AR TARGET SHEET

The following document was too large to scan as one unit, therefore, it has been divided into sections.

EDMC#:	0074018
SECTION:	1 OF 2
DOCUMENT #:	07-AMCP-0302
TITLE:	Feasibility Study for Plutonium/Organic-Rich Process Condensate/Process Waste Group OU: Includes 200-PW-1, 200-PW-3, and 200-PW-6 OUs DOE/RL-2007-27 Draft A and Proposed Plan for 200-PW-1, 200-PW-3, and 200-PW-6 OUs DOE/RL-2007-40 Draft A

0074018

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

07-AMCP-0302

SEP 27 2007

Mr. N. Ceto, Program Manager
Office of Environmental Cleanup
Hanford Project Office
U.S. Environmental Protection Agency
309 Bradley Blvd., Suite 115
Richland, Washington 99352

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EDMC

Dear Mr. Ceto:

FEASIBILITY STUDY FOR THE PLUTONIUM/ORGANIC-RICH PROCESS CONDENSATE/PROCESS WASTE GROUP OPERABLE UNIT: INCLUDES THE 200-PW-1, 200-PW-3, AND 200-PW-6 OPERABLE UNITS, DOE/RL-2007-27, DRAFT A AND PROPOSED PLAN FOR 200-PW-1, 200-PW-3, AND 200-PW-6 OPERABLE UNITS, DOE/RL-2007-40, DRAFT A

The purpose of this letter is to provide the Feasibility Study for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units, DOE/RL-2007-27, Draft A and Proposed Plan for 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units, DOE/RL-2007-40, Draft A for review and comment by the U.S. Environmental Protection Agency (EPA).

These two documents were prepared as a collaborative effort with early and frequent input from EPA. Several workshops were conducted to brief the State of Washington Department of Ecology, Tribal Nations, State of Oregon, and the Hanford Advisory Board on the methodology and progress of the risk assessment and the Feasibility Study process.

Submittal of the Feasibility Study for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units, DOE/RL-2007-27, Draft A and the Proposed Plan for 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units, DOE/RL-2007-40, Draft A to EPA satisfies the Tri-Party Agreement Interim Milestone M-015-45B. Please note that the Appendices A-F are included on a CD in the report. In accordance with the Tri-Party Agreement, please provide comments to the U.S. Department of Energy, Richland Operations Office (RL) by close of business on November 15, 2007.

RL has scheduled a briefing to discuss the key components of these documents the week of October 1, 2007. RL followed the CERCLA process in developing remedy alternatives and evaluated the alternatives using the first seven CERCLA criteria. As you are aware, these seven criteria focus on the environmental, technical, and implementation aspects of the alternatives. RL recognizes that the proposed plan may be modified, after public review, to address public and State acceptance, including potential concerns involving transuranic contaminants.

If you have any questions, please contact me, or your staff may contact Matt McCormick, Assistant Manager for the Central Plateau, on (509) 373-9971.

Sincerely,

David A. Brockman
Manager

AMCP:ACT

Attachments

cc w/attachs:
G. Bohnee, NPT
L. Buck, Wanapum
R. S. Dinicola, USGS
D. A. Faulk, EPA
S. Harris, CTUIR
J. Hedges, Ecology
R. Jim, YN
S. L. Leckband, HAB
K. Niles, ODOE
Administrative Record
Environmental Portal

cc w/o attachs:
B. A. Austin, FHI
B. H. Ford, FHI
D. S. Miller, FFS
R. E. Piippo, FHI
A. F. Shattuck, FFS
J. G. Vance, FFS

DOE/RL-2007-27
DRAFT A

Feasibility Study for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States Department of Energy
P.O. Box 550
Richland, Washington 99352

Approved for Public Release;
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DOE/RL-2007-27
DRAFT A

Feasibility Study for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units

Date Published
September 2007

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States Department of Energy
P.O. Box 550
Richland, Washington 99352

