 35).

- Cumulative risk exceeds the target maximum value at the WMA C fenceline and at the core zone boundary for the residential exposure scenario. Cumulative risk does not exceed the maximum target value for the industrial scenario at the fenceline. Cumulative risk is below the target maximum value for both scenarios at all downgradient evaluation points. Technetium-99 is the primary contributor to risk, accounting for greater than 87% of the total risk for the industrial scenario, and 99 % of the risk for the residential scenario (Table 36).

- Hazard Index values are less than the target value of one for both exposure scenarios at all evaluation points. Hexavalent chromium and nitrite are the primary contributors (Table 37).

Table 35. Hypothetical Retrieval Leak Contribution to Radiological Dose from Exposure to Groundwater and Drinking Water for Technetium-99 and Iodine-129.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Dose (mrem/yr)	Time (yr AD)	Dose (mrem/yr)	Time (yr AD)	Dose (mrem/yr)
All Pathways Farmer (compare to <25 mrem/yr target)						
Technetium-99	2082	7.3 E-01	2107	1.2 E-01	2324	3.9 E-02
Iodine-129	2082	4.3 E-01	2107	6.9 E-02	2324	2.3 E-02
Cumulative[a]		1.24 E-00		2.0 E-01		6.6 E-02
Native American Groundwater (compare to <25 mrem/yr target)						
Technetium-99	2082	1.8 E-00	2107	2.8 E-01	2324	9.3 E-02
Iodine-129	2082	1.0 E-00	2107	1.6 E-01	2324	5.4 E-02
Cumulative[a]		3.0 E-00		4.7 E-01		1.6 E-01
Industrial – Drinking Water (compare to <4 mrem/yr target)						
Technetium-99	2082	1.5 E-01	2107	2.4 E-02	2324	8.0 E-03
Iodine-129	2082	5.5 E-02	2107	8.7 E-03	2324	2.9 E-03
Cumulative[a]		2.1 E-01		3.4 E-02		1.1 E-03
Residential – Drinking Water (compare to <4 mrem/yr target)						
Technetium-99	2082	4.4 E-01	2107	7.0 E-02	2324	2.3 E-02
Iodine-129	2082	1.6 E-01	2107	2.6 E-02	2324	8.5 E-03
Cumulative[a]		6.2 E-01		9.9 E-02		3.3 E-02

NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a] Cumulative includes all COPCs from *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).

Table 36. Hypothetical Retrieval Leaks Contribution to Incremental Lifetime Cancer Risk from Exposure to Groundwater for Selected Constituents.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Risk	Time (yr AD)	Risk	Time (yr AD)	Risk
HSRAM Industrial Scenario – Risk (compare to <1.0 E-05 target)						
Technetium-99	2082	5.7 E-06	2107	9.1 E-07	2324	3.0 E-07
Iodine-129	2082	6.1 E-07	2107	9.7 E-08	2324	3.2 E-08
RAD TOTAL[a]		6.5 E-06		1.0 E-06		3.4 E-07
Chromium^{+6} [b]	2082	1.7 E-07	2107	2.8 E-08	2324	9.2 E-09
Nitrate	NA		NA		NA	
Nitrite	NA		NA		NA	
Uranium	NA		NA		NA	
Non-RAD Total[a]		1.7 E-07		2.8 E-08		9.2 E-09
HSRAM Residential Scenario – Risk (compare to <1.0 E-05 target)						
Technetium-99	2082	1.4 E-04	2107	2.2 E-05	2324	7.4 E-06
Iodine-129	2082	3.2 E-06	2107	5.0 E-07	2324	1.7 E-07
RAD TOTAL[a]		1.4 E-04		2.3 E-05		7.6 E-06
Chromium^{+6} [b]	2082	3.8 E-07	2107	6.1 E-08	2324	2.0 E-08
Nitrate	NA		NA		NA	
Nitrite	NA		NA		NA	
Uranium	NA		NA		NA	
Non-RAD Total[a]		3.8 E-07		6.1 E-08		2.0 E-08

HSRAM = Hanford Site Risk Assessment Methodology (DOE/RL-91-45).
NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a] Cumulative includes all COPCs from *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).
[b] For conservative purposes, all chromium is assumed to be in the +6 valence state. Additionally, when calculating ILCR, only the slope factors for inhalation are available, hexavalent chromium is assumed to be inhaled through shower, sprinklers, and/or dust contaminated with it.

Table 37. Hypothetical Retrieval Leak Contribution to Hazard Index from Exposure to Groundwater for Selected Constituents for Selected Constituents.

Constituent	WMA Fenceline		Proposed Core Zone Boundary		Columbia River (Groundwater)	
	Time (yr AD)	Hazard Index	Time (yr AD)	Hazard Index	Time (yr AD)	Hazard Index
HSRAM Industrial Scenario – Hazard Index (compare to < 1.00 target)						
Chromium^{+6}	2082	2.8 E-02	2107	4.4 E-03	2324	1.5 E-03
Nitrate	2082	4.1 E-03	2107	6.5 E-04	2324	2.2 E-04
Nitrite	2082	2.6 E-02	2107	4.1 E-03	2324	1.4 E-03
Uranium	12000	1.9 E-03	12000	1.3 E-03	12000	1.0 E-04
Cumulative[a]		6.7 E-02		1.1 E-03		3.6 E-03
HSRAM Residential – Hazard Index (compare to < 1.00 target)						
Chromium^{+6}	2082	1.5 E-01	2107	2.4 E-02	2324	8.1 E-03
Nitrate	2082	2.6 E-02	2107	4.2 E-03	2324	1.4 E-03
Nitrite	2082	1.7 E-01	2107	2.7 E-02	2324	8.9 E-03
Uranium	12000	1.3 E-02	12000	9.0 E-03	12000	7.3 E-04
Cumulative[a]		4.2 E-01		6.7 E-02		2.2 E-03

HSRAM = Hanford Site Risk Assessment Methodology (DOE/RL-91-45).
NA = not applicable. Risk metric does not apply to this constituent.
WMA = waste management area

[a] Cumulative includes all COPCs from *Inventory and Source Term Data Package* (DOE/ORP-2003-02) that have unit dose factors (HNF-SD-WM-TI-707 Rev 3).

7.5.1 Residual Ancillary Equipment Waste Source Term Impacts

The potential impact of residual waste remaining in the waste transfer piping components was evaluated and is discussed in this section. The ancillary piping components were assigned a conservative residual waste volume of 250 ft^3 based on an arbitrary 25% blockage in 20,000 linear feet of 3-in.-diameter piping. The average BBI minus liquids inventory for the entire WMA C was used due to lack of any other basis for deriving an inventory.

The constituents in the residual waste are assumed to release from the pipelines through a diffusion-controlled process. Release from a grouted* mass is realistic based on the existence of the current preliminary plans to fill ancillary piping components with grout* as part of closure activities. Applying the results of a scaled simulation Case 13 simulates this process.

* See Preface in *SST System Closure Plan* (RPP-13774).

Peak groundwater concentration of the highly mobile constituents (e.g., technetium-99, iodine-129) attributed to ancillary piping components occurs approximately 4892 AD, preceding the peak impact from residual tank waste by roughly 700 years. Groundwater dose, ILCR, and Hazard Index values attributed to this source term are roughly an order of magnitude less than those for residual tank waste and nearly two orders of magnitude less than the past leaks source term. The residual waste in the pipeline represents approximately 12% of cumulative impacts at the peak arrival time for release from the pipeline, which occurs 700 years before the impacts due to tank residual waste.

7.6 CUMULATIVE EFFECTS OF ALL SOURCE TERMS

An analysis of cumulative effects of multiple source terms is presented in this section.

The analysis identifies the individual source term contributions to ILCR and Hazard Index for the industrial worker exposure scenario, and radiological dose (EDE) for the all-pathways exposure farmer scenario. The summary results are presented in graphs for each performance metric with each graph including individual contribution curves for the individual source terms and the cumulative curve representing the additive effects of the source terms. All of the results of this analysis are based on groundwater concentrations at the WMA C fenceline.