S. D. Aardal 09/11/2007
Release Approval Date

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EXECUTIVE SUMMARY

The Plutonium/Organic-Rich Operable Unit (OU) Group waste sites are located in the 200 West and 200 East Areas of the Hanford Site within the industrial (exclusive) land-use boundary (Figure ES-1). The Plutonium/Organic-Rich Group OU consists of 17 *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*[1] (CERCLA) past-practice liquid-waste disposal sites within three OUs (the 200-PW-1, 200-PW-3, and 200-PW-6 OUs). Ten of these waste sites are cribs, two are settling tanks, and there is one each of the following waste sites: tile field, French drain, injection/reverse well, covered trench, and an unplanned release. The waste sites in both the 200-PW-1 and 200-PW-6 OU, located in the 200 West Area, received aqueous process and laboratory wastes containing primarily americium and plutonium. The 200-PW-1 OU waste sites also received organic waste consisting primarily of carbon tetrachloride, tributyl phosphate, and lard oil. The 200-PW-3 waste sites, located in the 200 East Area, received liquid wastes containing uranium, plutonium, fission products, and organics, primarily normal paraffin hydrocarbons, tributyl phosphate, and butanol.

The U.S. Department of Energy (DOE) recognized the potential risks posed by some of the contaminants and took expedited actions to reduce those risks at some of the more contaminated sites. In the 1970s, 0.3 m (1 ft) of soil was removed from the floor of the 216-Z-9 Trench, which was contaminated with high concentrations of plutonium and americium, to reduce the risk of a nuclear criticality reaction. In the early 1990s, soil-vapor extraction (SVE) was implemented at the 216-Z-9 Trench, 216-Z-1A Tile Field, and 216-Z-18 Crib waste sites to mitigate risks to groundwater by capturing volatile organic compounds, primarily carbon tetrachloride, from the subsurface soils. Both of these actions significantly reduced the mass of contaminants present at these sites. Approximately 58 kg (128 lb) of plutonium and a significant (but undocumented) amount of americium were removed from the floor of the 216-Z-9 Trench. SVE, which is still in operation, has removed approximately 79,000 kg (174,000 lb) of carbon tetrachloride as of September 2006, as well as an unquantified amount of other volatile contaminants.

The 216-Z-9 Trench and the 216-Z-1A Tile Field, along with the other Plutonium/Organic-Rich OU waste sites, represent significant challenges in terms of remedial design. Some of the sites received hazardous wastes with both long-lived radionuclides and organic components. The geometries (e.g., size, depth, piping configurations) are different for almost every waste site. The geologic conditions that influenced the migration of the waste components into the subsurface soils also vary within this group of waste sites. These complexities make the analysis and identification of remedial alternatives a challenging task, because the evaluation has to consider both radionuclide contamination that is held (sorbed) in the soil matrix at various depths as well as organic contamination that was more mobile in different phases (vapor, aqueous, and as a nonaqueous phase liquid), which spread organic (and some radionuclide) contaminants in a different subsurface pattern than typically found at sites with only radionuclide contamination.

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[1] *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, 42 USC 9601, et seq.

These waste-type and mixture complexities, along with the unique disposal geometries, combined with risks and safety concerns associated with human and environmental exposures to these contaminants, limit the remedial alternatives that are feasible. In all cases, contaminant mass reduction was considered in the alternative analysis along with containment and in situ treatment. Unfortunately, there are very few in situ treatment alternatives for radionuclides, thus requiring that the remedial alternatives rely on barriers or removal as remedial alternatives for those contaminants. By comparison, more active treatment such as SVE and other in situ treatments commonly are applied to organic contaminants.

All of the remedial alternatives considered for these waste sites will involve various degrees of institutional controls. Current institutional controls effectively restrict access to the waste sites, limit activities, and ensure that appropriate protective measures are implemented in instances where activities include the potential for exposure to contaminated media. These measures effectively eliminate the risks to current industrial workers. A common protective measure is implementation of engineered controls to eliminate or sufficiently mitigate an exposure pathway. Elimination of the exposure pathway is an effective technique to mitigate the risks associated with these waste sites. Although the U.S. Department of Energy will maintain institutional controls until approximately the year 2050, and active institutional controls are assumed until the year 2150, this feasibility study (FS) looked beyond this period to consider final remedies that provide acceptable levels of long-term protectiveness. Given the long-lived nature of many of the radionuclides and the depths at which some of the contaminants exist, an important aspect of the remedial alternatives is to provide a barrier such that the exposure pathway to human and ecological receptors is broken. These barriers can be configured in a variety of ways as appropriate for each waste site, as discussed below.

Because of the large number of waste sites within the three OUs, the representative and analogous waste-site approach was implemented with the consensus of the Tri-Parties (U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology) to streamline the remedial investigation/feasibility study (RI/FS) process. For the representative and analogous waste-site approach, waste sites are combined into groups of sites (Table ES-1) with such similar features as location, geology, waste-site history, contaminants, potential remedies (DOE/RL-98-28, Section 2.5.1[2] [Implementation Plan]). Within each group, one or more representative waste sites was selected for field investigations, with the intent that remedies developed for representative waste sites likely would apply to analogous waste sites in the waste group that might not be as fully characterized. This approach allows remediation to begin sooner, because the remedial decision is based on the information gathered from the select set of representative waste sites. The analogous waste sites will be characterized as part of the remedial process, to evaluate specifically if an identified remedy (i.e., the remedial alternative identified for the associated representative waste site) is appropriate, given the specific analogous waste site conditions.

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[2] DOE/RL-98-28, 1999, *200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

The analogous waste-site approach identifies and evaluates various remedial alternatives for each representative waste site using the data presented in the Remedial Investigation (RI) Report (DOE/RL-2006-51[3]). The remedial alternatives are evaluated with respect to the first seven of the nine CERCLA criteria (EPA/540/G-89/004, OSWER Directive 9355.3-01[4]) (two threshold criteria [(1) protection of human health and the environment; (2) compliance with applicable or relevant and appropriate requirements (ARAR)] and five balancing criteria [(3) long-term effectiveness and permanence; (4) reduction of toxicity, mobility, or volume through treatment; (5) short-term effectiveness; (6) implementability; (7) costs]) to identify a preferred alternative(s) for the evaluated waste sites. The resulting preferred remedial actions are summarized in the proposed plan (DOE/RL-2007-40[5]), which is made available for public review and comment. The two modifying criteria ([8] State acceptance; [9] community acceptance) will be evaluated by the U.S. Environmental Protection Agency through the public review process of the proposed plan (EPA/540/G-89/004) and documented in a record of decision.

Remedial alternatives for each representative waste site are evaluated in this FS. Remedies for the analogous waste sites are, by definition, selected by analogy to their representative waste site. The remedies for the analogous waste sites will be presented in the proposed plan. There, the analogous waste sites are described briefly, the anticipated risks are listed, and a remedial alternative is identified for each waste site. A key principle of the analogous waste sites approach is to recognize that contingencies are considered whereby alternative remedial action may be required, should data collected during the remedial design or implementation demonstrate that the preferred remedy identified in the FS or proposed plan is not appropriate.

After the selection and documentation of the preferred remedial alternatives for these waste sites, including contingent actions, is published in the record of decision, the remedial design process can begin. This process will require the collection of additional site-specific data to confirm that the selected remedy or a contingent remedy is appropriate for the waste-site conditions. During this confirmation process, if new data are found that deviate from those anticipated in the site conceptual contamination model, then contingent actions to the preferred alternative can be invoked (as described in this FS and the proposed plan) and can be incorporated into the remedial design. Two examples of how the contingent actions would be applied are as follows: (1) If volatile organic compounds are found to be present at an analogous waste site, an SVE system would be used to remediate that site, even though the representative waste site did not have SVE as part of the preferred alternative except as a contingent action; and

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[3] DOE/RL-2006-51, 2006, *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

[4] EPA/540/G-89/004, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final*, OSWER 9355.3-01, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

[5] DOE/RL-2007-40, in process, *Proposed Plan for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

(2) If contamination is found at levels above the risk-based concentrations at a waste site, additional excavation or additional barrier features may be required, beyond what was originally postulated as part of the preferred remedy in the FS. The uncertainty raised by the limited characterization of some waste sites was considered in the range of remedial alternatives presented in this FS and also is mitigated by the inclusion of contingent remedial alternatives that would be invoked, should new risks be found during the remedial design and implementation sampling process.

As discussed above in the overall remedial strategy, the purpose of this FS is to develop and evaluate remedial alternatives for the six representative and unique waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. These sites include the 216-Z-1A Tile Field, 216-Z-8 French Drain, 216-Z-9 Trench, 216-Z-10 Injection/Reverse Well, 241-Z-361 Settling Tank, and the 216-A-8 Crib. This FS refines preliminary ARARs, remedial-action objectives, and general-response actions initially identified in DOE/RL-98-28 (Implementation Plan). Technology screening and development of alternatives initially performed in the Implementation Plan have been reviewed and refined, as necessary, based on the site-specific data presented in the RI Report (DOE/RL-2006-51) and other sources of existing information. The alternatives considered provide a range of potential response actions (e.g., no action; institutional controls; capping; partial removal, treatment, and disposal (RTD) with capping; in situ treatment or containment) that are appropriate to address site-specific conditions. In all cases, the primary remedial goals were (1) protection of human health and the environment and (2) compliance with ARARs. These can be achieved by in situ treatment, contaminant-mass removal, or engineered barriers and institutional controls to eliminate the exposure pathways.