Figure 25 indicates the cumulative effects in terms of ILCR to the industrial worker scenario. This figure indicates that the ILCR Risk (1.3E-05) is greater than the performance objective of 1.0E-05. However, the source term that pushes the risk over the performance objective is the hypothetical retrieval leaks, in which it is assumed that all tanks leak 8,000 gal. However, that scenario is somewhat unrealistic because steps would be taken to mitigate retrieval leaks, especially if retrieval leaks occur in tanks that are retrieved early in the process. Figure 26 shows the cumulative effects in terms of Hazard Index to the industrial worker scenario. The cumulative total (0.095) for the Hazard Index is an order of magnitude below the performance objective of 1.0. Figure 25 shows the cumulative effects of radiological dose (EDE) to the all-pathways farmer exposure scenario. The cumulative total for this performance metric (2.8 mrem in a year) is also almost an order of magnitude below the performance objective of 25 mrem/yr. The all-pathways farmer is identified as a conservative exposure scenario for radiological dose and is selected for comparison to dose limits established by the DOE for closure of radiological waste facilities.

In all cases of cumulative effects of residual tank waste, past leaks and hypothetical retrieval leaks in WMA C, the highest peak concentration occurs early in the post-closure period and existing past leaks contribute almost the entire peak value. After approximately 4700 AD, the residual waste contribution becomes the primary contributor to risk.

The potential contribution of hypothetical retrieval leaks would occur in a time frame parallel with the existing past leaks, although the magnitude is all most the same as existing past leaks under the assumption that all C-100 series tanks in WMA C may exhibit retrieval leaks.

Figure 25. Impacts of Base Case Multiple Source Terms on Incremental Lifetime Cancer Risk – Tank Residuals after Retrieval, Past Leaks, and Hypothetical Retrieval Leaks. Waste Management Area C. DOE/RL-91-45 Industrial Receptor at Downgradient Fenceline.

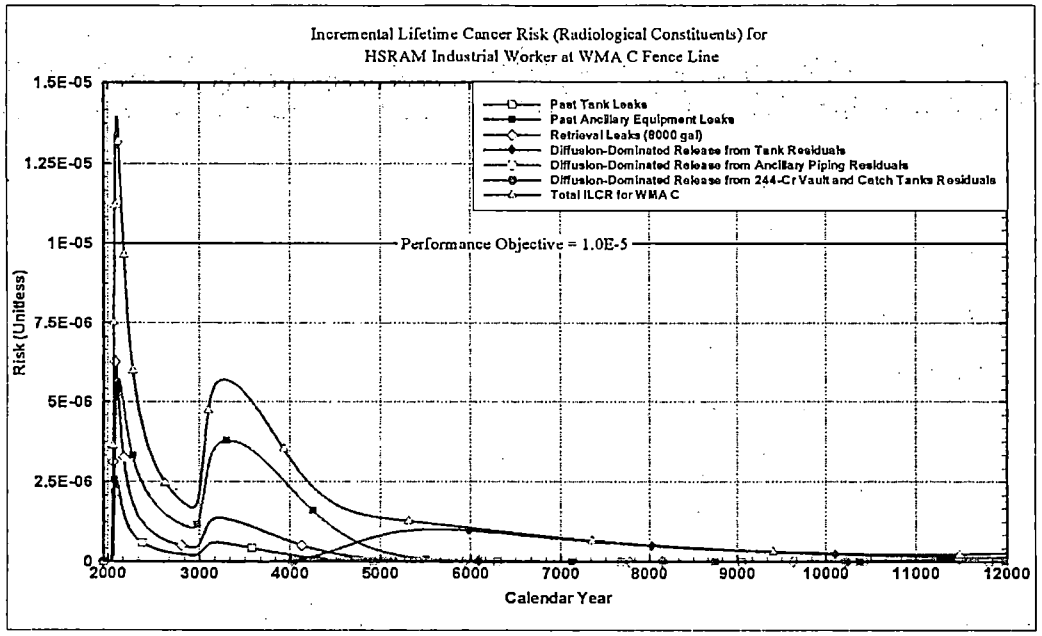


Figure 26. Impacts of Base Case Multiple Source Terms on Hazard Index – Tank Residuals after Retrieval, Past Leaks and Hypothetical Retrieval Leaks from Selected Tanks in Waste Management Area C. DOE/RL-91-45 Industrial Receptor at Downgradient Fenceline.

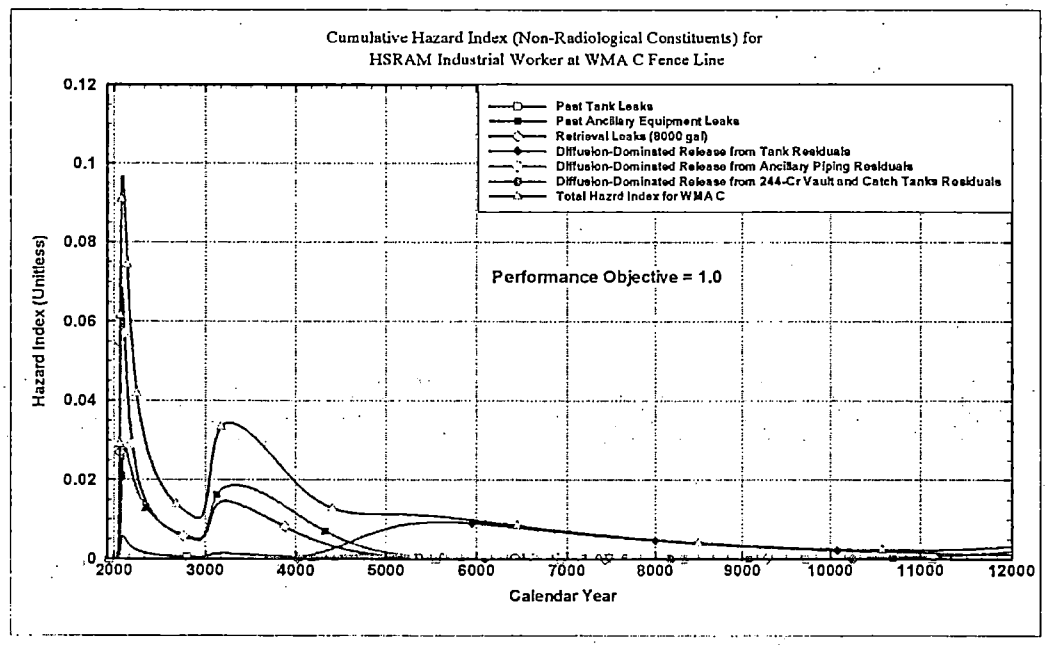
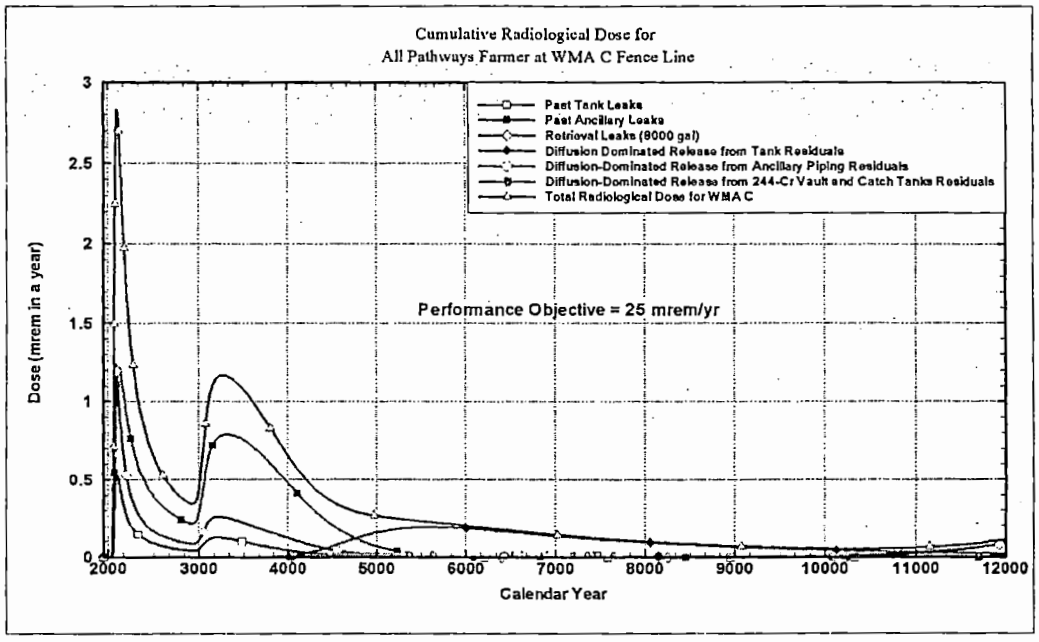


Figure 27. Impacts of Base Case Multiple Source Terms on Groundwater Dose – Tank Residuals after Retrieval, Past Leaks, and Hypothetical Retrieval Leaks from Selected Tanks in Waste Management Area C. All-Pathways Farmer Receptor at Downgradient Fenceline.



7.7 EVALUATION OF DRINKING WATER QUALITY IMPACTS

The primary drinking water standards were identified as tank closure performance objectives for protection of groundwater. The respective standards are the MCLs. The MCLs include both concentration-based standards (e.g., for metals and inorganic compounds/ions) and dose-based standards (e.g., for beta/photon-emitting radionuclides). The WMA C fenceline groundwater concentrations resulting from the individual source terms discussed above are presented in Table 38 and compared to concentration-based standards. The MCL for iodine-129 is exceeded in 2104 AD at the peak contribution from past leak and hypothetical retrieval leak source terms.

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Table 38. Comparison of Resultant Groundwater Concentrations to Concentration-Based Drinking Water Standards

Constituent	Post-Retrieval Tank Residual Peak Contribution[a]	Past Leaks Peak Contribution	Hypothetical Retrieval Leaks Peak Contribution	Ancillary Equipment (Transfer lines) Peak Contribution	Baseline Closure Conditions – Concen-trations at Peak Impact	Drinking Water Standard (MCL)
Technetium-99	66 pCi/L	497 pCi/L	416 pCi/L	7.4 pCi/L	871 pCi/L	900 pCi/L[b]
Iodine-129	0.14 pCi/L	0.96 pCi/L	0.82 pCi/L	0.0153 pCi/L	1.7 pCi/L	1 pCi/L[b]
Nitrate	0.073 mg/L	0.27 mg/L	0.66 mg/L	0.00829 mg/L	0.794 mg/L	44 mg/L[c]
Nitrite	0.034 mg/L	0.14 mg/L	0.26 mg/L	0.0038 mg/L	0.359 mg/L	3.3 mg/L[c]
Chromium^{+6}	0.001 mg/L	0.004 mg/L	0.0064 mg/L	0.00012 mg/L	0.0094 mg/L	0.10 mg/L[d]
Total Uranium	2.9E-7 mg/L	8.5E-6 mg/L	0.00012 mg/L	4.2E-8 mg/L	0.00012 mg/L	0.030 mg/L

[a] Includes post-retrieval residual waste contribution from 301 catch tank and 244-CR vault.
[b] The radionuclide concentrations shown are the "C4" concentration which is the concentration of the nuclide in drinking water that would result in an annual dose of 4 mrem/yr using the target organ dose methodology specified by EPA.
[c] These concentrations are for nitrate and nitrite reported as the ions. The MCLs for nitrate and nitrite, reported as nitrogen, are 10 mg/L and 1 mg/L, respectively.
[d] The MCL for chromium is for total chromium, not just chromium(VI).
EPA = U.S. Environmental Protection Agency.
MCL = maximum contaminant level.

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8.0 SHORT-TERM HUMAN HEALTH RISK APPROACH

The worker and public exposure human health risk analysis estimated the potential health impacts from both accident and normal (non-accident) conditions resulting from various scenarios for C-106 and the C farm during closure activities. However, a safety analysis that identifies accident scenarios for closure activities is currently being developed under the document safety analysis effort and will be considered in future evaluation of short-term risk. The analysis provided below shows the methodology and calculations used in a worker and public exposure risk assessment. It uses the safety analysis completed for retrieval of wastes from tanks for its accident scenarios. Thus, these are expected to provide conservatively high risk estimates because much of the waste has been removed and less contact between waste and workers is expected during closure.

The hazards associated with these activities include potential occupational hazards resulting in physical trauma, radiological exposure resulting in latent cancer fatalities (LCFs) and chemical exposure resulting in a hazard index. Initiating events that could result in hazardous health effects may include natural phenomena, human error, component failure, and spontaneous reactions. Health risks during normal conditions include anticipated exposure to radiation and chemical fields and radiological and chemical releases to the atmosphere during normal closure activities. More specific information regarding approaches is presented in the following sections.

Tank filling will present potential exposures to workers and the general public. Worker and general public exposure scenarios were developed for tank (i.e., component) closure activities. The preliminary scenario presented in this document is Phase I grouting* (i.e., stabilizing grout*) and represents the type of exposure that is expected based on planned tank closure activities. Various options for tank filling following waste retrieval will be evaluated.

Because the short-term human health risks will be encountered in the near future while the site is under physical and administrative control of DOE, it can be reasonably anticipated that the tank closure activities will be conducted in a manner that maintains exposure to tank wastes as low as reasonably achievable through the use of engineering controls and protective equipment. It is assumed that after final closure of the tanks, short-term human worker health risk will be fully mitigated. Inadvertent intruder risk is mitigated by the Modified RCRA C Barrier (Section 3.2.1).

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

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* See Preface in *SST System Closure Plan* (RPP-13774).

8.1 OCCUPATIONAL INJURIES, ILLNESSES, AND FATALITIES APPROACH

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

8.2 RADIOLOGICAL RISK FROM ACCIDENTS APPROACH

Radiological risk is expressed as the number of LCFs resulting from accidents in which people are exposed to radiation fields or radiological constituents released to the atmosphere. Radiological accidents are unplanned events or a sequence of events that result in undesirable consequences. The potential exists for radiological accidents to result from the tank closure operations. Radiological accidents could result in the unmitigated release of radiological constituents to the atmosphere, exposing the involved worker, the noninvolved worker, and general public, resulting in an LCF risk. The probability of the accident occurring also is evaluated. The methodology used to identify and quantify radiological risk from accidents is performed using the following steps.

- **Step 1. Accident Identification**. Potential hazards associated with closure activities are identified from existing preliminary hazard analyses and other safety documents. The hazards will be reported in a tabular format showing, for each accident, the barriers within the facility that prevent or mitigate the consequences of the accident, a rough estimate of the magnitude of consequences of the accident assuming that the listed preventive barriers fail, and the estimated likelihood of the accident occurring.

- **Step 2. Accident Strategy Selection**. The accident with the highest risk is screened for further analysis to determine, as accurately as possible, the consequences and probability of occurrence. The risk of a given accident is the product of the consequences of the accident and the estimated likelihood of the event occurring. Screening for the highest-risk accidents follows the same methodology as outlined in Section B.3.3.2.3.5 of *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports* (DOE-STD-3009-94). Accident frequencies are based on published safety hazard documents, for example *Tank Waste Remediation System Final Safety Analysis Report* (HNF-SD-WM-SAR-067).

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

- **Step 4. Source Term Development**. The source term is the respirable fraction of inventory from which the receptor dose is calculated. The source term is developed based on the inventory that could be released to the environment from an accident. The major reduction factors that control the source term are considered in the evaluation. The reduction factors include airborne release fractions, airborne release rates, and respirable fractions. Use of the reduction factors will be dependent upon the nature of the accident (i.e., energy of accident at impact, waste form, and effectiveness of mitigating

barriers). Exposure resulting from direct exposure to radiation under accident conditions also is evaluated. Direct exposure is the direct beta and gamma radiation dose rate to a receptor. Exposure due to ingestion would be negligible compared to inhalation and is not analyzed.

- **Step 5. Atmospheric Dispersion Coefficients.** The atmospheric dispersion coefficient (χ/Q) values are generated using the GXQ computer code in *GXQ 4.0 Program Users' Guide* (WHC-SD-GN-SWD-30002) following the methodology outlined in *Atmospheric Dispersion Models for Potential Accident Consequence Assessment at Nuclear Power Plants* (NUREG 1.145). The meteorological data used by the GXQ code are in the form of joint frequency tables. The joint frequency data are taken from data collected at the Hanford Site meteorology tower in the 200 Areas. The atmospheric dispersion coefficient values are used in equations to calculate the radiological dose experienced by the involved and noninvolved worker and general public receptors as a result of inhaling radioactive materials. Ingestion of radioactive materials is also included for the general public receptor dose.

- **Step 6. Receptor determination.** Potential health effects from radiological exposures are estimated for three subsets of populations and maximally exposed individuals (MEI) in those populations. The dose to a receptor depends on the location of the receptor relative to the point of release of the radioactive material. The involved workers are those involved in the proposed action and are performing work at the facility. Those workers are assumed to be in the center of a 10 m (33 ft) radius hemisphere where the airborne released material has spread instantaneously and uniformly. The noninvolved workers are those that would be on the Hanford Site but not involved in the action. Those workers are assumed to extend from 100 m (330 ft) out to the Hanford Site boundary. The general public is assumed to be located at the Site boundary to a distance of 80 km (50 mi) from the point of release. The Hanford Site boundary used in the analysis is the adjusted Site boundary that excludes areas designated as part of the Hanford Reach National Monument ("Establishment of the Hanford Reach National Monument" [65 FR 7319]). Those areas include the North Slope, the Hanford Reach of the Columbia River, and the Fitzner-Eberhardt Arid Lands Ecology Reserve. The Site boundaries are as follows:

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

- **Step 7. Radiological dose assessment.** The inventory involved in each accident is evaluated to determine the activity concentrations. The activity concentrations are converted to unit liter dose factors. A single unit inhalation dose factor for each composite source term for a 50-year dose commitment period is taken from *Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments*

(HNF-SD-WM-TI-707 Rev. 3). The receptor doses are given in terms of committed effective dose equivalents. The unit inhalation dose factors are used with the appropriate atmospheric dispersion coefficient, breathing rates, and the source term to determine the radiological dose to the involved worker, noninvolved worker, and general public receptors.