A baseline risk assessment was conducted to establish the need for taking action under CERCLA and to identify the contaminants of concern (COC) that are to be addressed by the remedial action. This included a human-health risk assessment, screening-level ecological risk assessment, and a groundwater protection evaluation to evaluate risk levels for these exposure pathways and identify COCs. The human-health risk assessment was based on the current and potential future uses of the land. It evaluates risks to adult construction workers from potential exposures under current and expected future industrial land-use conditions, assuming that the existing institutional controls remain in place. For comparison, the human-health risk assessment also evaluates a hypothetical future unrestricted land-use scenario if the existing institutional controls were to fail after the year 2150. In the unrestricted land-use scenario, the risks were evaluated from potential exposures to a future working population (well drillers) and a future residential farming population (adults and children). The screening-level ecological risk assessment concluded that there are no ecological risks at any of the 17 waste sites. The risk assessment and groundwater protection evaluation identified COCs for the representative and unique waste sites, as shown in the following table.

Contaminants of Concern for Representative and Unique Waste Sites.

Waste Site	Risk Receptor				
	Industrial Site Construction Worker	Ecological Risk	Future Well Driller	Future Residential Farmer	Groundwater Protection
216-Z-1A Tile Field	Am-241, Pu-239/240	None identified	None identified	Am-241, Pu-239/240	CCl_4 [a]
216-Z-8 French Drain	None identified	None identified	None identified	None identified	None identified
216-Z-9 Trench	Am-241, Pu-239/240 [b]	None identified	None identified	Am-241, Pu-239/240	CCl_4 Hexachloroethane Tetrachloroethylene
216-Z-10 Injection/ Reverse Well	None identified	None identified	None identified	None identified	None identified
241-Z-361 Settling Tank [c]	None identified	None identified	None identified	None identified	None identified
216-A-8 Crib	Cs-137	None identified	None identified	Cs-137	Tc-99 [d]

"None identified" – The CERCLA risk assessment process did not identify any condition that would result in unacceptable levels of risk to human health or the environment.

[a] Although not identified in remedial investigation soil samples, soil-vapor recovery activities continue to remove kilogram quantities of carbon tetrachloride from the vadose zone annually, suggesting that migration to groundwater is possible.

[b] Not identified as contaminants of concern for site construction worker, but best management practice warrants a more substantial form of physical separation from the contaminated soil.

[c] Contaminants of concern were not identified for this site, because there has been no identified release to the environment.

[d] Technetium-99 was identified at significant concentrations in only one soil sample (79.6 pCi/g at 5.8 to 6.5 m [19 to 21.5 ft] below ground surface). Pending confirmatory soil sampling, the preferred alternative will mitigate the potential future impacts that this contaminant may have on groundwater beneath the waste site.

Having established the need for remedial action at three of the representative waste sites, the preliminary ARARs, along with remedial-action objectives (RAO) and general-response actions initially identified in the Implementation Plan were refined. The RAOs provide a basis for evaluating the capability of a specific remediation alternative to achieve compliance with potential ARARs and/or an intended level of risk protection for human health or the environment. The RAOs developed for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are:

- **RAO 1**. Prevent unacceptable risk to human health from direct contact with COCs in the soil within 4.6 m (15 ft) of the ground surface. Unacceptable risks are (1) an excess lifetime cancer risk greater than 1 in 10,000 (1×10^{-4}) or (2) a dose exceeding 100 mrem/yr, consistent with an industrial land-use scenario. With respect to this RAO, COCs include Am-241 and Pu-239/240 at the 200-PW-1 OU and 200-PW-6 OU waste sites, and Cs-137 at the 200-PW-3 OU waste sites.

- **RAO 2**. Prevent migration of COCs to groundwater in concentrations that exceed maximum contaminant levels. With respect to this RAO, COCs include carbon tetrachloride, hexachloroethane, and tetrachloroethylene at the 200-PW-1 OU waste sites, and Tc-99 at 200-PW-3 OU waste sites.

Technologies that may meet the RAOs for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs were identified and screened. Because of the complexities of both the contaminant distribution at these waste sites and the relatively high levels of radionuclide contamination, the list of available technologies was fairly limited. Representative technologies that were retained after screening were combined into a range of alternatives to meet RAOs. The alternatives considered provide a range of potential response actions as described for each waste site below.

216-Z-1A Tile Field. The RI identified high concentrations of radionuclides at the 216-Z-1A Tile Field, all found at depths of 1.8 m (6 ft) or more below the surface of the tile field, with most being very near the vertical projection of the central waste distribution line. By design, the land surface above the tile field is approximately 2.4 m (8 ft) below the adjacent natural ground surface. Based on the continual removal of significant carbon tetrachloride by the interim SVE system, all remedial alternatives, except Alternative 0 – No Action, are assumed to contain a continued SVE operation.

The alternatives considered for the 216-Z-1A Tile Field include the following:

- Alternative 0 – No Action
- Alternative 1 – Soil Backfill plus Expanded SVE
- Alternative 2 – Intrusion-Prevention Feature plus Expanded SVE
- Alternative 3 – In Situ Vitrification (ISV) plus Expanded SVE
- Alternative 4 – Partial RTD plus Expanded SVE.

Based on comparative analysis of the alternatives carried forward for the 216-Z-1A Tile Field, **Alternative 2 – Intrusion-Prevention Feature plus Expanded SVE** was identified as the preferred alternative (see Table ES-2). It achieves protectiveness by establishing 4.6 m (15 ft) of separation between the contaminants that exceed the risk-based concentrations and provides a durable physical barrier to intrusion that is effective under both industrial land-use and unrestricted land-use scenarios. Short-term risks are minor, associated with activities that are routine at the Hanford Site and readily and effectively controlled by existing Site worker protection and environmental-protection programs. The only waste stream generated is from the SVE system, currently implemented at the Site as an expedited response action to remove carbon tetrachloride mass from the vadose zone and protect groundwater. The present-worth cost for this alternative is estimated at $5,814,907.

216-Z-9 Trench. The RI identified high levels of contaminants of potential concern (COPC) in the soil at two depth intervals beneath the 216-Z-9 Trench. Historical sampling revealed high concentrations of Pu-239/240 and Am-241 in soils at the base of the trench, approximately 6.4 m (21 ft) below grade. More recent characterization work identified high concentrations of these radionuclides as well as carbon tetrachloride dense, nonaqueous-phase liquid in a thin silt lens approximately 19.8 m (65 ft) beneath the southern end of the trench.

The alternatives considered for the 216-Z-9 Trench are as follows:

- Alternative 0 – No Action
- Alternative 1 – Controlled-Density Fill plus Targeted SVE

- Alternative 2 – Intrusion-Prevention Feature plus Targeted SVE
- Alternative 3 – ISV plus Targeted SVE
- Alternative 4 – Partial RTD plus Targeted SVE.

Based on the comparative analysis of the remedial alternatives carried forward for the 216-Z-9 Trench, **Alternative 1 – Controlled-Density Fill plus Targeted SVE** was identified as the preferred alternative (see Table ES-3). It achieves protectiveness upon implementation by upgrading the SVE system to enhance its ability to reduce contaminant mass in the source area. It also provides a durable physical barrier to potential exposures and intrusion by backfilling the trench with controlled-density fill that is effective under both industrial land-use and unrestricted land-use scenarios. Short-term risks are minor, associated with activities that are routine at the Hanford Site and readily and effectively controlled by existing Site worker protection and environmental-protection programs. The only waste stream generated is from the SVE system, currently implemented at the Site as an expedited response action to remove carbon tetrachloride mass from the vadose zone and protect groundwater. The present-worth cost for this alternative is estimated at $4,706,371.

241-Z-361 Settling Tank. Characterization from 1999 to 2001 identified plutonium in the sludge remaining in the tank. There is no indication that the tank has leaked. Potential remedial technologies for removal of the sludge were developed and evaluated in a previous study (DOE/RL-2003-52[6]). This report identified a preferred alternative for removing the sludge, consisting of Power Fluidics[7] to loosen and homogenize the sludge. Slurry plumps would be used to transfer the fluidized sludge to standard waste boxes, where adsorbents are used to stabilize the sludge. Based on available data, the standard waste boxes would be designated as mixed transuranic waste. The only path forward for mixed transuranic wastes at this time is disposal at the Waste Isolation Pilot Plant near Carlsbad, New Mexico. Once the sludge has been removed from the tank, the tank would be left in place and backfilled with controlled-density fill. No new information has been developed for this tank since that report, so the recommended preferred alternative is carried forward in this FS. The present-worth cost for this alternative is estimated at $12,918,889.