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

  - **Involved worker and noninvolved worker**: 4.0×10^{-4} LCF/rem for low doses less than 20 rem and 8.0×10^{-4} LCF/rem for doses greater than or equal to 20 rem.

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

8.3 RADIOLOGICAL LATENT CANCER FATALITY RISK FROM ROUTINE EXPOSURE APPROACH

Closure activities require radiation workers to work in radiation zones during the construction and installation of closure equipment and during closure operations. Due to the nature of the work in a radiation zone, the workers will be exposed to and receive a radiological dose from ionizing radiation. The involved worker exposure is a combination of exposure from inhalation and direct radiation. Involved worker dose rates are estimated based on time, distance, and shielding considerations associated with the various tasks. Atmospheric emissions will also result from closure activities. Although the emissions are first filtered through high-efficiency particulate air filters, the abated emissions related to the atmosphere and carried downwind will be inhaled by onsite workers and the offsite population, resulting in an exposure and subsequent dose. Noninvolved worker and general public exposure are estimated by determining the expected routine radiological releases during closure. Exposure to the noninvolved worker is assumed to be from inhalation and external radiation from the plume continuously throughout the year, and from deposition of radionuclides on the ground. The offsite population will receive an additional dose from ingesting radiological contaminants attached to food substances such as fruits, vegetables, meat, and milk. Every effort is made to reduce the exposures to the radiation workers and the air emissions, but the exposures are still anticipated and are considered routine. The risk from these exposures is measured in terms of LCFs.

This analysis considers the risk from routine radiological exposures to three receptor groups of people and an MEI from each group:

- **Involved workers**: Radiation workers in radiation zones directly involved in the construction and closure operation activities.

- **Noninvolved workers**: Hanford Site workers distributed within the Hanford Site boundary but no closer than 100 m (328 ft) from the source of the emissions.

- **General public**: Offsite population distributed from the Hanford Site to a distance of 80 km (50 mi).

The LCF risk is calculated by multiplying the dose (in units of person-rem for the population and rem for the MEI) by an appropriate dose-to-risk conversion factor (in units of LCF/person-rem for the population and LCF/rem for the MEI). The involved worker population dose resulting from construction and operations is based on worker exposures to support closure of C-106 in *Engineering Report for Interim Closure of Tank 241-C-106 and the 241-C Farm 200-Series Tanks* (RPP-14590). The involved worker MEI dose is based on a current site administrative control of 0.5 rem/yr (*Tank Farms Radiological Control Manual (TFCRM)* [HNF-5183]).

Exposures to the noninvolved workers and general public are from abated air emissions of radionuclides. The radionuclides released in the abated air emissions are then used as input to the GENII computer code (*GENII – The Hanford Environmental Radiation Dosimetry Software System* [PNL-6584]). The GENII system has been designed for calculating radiation doses for acute and chronic releases. It evaluates direct exposure, inhalation and ingestion pathways and targeted populations identified by distance and direction for individuals and populations. Atmospheric dispersion coefficients used in the GENII code are calculated using the GXQ computer code (WHC-SD-GN-SWD-30002).

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

8.4 CHEMICAL EXPOSURE FROM ACCIDENTS

The chemical inventory used for this assessment is made up of two components, the organic chemicals and the inorganic chemicals. The emission rates for organic chemicals are taken from *Organic Vapor Source Term for Tanks 241-C-201, 241-C-202, 241-C-203, and 241-C-204 During Waste Retrieval Operations*, RPP-14841. The emission rates for inorganic chemicals are taken from *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment*, HNF-SD-WM—TI-707. Potential acute hazards associated with exposure to concentrations of postulated accidental chemical releases were evaluated using a screening-level approach for the receptors. This involves directly comparing calculated exposure point concentrations of chemicals to a set of air concentration screening criteria, known as emergency response planning guidelines (ERPGs). The ERPGs, as developed by the American Industrial Hygiene Association, are specific levels of chemical contaminants in air designed to be protective of acute adverse health impacts for the general population. ERPGs are the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing the following effects:

- ERPG 1 - Mild transient adverse health effects or perceiving a clearly defined objectionable odor
- ERPG 2 - Irreversible or other serious health effects, or symptoms that could impair ability to take protective action
- ERPG 3 - Irreversible or life-threatening health effects could result from exposures exceeding one hour.

In the event that an ERPG value does not exist, DOE requires the use of Threshold Emergency Exposure Limit (TEEL) values. Like the ERPGs, there are multiple levels of TEELs as follows:

TEEL-0 The threshold concentration below which most people will experience no appreciable risk of health effects;

TEEL-1 The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

TEEL-2 The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action;

TEEL-3 The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.

Cumulative hazards or the acute hazard index (HI) for toxic and corrosive/irritant chemical classes were evaluated using the following equation.

$$HI = \sum \frac{C_{chemical}}{ERPG_{chemical}}$$

where:

HI is the cumulative hazard index for acute exposure

$C_{chemical}$ is the concentration at the exposure point of each chemical (mg/m^3)

$ERPG_{chemical}$ is the ERPG (or TEEL if no ERPG available) for each chemical (mg/m^3).

A cumulative HI is calculated for each ERPG/TEEL level (1, 2, and 3). If the HI is greater than 1.0 indicates that the acute hazard guidelines for a mixture of chemicals has been exceeded and the chemical mixture may pose a potential acute health impact. The potential impact is described in the level definition shown above. To be consistent with previous tank farm worker risk assessments and DOE guidance TEELs and ERPGs were chosen as the hierarchy approach versus other hierarchy approaches used in the WTP risk assessment on-site.

Determining the accidents to be used in the strategies, the source term, atmospheric dispersion coefficients, and the receptor location followed the same methodology as that applied to radiological risk from accidents in Section 8.2.

8.5 CHEMICAL HAZARDS FROM ROUTINE EXPOSURE

The chemical inventory used for this assessment is made up of two components, the organic chemicals and the inorganic chemicals. The emission rates for organic chemicals are taken from RPP-14841. The emission rates for inorganic chemicals are taken from HNF-SD-WM—TI-707.

To estimate the potential noncarcinogenic effects from exposure to multiple chemicals, the HI approach was used consistent to EPA methodology that was used in DOE/EIS-0189 and DOE/RL-98-72. The HI is defined as the summation of the inhalation HQ (chemical concentration divided by the reference concentration [RfC] for that chemical). This HI was calculated as follows:

$$HI = \sum \frac{C_{chemical}}{RfC_{chemical}} \qquad (8\text{-}2)$$

where:

HI is the cumulative hazard index for acute exposure

$C_{chemical}$ is the concentration at the exposure point of each chemical (mg/m^3)

$RfC_{chemical}$ is the reference concentration of the chemical from the EPA IRIS database (mg/m^3).

A total HI less than or equal to 1.0 is indicative of acceptable levels of exposure.

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9.0 SHORT-TERM HUMAN HEALTH RISK CALCULATION

Short-term human health risk calculation will be based on RPP-14590. That report evaluates closure activities for C-106 with its current inventory and schedule. This section provides the calculation detail and results for the short-term human health risk analysis. The analysis focuses on two evaluation cases involving:

- Phase I grouting* of C-106
- Phase I grouting* of the worst-case 200-series tank in the C farm, except where otherwise noted.

9.1 OCCUPATIONAL ACCIDENT RISK CALCULATION

The potential exists for accidents (e.g., cuts, falls) to occur resulting from construction and operation activities associated with component closure (i.e., tank closure). The occupational injuries, illnesses, and fatalities resulting from potential accidents are calculated based on the following assumptions:

- C-106 labor requirements for Phase I grouting* of the tank

  Phase I grouting* of tank = 3,800 hours

  Phase I grouting* of all C farm tanks = 60,800 hours.