216-A-8 Crib. The RI identified significant Cs-137 contamination at the 216-A-8 Crib. Geophysical logging in RI Borehole C4545 during 2005 showed very high readings between 3.4 and 22.3 m (11 and 73 ft) below ground surface (bgs), with a maximum of $1.5 \times 10^{+6}$ pCi/g identified at 6.1 m (20 ft) bgs. Soil sampling from Borehole C4545 in 2005 showed a maximum concentration of 877,000 pCi/g, found in a sample collected from the interval between 5.8 and 6.6 m (19 and 21.5 ft) bgs. The depths given are depths below the top of a 0.6 m (2 ft) thick stabilization cover emplaced in 1990.

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[6] DOE/RL-2003-52, 2003, *Tank 241-Z-361 Engineering Evaluation/Cost Analysis*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

[7] Power Fluidics is a trademark of NuVision Engineering, Inc., Pittsburgh, Pennsylvania.

The alternatives considered for the 216-A-8 Crib are as follows:

- Alternative 0 – No Action
- Alternative 1 – Monofill Evapotranspiration Barrier
- Alternative 2 – Partial RTD.

Based on comparative analysis of the alternatives carried forward for the 216-A-8 Crib, **Alternative 1 – Monofill Evapotranspiration Barrier** was identified as the preferred alternative (see Table ES-4). It achieves protectiveness by controlling access to the principal threat contaminant and limits infiltration and thus migration of contaminants (specifically Tc-99). The principal threat contaminant, Cs-137, is expected to decay to levels that pose no unacceptable risk to the industrial-site construction worker within 136 years, and to levels that pose no unacceptable risk to the future well driller or future residential farmer within 249 years. Institutional controls will ensure that the barrier is protected and maintained during that time period. Short-term risks incurred are associated with activities that are routine at the Hanford Site and readily and effectively controlled by existing Site worker protection and environmental-protection programs. The present-worth cost for this alternative is estimated at $3,965,968.

216-Z-10 Injection/Reverse Well. As discussed in the RI, historical soil sampling and geophysical logging in three adjacent boreholes identified no significant plutonium contamination near the 216-Z-10 Injection/Reverse Well. Because no contamination was identified in the upper 4.6 m (15 ft) of the soil column, there is no identified direct-contact risk to potential human and ecological receptors. The plutonium disposed of in this well is expected to be bound to the sediments in proximity to the well perforations from 36 to 46 m (118 to 150 ft) bgs. The RESidual RADioactivity (RESRAD) (ANL, 2005[8]) modeling of plutonium fate and transport at the 216-Z-9 Trench showed no risk to groundwater, so even though there are differences in the depth of the plutonium contamination between these sites, the limited amount of plutonium at the 216-Z-10 Injection/Reverse Well is not likely to migrate to groundwater. Therefore, there is no regulatory requirement to develop or implement remedial alternatives for this waste site.

This waste site will be closed by decommissioning the well in accordance with WAC 173-160-381.[9] As a precaution, decommissioning activities will be modified to the extent possible to minimize the volume of liquid introduced into the well during the decommissioning process. Grouting will seal the well and annular space, precluding infiltration of water from the surface.

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[8] ANL, 2005, *RESRAD*, Version 6.3, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois, available on the Internet at: http://web.ead.anl.gov/resrad/register2/.

[9] WAC 173-160-381, "Minimum Standards for Construction and Maintenance of Wells," "What are the Standards for Decommissioning a Well?" *Washington Administrative Code*, as amended, Washington State Department of Ecology, Olympia, Washington.