- Hanford-specific incidence rates for occupational accidents

  Total recordable cases = 1.93×10^{-5} total recordable cases/hour

  Lost workday cases = 8.04×10^{-6} lost workday cases/hour

  Fatalities = 1.35×10^{-8} fatalities/hour.

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* See Preface in *SST System Closure Plan* (RPP-13774).

The number of incidences (I) resulting from potential occupational accidents is calculated using Equation 9.1 and presented in Table 39.

$$I = L \times ir \qquad (9\text{-}1)$$

Where:

I = incident
L = labor requirement (hours)
ir = incidence rates (I/hour).

Table 39. Worker Risk From Occupational Accidents

Case	Incidence	Tank	
		C-106	All
Phase I grouting* of C-106	TRC	7.3 E-02	NA
	LWC	3.1 E-02	NA
	Fatalities	5.1 E-05	NA
Phase I grouting* of all C farm tanks	TRC	NA	1.2 E+00
	LWC	NA	4.9 E-01
	Fatalities	NA	8.2 E-04

LWC = lost workday case
NA = not applicable
TRC = total recordable case

9.2 RADIOLOGICAL ACCIDENT RISK

Past safety assessments were used for the radiological accident risk. A spectrum of potential accidents associated with from C-106 is reviewed in *Safety Assessment for Tank 241-C-106 Waste Retrieval Project W-320* (WHC-SD-WM-SAD-024). Several of the more bounding accidents identified in the safety assessment are summarized in Table 40. The WHC-SD-WM-SAD-024 safety assessment was used to provide the technical basis for a change to the authorization basis to allow the Project W-320 retrieval of high-heat waste from C-106 to tank AY-102 to proceed. An additional review in *Preliminary Hazard Identification and Evaluation for the Tank 241-C-106 Waste Heel Retrieval Demonstration* (10245-CD-006) identifies several more potential accidents that are not identified in WHC-SD-WM-SAD-024. These accidents are also summarized in Table 40. The ventilation failure accident with a high severity level (major onsite and offsite impacts on people) and an extremely unlikely probability (1.0×10^{-4} to 1.0×10^{-6}) was selected for evaluation in this analysis because it was determined to be a bounding accident.

* See Preface in *SST System Closure Plan* (RPP-13774).

Table 40. Preliminary Hazard Analysis

Accident	Consequences	Mitigative/Preventive Barriers		Severity Level	Probability
		Administrative	Engineered		
Opening a riser[a]	Increases exposure to worker from direct radiation and release of radiological contaminants	Surveillance by radiation protection technician Radiological workers will wear personal protective gear while removing risers	Radiation detectors	Low	Likely
Flammable gas deflagration[b]	Energy from deflagration could compromise the tank dome or ventilation system resulting in release of radiological contaminants and exposure to the workers Potential trauma to workers from deflagration	Flammable gas control	Tank ventilation system	High	Extremely unlikely
Spray leak from transfer line[a]	Spray leak from transfer line resulting in release of radiological contaminants and exposure to the workers	Operator surveillance	Cover block over jumper pit Leak detection Radiation detectors	High	Unlikely
Ventilation failure[a]	Ventilation failure resulting in unfiltered release of radiological contaminants and exposure to the workers	Evacuation procedures	Differential pressure alarms	High	Extremely unlikely
Natural phenomena[a]	Seismic event comprises waste tank or transfers lines resulting in release of radiological contaminants and exposure to the workers	Evaluation procedures	Seismic switch on transfer pump	Medium	Extremely unlikely

[a]Accident taken from WHC-SD-WM-SAD-024.

[b]Accident taken from 10245-CD-06.

During the ventilation failure accident, a volume of waste with a concentration of radionuclides would be released to the atmosphere, dispersed in the atmosphere as it travels downwind from

the point of release, inhaled by the various receptors, and result in an LCF risk. The following assumptions were made in calculating the LCF risk:

- Volume of respirable waste released in the accident is as calculated in *Potential Accidents with Radiological and Toxicological Source Terms for Hanford Tank Waste Remediation System Environmental Impact Statement* (WHC-SD-WM-ANAL-041).
- Concentration of radionuclides is calculated from the inventory presented in DOE/ORP-2003-02 and provided in Table 8b.
- For the noninvolved workers and general public exposure scenarios, the atmospheric dispersion coefficients were calculated using the GXQ computer code (WHC-SD-GN-SWD-30002).
- For the involved workers it was assumed the respirable waste released in the accident would be released as a "puff" and spread instantaneously and uniformly around the exhaust port over a hemisphere 10 m (33 ft) in radius (WHC-SD-WM-ANAL-041).
- Breathing rates for the various receptors are provided in HNF-SD-WM-TI-707.
- Inhalation dose conversion factors for a 70-year dose commitment for each radionuclide are taken from HNF-SD-WM-TI-707.
- Dose-to-risk conversion factors for converting receptor doses to LCFs are referenced in "Preamble to Standard for Protection Against Radiation" (56 FR 23363) and ICRP (1991) and apply as follows:

  Involved worker and noninvolved worker = 4.0×10^{-4} LCF/rem for low doses under 20 rem, 8.0×10^{-4} LCF/rem for high doses over 20 rem

General public = 5.0×10^{-4} LCF/rem for low doses under 20 rem, 1.0×10^{-3} LCF/rem for doses equal to or over 20 rem.

The number of accidents is calculated by multiplying the annual frequency of the accident by the time required to perform the activity. The annual frequency of a ventilation failure accident is referenced in WHC-SD-WM-ANAL-041. The time required to close the tanks was based on RPP-14590.

It is estimated that the involved workers would receive a dose within 15 minutes from tanks C-106 and a worst-case 200-series C farm tank. The dose to the involved workers resulting from a postulated ventilation failure accident is calculated using Equation 9.2:

$$D = IQ\ (L) \times BR(m^3/s) \times t(s) \times (2/3 \times \pi r^3)^{-1} \times ULD(mrem/L) \qquad (9\text{-}2)$$

Where:

IQ = liters of respirable tank waste released, 5 L (1.3 gal)

BR = typical acute breathing rate, 3.0 E-04 m^3/s

t = duration of worker exposure, 15 minutes for C-106 and worst-case C farm 200-series tank

r = assumed radius for distribution of source activity, 10 m (33 ft)

ULD = committed EDE per unit liter inhaled of inhaled material (mrem/L) summed over the list of nuclides (i.e. $\sum$ ($IDF_{nuclide}$ x $Concentration_{nuclide}$) (IDF taken from Table A.22 from WHC-SD-WM-TI-707)

The LCF risk to the noninvolved workers and general public resulting from a postulated ventilation failure accident is calculated using Equation 0.3:

$$LCF = IQ\ (L) \times BR(m^3/s) \times \chi/Q\ (s/m^3) \times ULD\ (rem/L) \times cf\ (LCF/rem) \quad (9\text{-}3)$$

Where:

IQ = liters of respirable tank waste released, 5 L (3.7 gal)

BR = typical acute breathing rate, 3.0 E-04 m^3/s

χ/Q = atmospheric dispersion coefficient, (taken from RPP-12194)

1.13 E-02 s/m^3, noninvolved worker MEI

2.65 E-01 s/m^3, noninvolved worker population

1.34 E-05 s/m^3, general public MEI

4.86 E-02 s/m^3, general public population

ULD = committed EDE per unit liter inhaled of inhaled material (mrem/L) summed over the list of nuclides (i.e. $\sum$ ($IDF_{nuclide}$ x $Concentration_{nuclide}$) (IDF taken from Table A.22 from WHC-SD-WM-TI-707)

Cf = dose-to-risk conversion factor,

8.0 E-04 LCF/rem for the noninvolved worker receptors for doses over 20 rem

4.0 E-04 LCF/rem for the noninvolved worker receptors for doses under 20 rem,

5.0 E-04 LCF/rem for the general public receptors.

Applying Equation 9.2 for the involved worker and Equation 9.3 for the noninvolved worker and general public the LCF risk to the various receptors are calculated and summarized in Table 41.

Table 41. Latent Cancer Fatality Risk
From Ventilation Failure Accident

Receptor	C-106[a]	C Farm[b]
IW MEI	LD[c]	LD[c]
IW Pop	LD[c]	LD[c]
NIW MEI	0.17	2.7
NIW Pop	4.0	62.3
GP MEI	1.0 E-04	1.6 E-03
GP Pop	0.74	11.4

[a] LCF risk from ventilation failure accident during Phase I grouting.*
[b] LCF risk from ventilation failure accident from the worst-case tank.
[c] LD = lethal dose for involved worker within 15 minutes of exposure
GP MEI = general public maximum exposed individual.
GP Pop = general pubic population.
IW MEI = involved worker maximum exposed individual.
IW Pop = involved worker population.
LCF = latent cancer fatality.
NIW MEI = noninvolved worker maximum exposed individual.
NIW Pop = noninvolved worker population.

The values shown in Table 41 represent the statistical probability of cancer fatality resulting from exposure to radioactive material released from a ventilation failure accident. The values in Table 41 represent the most conservative case for exposure (i.e. resulting from ventilation failure accident with a extremely unlikely probability of occurring [Table 40]). In the event of an actual accident occurring, numerous safety protocols would be invoked to mitigate of the effects to the NIW MEI and population (*Tank Farms Documented Safety Analysis* [RPP-13033, Rev. 0]).

The frequency for a ventilation failure is estimated to range from 1.1×10^{-4} per year to 8.0×10^{-3} per year (WHC-SD-WM-ANAL-041). The time of Phase I grouting* is estimated to be approximately two years (RPP-14590). Therefore, the probability of the accident is calculated as follows:

$$\text{C-106 Phase I grouting}^* = (1.1\ \text{E-04/yr}) \times (2\ \text{yr}) = 2.2\ \text{E-04}.$$

The point estimate risks are calculated by multiplying the receptor LCF risk by the probability of the accident occurring. The results are summarized in Table 42.

* See Preface in *SST System Closure Plan* (RPP-13774).

Table 42. Point Estimate Risk From Ventilation Failure Accident.

Case	Receptor	C-106	C Farm
Phase I Grouting*	IW MEI	2.2 E+01	1.4 E-00
	IW Pop	2.2 E+01	1.4 E-00
	NIW MEI	3.8 E-05	5.9 E-04
	NIW Pop	8.8 E-04	1.4 E-02
	GP MEI	2.3 E-08	3.5 E-07
	GP Pop	1.6 E-04	2.5 E-03

GP MEI = general public maximum exposed individual.
GP Pop = general pubic population.
IW MEI = involved worker maximum exposed individual.
IW Pop = involved worker population.
NIW MEI = noninvolved worker maximum exposed individual.
NIW Pop = noninvolved worker population.

The values shown in Table 42 represent the statistical probability of cancer fatality resulting from exposure to radioactive material released from a ventilation failure accident occurring during Phase I Grouting*. The values presented 42 represent the most conservative case for exposure (i.e. resulting from a ventilation failure accident with an extremely unlikely probability of occurring [Table 40]). In the event of an actual accident occurring, numerous safety protocols would be invoked to mitigate of the effects to the IW MEI and population and NIW MEI and population (*Tank Farms Documented Safety Analysis* (RPP-13033, Rev. 0)).

9.3 ROUTINE RADIOLOGICAL EXPOSURE RISK

The LCF risk is calculated by multiplying the dose (in units of person-rem for the population and rem for the MEI by an appropriate dose-to-risk conversion factor (in units of LCF/person-rem for the population and LCF/rem for the MEI). The involved worker population dose resulting from construction and operations is based on worker exposures to support closure of C-106 in RPP-14590. The involved worker MEI dose is based on a current site administrative control of 0.5 rem/yr (HNF-5183).

The LCF risk from routine radiological exposures to the various receptor populations and MEIs is calculated using Equation 9.4:

$$LCF = D \times cf \qquad (9\text{-}4)$$

Where:

D = Dose to the receptor (person-rem [population] or rem [MEI])

cf = Dose-to-risk conversion factor (LCF/person-rem [population] or LCF/rem [MEI]).

* See Preface in *SST System Closure Plan* (RPP-13774).

The dose to the involved worker population for the Phase I grouting* of C-106 is based on (RPP-14590). The dose from Phase I grouting* is estimated as follows:

Phase I grouting for C-106 – The dose is equal to the sum of the doses from the following activities (RPP-14590) and is typical for only C-106.

6.13 person-mrem; riser installation

+ 3.71 person-mrem; Phase I grouting*

= 9.84 person-mrem; total dose

Phase I grouting* of worst-case 200-series tank – The dose is equal to the sum of the doses from the following activities (RPP-14590) and is typical for only C-106.

6.13 person-mrem; riser installation

+ 3.71 person-mrem; Phase I grouting*

= 9.84 person-mrem; total dose

The dose to the non-involved workers and general public are based on air emissions that are scaled from the abated air emissions and presented in Table 43.

Table 43. Abated Air Emissions from Retrieval Activities.

Radionuclide	Abated Air Emissions (Ci/yr)	
	C-106	Worst-Case Composite Tank
C-14	6.4 E-12	5.2 E-09
Co-60	1.9 E-10	8.5 E-07
Sr-90	2.2 E-04	6.9 E-03
Technetium-99	8.0 E-10	9.1 E-08
Iodine-129	6.4 E-12	4.3 E-10
Cs-137	8.9 E-06	4.1 E-04
Pu-239	5.8 E-08	5.0 E-06
Pu-240	1.2 E-08	7.7 E-07
Am-241	1.8 E-07	5.5 E-06

Note: Tank inventory was based on DOE/ORP-2003-02.

* See Preface in *SST System Closure Plan* (RPP-13774).

The radionuclides released in the abated air emissions are then used as input to the GENII computer code (PNL-6584) to calculate the dose. The atmospheric dispersion coefficients for exposures used in the GENII code that are calculated using the GXQ computer code are summarized as follows:

- Noninvolved worker MEI = 4.0×10^{-4} s/m^3
- Noninvolved worker population = 1.8×10^{-2} s/m^3
- General public MEI = 1.0×10^{-7} s/m^3
- General public population = 2.9×10^{-3} s/m^3.

These values are chronic and calculated from extensive meteorological data. The doses generated from the GENII computer code for the Phase I grouting* are presented in Table 44.

Table 44. Dose From Routine Radiological Exposure

Receptor	C-106 (mrem/yr)	Worst-Case Composite Tank (mrem/yr)	Regulatory Limit (mrem/yr)
	Dose (person-mrem/yr for population or mrem/yr for MEI)		
NIW MEI	4.4 E-01	1.8 E+01	5,000
NIW Pop	1.0 E+01	4.3 E+02	NA
GP MEI	5.2 E-04	2.2 E-02	100
GP Pop	1.9 E+00	7.9 E+01	NA

GP MEI = general public maximum exposed individual.
GP Pop = general public population.
NIW MEI = noninvolved worker maximum exposed individual.
NIW Pop = noninvolved worker population.

Applying Equation 9.4 with the appropriate dose values estimated for the Phase I grouting* and using the appropriate dose-to-risk conversion factors, the LCF risk to the various receptor populations and MEIs are calculated and presented in Table 45.

* See Preface in *SST System Closure Plan* (RPP-13774).

Table 45. Latent Cancer Fatality Risk
From Routine Radiological Exposure

Receptor	C-106 (LCF/yr)	Worst-Case Composite Tank (LCF/yr)
IW MEI	2.0 E-04	2.0 E-04
IW Pop	4.0 E-06[2]	4.0 E-06
NIW MEI	1.8 E-07	7.2 E-06
NIW Pop	4.0 E-06	1.7 E-04
GP MEI	2.6 E-10	1.1 E-08
GP Pop	9.5 E-07	4.0 E-05

[1] Dose used for involved worker MEI was 500 mrem/yr
[2] Dose used for IW population was 9.84 person-mrem/yr.
GP MEI = general public maximum exposed individual.
GP Pop = general public population.
IW MEI = involved worker maximum exposed individual.
IW Pop = involved worker population.
NA = not applicable.
NIW MEI = noninvolved worker maximum exposed individual.
NIW Pop = noninvolved worker population.

9.4 CHEMICAL ACCIDENTS RISKS

The chemical inventory is presented in Table 46 and represents the same inventory as used in RPP-14841. The chemical inventory is from tank C-204. Organic pollutant release concentrations and ammonia release concentrations were calculated assuming that 900 m3/hr of air containing the pollutant concentrations observed in tank C-204 are exhausted year around. In addition the mean concentrations of the organic pollutant and ammonia release were increased by 2 times the standard deviation to reflect statistical variability in the results. Two times the standard deviation represents a 95 percent confidence that the actual concentration is bounded. Therefore, the results for the cumulative hazards or the acute hazard index is extremely conservative. The cumulative hazards or the acute hazard index (HI) for chemicals was evaluated using the following equation.

$$HI = \sum \frac{C_{chemical}}{ERPG_{chemical}}$$

Where:

HI is the cumulative hazard index for acute exposure

$C_{chemical}$ is the concentration at the exposure point of each chemical (mg/m3)

$ERPG_{chemical}$ is the ERPG (or TEEL if no ERPG available) for each chemical (mg/m3).