216-Z-8 French Drain. COPCs at the 216-Z-8 French Drain are Pu-238, Pu-239/240, and Am-241. Historical sampling results, documented in the RI, indicate that these contaminants are primarily 5 to 11 m (16 to 35 ft) bgs. The risk-assessment process determined that human-health risks incurred under the industrial land-use and unrestricted land-use scenarios were less than 1×10^{-4}, primarily because there were no significant concentrations identified within the upper 4.6 m (15 ft) of the soil column. The RESRAD modeling of plutonium and americium fate and transport at the 216-Z-9 Trench showed no risk to groundwater, so even though there are differences in the depth of the plutonium and americium contamination between these sites, the limited amount of plutonium and americium at the 216-Z-8 French Drain is not likely to migrate to groundwater. Therefore, there is no regulatory requirement to develop or implement remedial alternatives at the 216-Z-8 French Drain.

Summary of Preferred Alternatives. The following table provides a summary of the preferred alternatives and the costs for the six representative and unique waste sites addressed in this FS. These alternatives and their application to the analogous waste sites will be presented in the proposed plan.

Summary of Preferred Alternatives.

Waste Site	Preferred Alternative	Present-Worth Cost
216-Z-1A Tile Field	Intrusion-Prevention Feature plus Expanded Soil-Vapor Extraction	$5,814,907
216-Z-8 French Drain	No Action Required	$0
216-Z-9 Trench	Controlled-Density Fill plus Targeted Soil-Vapor Extraction	$4,706,371
216-Z-10 Injection/ Reverse Well	No Action Required	$0
241-Z-361 Settling Tank	Remove Sludge and Backfill with Controlled-Density Fill	$12,918,889
216-A-8 Crib	Monofill Evapotranspiration Barrier	$3,965,968

Figure ES-1. Location of the Hanford Site.