A cumulative HI is calculated for each ERPG/TEEL level (1, 2, and 3). If the HI is greater than 1.0 indicates that the acute hazard guidelines for a mixture of chemicals has been exceeded and the chemical mixture may pose a potential acute health impact. Table 46 shows the results of the accident hazard index.

Table 46. Chemical Risk from Accident – Hazard Index.

Activity	TEEL-0	TEEL-1	TEEL-2	TEEL-3
Involved Worker	1.86 E+01	7.09 E+00	1.02 E+00	6.63 E-02
Noninvolved Worker	5.25 E-02	2.00 E-02	2.98 E-03	1.94 E-04

For the involved worker, TEEL-2 is the corresponding potential health impact. For the noninvolved worker and general public, TEEL-0 is the corresponding health impact. The general public MEI would be exposed to concentrations less than the ERPG-1 threshold values, which translates to no expected health effects.

9.5 ROUTINE CHEMICAL EXPOSURE

Routine chemical exposure from noncarcinogenic chemicals were evaluated. Table 47 presents the noncarcinogenic health impacts as hazard index for all the chemicals with reference inhalation dose factors.

Table 47. Chemical Noncarcinogenic Hazard Index[(1)].

CAS	Name	Reference Concentration RfC (mg/m^3)	Hazard Quotient HQ
7440-47-3	Cromium(VI) [(2)]	1 E-04	4.6 E-05
7439-97-6	Mercury	3 E-04	3.3 E-06
7439-96-5	Manganese	5 E-05	3.3 E-03
100-41-4	Ethyl benzene	1 E+00	1.2 E-02
106-99-0	Butadiene,1,3-	2 E-03	5.1 E+02
108-10-1	Methyl isobutyl ketone; (Hexone)	3 E+00	8.5 E-03
108-88-3	Benzene, methyl (Toluene)	4 E-01	4.5 E-01
110-54-3	Hexane	2 E-01	2.5 E-01
110-82-7	Cyclohexane	6 E+00	1.0 E-02
71-43-2	Benzene	3 E-02	4.0 E-01
74-87-3	Methyl chloride	9 E-02	1.5 E-01
75-05-8	Acetonitrile	6 E-02	5.8 E+00
75-07-0	Acetaldehyde	2.2 E-03	1.2 E+02

Table 47. Chemical Noncarcinogenic Hazard Index[1].

CAS	Name	Reference Concentration RfC (mg/m^3)	Hazard Quotient HQ
75-68-3	Chloro-1,1-difluoroethane, 1-; (HCFC-142b)	5 E+01	1.8 E-02
7664-41-7	Ammonia	1 E-01	6.7 E-03
78-93-3	Butanone, 2-; (MEK)	5 E+00	1.3 E-01
Total Hazard Index (HI):			**6.4 E+02**

[1] For convenience only the substances with available RfC are listed.
[2] 33% of total Chromium assumed to be Cr(VI)

The hazard quotients (HQs) calculated here are based on conservative maximum emission concentrations from the C Farm tanks as listed in RPP-14841. These estimates were developed to describe a maximum anticipated emissions concentration for each chemical species for which there was data. This data represents the HI to the IW MEI without any mitigation. Current tank farm safety protocols require respiratory protection which would mitigate the exposure and risk to the IW MEI.

10.0 SUMMARY AND CONCLUSIONS

The scope of this initial closure risk assessment was to provide estimates of short- and long-term human health risks related to closure activities and the anticipated endstate conditions at WMA C. Additionally, this document is being prepared before any waste retrieval to support closure has been performed. Therefore, the focus of this document was not only to provide estimates of short- and long- term human health risks using existing data, but also to present the methods, procedures, existing data, and analysis approaches.

This report concludes that residual tank waste alone contributes to a concentration of 66 pCi/L for technetium-99 and 0.14 pCi/L for iodine-129 (Table 38). The calculated peak residential drinking water dose for all beta/photon emitters, is 0.097 mrem in a year (Table 29) at the WMA C fenceline with the peak occurring approximately 3,500 years after closure. Technetium-99 and iodine-129 make up approximately 90 % of the dose. This dose is below the DOE Order 5400.5 (II)(d) value of 4 mrem in a year. The simulated peak concentration at the WMA C fenceline attributed to unplanned releases and hypothetical retrieval leaks for technetium-99 is 497 pCi/L and 416 pCi/L (table 38), respectively, while the peak concentration for iodine-129 for those same sources is 0.96 pCi/L and 0.82, respectively (Table 38). The calculated peak residential drinking water dose for these sources is 0.8 mrem in a year (Table 32) and 0.62 mrem in a year (table 35), respectively.

As one moves downgradient from the WMA C fenceline to the 200 Area core zone boundary (2,900 m from the WMA C fenceline) and the Columbia River (14,300 m from the WMA C fenceline), the simulated peaks (concentration, dose, ILCR, and HI) drop by a factor of approximately 6 (Core Zone Boundary and 18 (Columbia River).

10.1 LONG-TERM HUMAN HEALTH RISK

This preliminary risk assessment highlights analyses and findings when data is sufficient and identifies gaps in existing data. Reasonable assumptions have been made, of necessity, when the data is insufficient or absent to enable the long-term human health risks to be estimated for C farm and tentative conclusions to be drawn. Implications of the conclusions on retrieval are included.

Where the data is insufficient or absent, additional data collection should be accomplished before preparation of the risk assessment after closure. Such additional data should improve the accuracy of analyses after closure, and strengthen the analyses and conclusions in the post-closure document.

10.1.1 C Waste Management Area Risk

Assumptions

Conclusions concerning risk are based on the simulation of COCs released from the entire closed WMA C incorporate the following major assumptions:

- A surface water infiltration barrier that lasts 500 years is present at the end of tank closure.

- Residual tank waste contents are based on selected phase retrieval to the HFFACO goal of 360 ft^3 for the 100-series tanks and 30 ft^3 for the 200-series tanks.

- Tanks are filled with a cement-based grout*.

- Long-term infiltration returns to desert conditions (3.5 mm/yr) (after 500 years).

Related Data Gaps

- BBI data has been used to represent the concentrations of contaminants that are expected to be present in the C farm tanks after interim closure. The representativeness of this data can only be confirmed by sampling and analysis performed after retrieval.

- Concentration of retrieval leaks is calculated based on hypothetical leak volumes divided by the estimated total volume of fluids used for retrieval and the multiplying by the total BBI for the tank.

- Data on contaminant concentrations in the vadose zone at C farm has been obtained from various existing sources. Detailed analysis of contamination in the vadose zone at C farm will be provided in a field investigation report for C farm. This report will incorporate new data obtained from future characterization drilling. The C farm field investigation report is scheduled for completion in fiscal year 2006.

- The hydraulic conductivity of the unconfined aquifer is based on both laboratory measurements and field-testing in other parts of the 200 East Area. Site-specific hydraulic conductivity of the unconfined aquifer in the vicinity of WMA C is not presently available. However, RCRA monitoring well, which penetrates to the base of the aquifer, will be placed just to the north of the WMA in the summer of 2003. During the development of this well, an estimate of the hydraulic conductivity of the unconfined aquifer will be made.

Conclusions

- The primary contributors to groundwater contamination are contaminants contained in past leaks from tanks and ancillary equipment and that have $K_d = 0.0$ mg/L.

- The placement of the surface barrier greatly reduces recharge through vadose contamination, which results in a decrease in the predicted groundwater concentration until the barrier degrades.

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* See Preface in *SST System Closure Plan* (RPP-13774).

- Key parameters affecting the predicted groundwater contaminant concentrations resulting from tank residual waste releases are inventory, groundwater flow rate under the WMA, recharge, release rate, and contaminant mobility (i.e., K_d).

- Past leaks potentially have the largest impact (depending upon inventory).

- Retrieval of tank residuals to levels at or near the HFFACO goal of 360 ft^3(100-series tanks) and 30 ft^3 (200-series tanks) can reduce fenceline concentrations to below the MCL or MCL derived constituent concentration.

- The foundation for the risk assessment calculations presented in this document is the inventory established by the BBI, which is based on both process knowledge and sampling data. Over time as more knowledge about a tank becomes available, the inventory estimates for a tank are updated. In some cases, this has led to significant changes in inventory values. Post-retrieval sampling and analysis of residuals must be made to further assess the risk associated with the residuals. The risk assessment presented here could easily over/under estimate the risk without this information.

10.1.2 Tank Waste Release Mechanism

The retrieval approach determines the contaminant release mechanism of the remaining waste in each tank at C farm. Thus, the retrieval approach selected directly affects the long-term human health risk assessment.

Assumptions

- The impacts of three tank waste release mechanisms were simulated because the stabilized waste form for each tank in C farm has not been determined. Simulations chosen were:

  A diffusion-dominated release mechanism corresponding to a stabilized waste form covered with grout or cementitious grout*.

  An advection-dominated release mechanism corresponding to an unstabilized waste form covered with sand and gravel backfill.

  A solubility-dominated mechanism corresponding to a material that releases risk driving contaminants congruently with the dissolution of the waste form, such as saltcake releases.

- The diffusion-dominated release mechanism is assumed to be the release mechanism.

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* See Preface in *SST System Closure Plan* (RPP-13774).

Related Data Gaps

- The waste form that will remain in each of the C farm tanks is continuing to be evaluated through engineering and regulatory reviews.

- There is minimal laboratory data for the C farm tanks that is available to support the choice of the three release models included in this risk document.

Conclusions

- The residual waste inventory has a dominant influence on the second peak concentration at the fenceline. If the inventory is contained within the aqueous phase of the waste form, and the release from the waste form is advection-dominated, the peak concentration based on the BBI is 9,640 pCi/L (Figure 11a) for technetium-99, With retrieval to HFFACO limits, the resulting peak concentration is 210 pCi/L (Figure 11b) for the advection dominated model. The MCL Derived Constituent Concentration for technetium-99 is 900 pCi/L

- If the release mechanism is diffusion-dominated, retrieving waste to HFFACO goals reduces the technetium-99 concentration from 3030 pCi/L (Figure 11a) to 65 pCi/L (Figure 11b).

Implications to Retrieval and Closure

Determining the type of release form of waste from each C farm tank is important in direct proportion to the amount of waste that remains in the tank after waste retrieval. The more waste left behind, the more important the release model becomes.

10.1.3 Quantitative Dose and Risk Estimates

Comparison of the dose and risk estimates with the performance objectives show that the performance objectives are satisfied in all, but a few cases. Larger values occur for wastes containing the largest inventories of mobile constituents (past leaks) and for groundwater collected closest to the WMA C fenceline. DOE/RL-91-45 industrial and residential exposure scenarios were used for this analysis.

Conclusions

- Following retrieval of tank waste to meet the maximum residual specified in the HFFACO, known past leaks are responsible for the largest peak values for dose and cancer risk (Figures 25 and 27).

- Radiological dose does not exceed the performance objected for any of the sources at the WMA C fenceline (Figure 27).

- ILCR exceeded the target value of 1.00×10^{-5} for tank residuals at the WMA C fenceline, but not at downgradient Core Zone Boundary or at the Columbia River for DOE/RL-91-45 residential receptor with technetium-99 responsible for the majority of

the estimated risk. For unplanned releases ILCR was below the target value of 1.00×10^{-5} for the industrial scenario, but not the residential scenario, which was above the target value at the fenceline, core zone boundary, and Columbia River. For hypothetical retrieval leaks, ILCR was below the target value of 1.00×10^{-5} for the industrial scenario, but not the residential scenario, which was above the target value at the fenceline, and core zone boundary, but not the Columbia River (Tables 30, 33, and 36)

- Hazard Index did not exceed the target value for residual waste, past unplanned releases or hypothetical retrieval leaks for any of the scenarios presented (Tables (31, 34, and 37)

10.2 SHORT-TERM HUMAN HEALTH RISK

The short-term human health risk analysis estimated the potential health impacts from both accident and normal (nonaccident) conditions resulting from various scenarios for C-106 and the C farm during closure activities. However, at this point in time, a safety analysis that identifies accident scenarios for closure activities has not been prepared. The analysis provided in this paper was to show the methodology and calculations, which will be used in a short-term human health risk assessment. It uses the safety analysis completed for retrieval of wastes from tanks for its accident scenarios.

Assumptions

For occupational injuries, illnesses, and fatalities resulting from potential accidents are calculated based on the following assumptions:

- C-106 labor requirements for Phase I grouting* of the tank
  - Phase I grouting* of tank = 3,800 hours
  - Phase I grouting* of all C farm tanks = 60,800 hours.
- Hanford-specific incidence rates for occupational accidents
  - Total recordable cases = 1.93×10^{-5} total recordable cases/hour
  - Lost workday cases = 8.04×10^{-6} lost workday cases/hour

  Fatalities = 1.35×10^{-8} fatalities/hour.

In calculating the radiological LCF risk from routine exposure approach risk, the following assumptions were made:

- Volume of respirable waste released in the accident is as calculated in WHC-SD-WM-ANAL-041.

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* See Preface in *SST System Closure Plan* (RPP-13774).

- Concentration of radionuclides is calculated from the inventory presented in DOE/ORP-2003-02 and provided in Table 8.

- For the noninvolved workers and general public exposure scenarios, the atmospheric dispersion coefficients were calculated using the GXQ computer code (WHC-SD-GN-SWD-30002).

- For the involved workers it was assumed the respirable waste released in the accident would be released as a "puff" and spread instantaneously and uniformly around the exhaust port over a hemisphere 10 m (30 ft) in radius (WHC-SD-WM-ANAL-041).

- Breathing rates for the various receptors are provided in HNF-SD-WM-TI-707.

- Inhalation dose conversion factors for a 50-year dose commitment for each radionuclide are taken from HNF-SD-WM-TI-707.

- Dose-to-risk conversion factors for converting receptor doses to LCFs are referenced in 56 FR 23363 and ICRP (1991) and apply as follows:

  Involved worker and noninvolved worker = 4.0×10^{-4} LCF/rem for low doses under 20 rem, 8.0×10^{-4} LCF/rem for high doses over 20 rem

  General public = 5.0×10^{-4} LCF/rem for low doses under 20 rem, 1.0×10^{-3} LCF/rem for doses equal to or over 20 rem.

The number of accidents is calculated by multiplying the annual frequency of the accident by the time required to perform the activity. The annual frequency of a ventilation failure accident is referenced in WHC-SD-WM-ANAL-041. The time required to close the tanks was based on RPP-14590.

In calculating the chemical hazard index from accident and routine exposure approach, the following assumptions were made:

- The chemical inventory used for these assessments were made up of two components, the organic chemicals and the inorganic chemicals. The emission rates for organic chemicals are taken from *Organic Vapor Source Term for Tanks 241-C-201, 241-C-202, 241-C-203, and 241-C-204 During Waste Retrieval Operations*, RPP-14841.

- Organic pollutant release concentrations and ammonia release concentrations were calculated assuming that 900 m3/hr of air containing the pollutant concentrations observed in tank C-204 are exhausted year around.

- The mean concentrations of the organic pollutant and ammonia release were increased by 2 times the standard deviation to reflect statistical variability in the results. Two times the standard deviation represents a 95 percent confidence that the actual concentration is bounded.

- Only 33% of total chromium was assumed to be chromium(VI).

Related Data Gaps

- A safety analysis of tank closure activities at C farm has not been performed. Consequently, safety data from other tank farm construction and operation activities for past component retrieval are used to approximate short-term risk at C farm.

Conclusions

- In no case is the administrative control level of 0.5 rem/yr for a worker exceeded under routine conditions.
- In no case are the standards for routine exposure of the public of 0.1 rem/yr exceeded.
- In all cases the acute exposure limit of 5.0 rem to an involved worker (located at 10 m [33 ft] from the point of release) from a radiological accident with an extremely unlikely probability of occurrence ($>10^{-6}$ to $\leq 10^{-4}$) would be exceeded. Mitigative measures are currently employed to reduce this accident. However, the assumptions used in calculating this probability are extremely conservative.
- In no case would there be a fatality from occupational accidents.
- In all cases, there would be at least one total recordable case for closing all C farm tanks.
- Short-term radiation risk to the public for closure activities, expressed as LCFs, is very small, and the order of 1.0×10^{-10} LCF.
- Conservative chemical accident impacts do not exceed the TEEL/ERPG-3 threshold for the involved worker, however small refinements to the methodology may allow the impacts to meet the TEEL/ERPG-2 threshold as the current estimate exceeds the threshold values by only 2 percent. The impacts to the non-involved worker and the general public would not exceed the TEEL-0 threshold, of no impact.
- Total Hazard Index exceeded 1.0 for routine chemical exposure.

Implications to Closure

- A safety analysis of potential tank closure activities at C farm should be prepared.

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