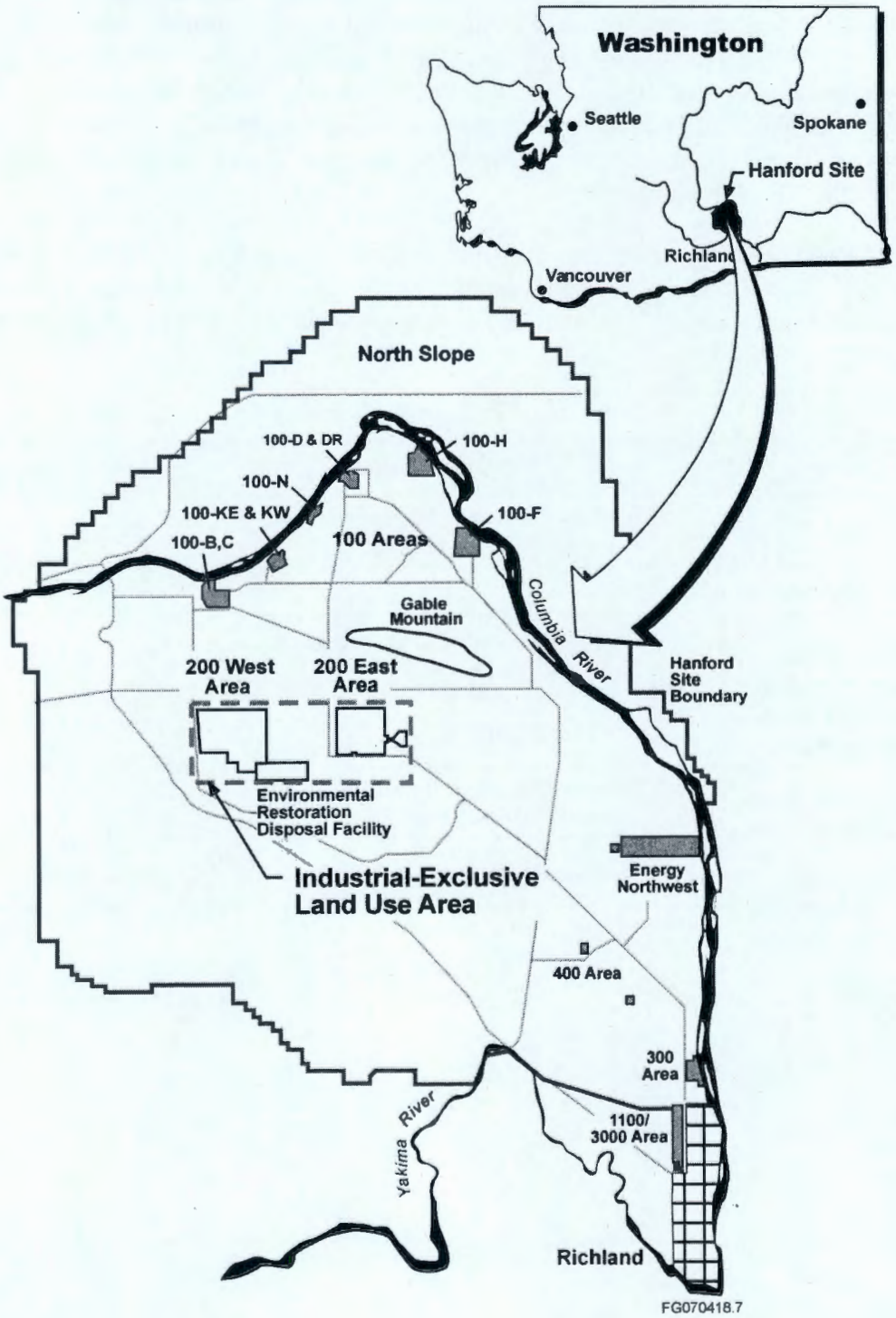

Table ES-1. Alignment of 200-PW-1, 200-PW-3, and 200-PW-6 Operable Unit Representative and Analogous Waste Sites.

Representative or Unique Waste Site	Analogous Waste Site
216-Z-1A Tile Field[a]	216-Z-1 Crib[a]
	216-Z-2 Crib[a]
	216-Z-3 Crib[a]
	216-Z-5 Crib[c]
	216-Z-12 Crib[a]
	216-Z-18 Crib[a]
216-Z-8 French Drain[c]	None
216-Z-9 Trench[a]	None
216-Z-10 Injection/Reverse Well[c]	None
241-Z-361 Settling Tank[a]	241-Z-8 Settling Tank[c]
216-A-8 Crib[b]	216-A-7 Crib[b]
	216-A-24 Crib[b]
	216-A-31 Crib[b]
	UPR-200-E-56 unplanned release[b]

[a] 200-PW-1 Operable Unit waste site.
[b] 200-PW-3 Operable Unit waste site.
[c] 200-PW-6 Operable Unit waste site.

Table ES-2. Comparative Analysis of the 216-Z-1A Tile Field Remedial Alternatives.

CERCLA Evaluation Criterion	Alternative 0	Alternative 1	Alternative 2[a]	Alternative 3	Alternative 4
			☑		
	No Action	Soil Backfill + Expanded SVE	Intrusion-Prevention Feature + Expanded SVE	In Situ Vitrification + Expanded SVE	Partial Removal, Treatment and Disposal + Expanded SVE
Overall Protection of Human Health and the Environment [b]	c	4	1	2	3
ARARs	c	d	d	d	d
Long-Term Effectiveness and Permanence	N/A	4	3	1	2
Reduction of Toxicity, Mobility, or Volume through Treatment	N/A	4	4	1	4
Short-Term Effectiveness	N/A	1	1	3	4
Implementability	N/A	1	2	4	3
Present-Worth Cost	$0	$5,619,236	$5,814,907	$356,819,181	$418,806,585

[a] Preferred alternative will be contingent on confirmatory sampling.
[b] This criterion does not consider unrestricted land-use scenarios (e.g., residential farmer population) or related risks.
[c] Alternative does not meet this threshold criterion.
[d] Alternative meets this criterion.
Ranking is relative to the other alternatives, with a rank of "1" being best.
☑ Preferred alternative.
ARAR = applicable or relevant and appropriate requirement.
CERCLA = *Comprehensive Environmental, Response, Compensation, and Liability Act of 1980.*
N/A = not applicable.
SVE = soil-vapor extraction.

Table ES-3. Comparative Analysis of the 216-Z-9 Trench Remedial Alternatives.

CERCLA Evaluation Criterion	Alternative 0	Alternative 1[a]	Alternative 2	Alternative 3	Alternative 4
		☑			
	No Action	Controlled-Density Fill + Targeted SVE	Intrusion-Prevention Feature + Targeted SVE	In Situ Vitrification + Targeted SVE	Partial Removal, Treatment and Disposal + Targeted SVE
Overall Protection of Human Health and the Environment [b]	c	1	2	3	4
ARARs	c	d	d	d	d
Long-Term Effectiveness and Permanence	N/A	4	3	1	2
Reduction of Toxicity, Mobility, or Volume through Treatment	N/A	2	2	1	2
Short-Term Effectiveness	N/A	1	2	3	4
Implementability	N/A	1	2	4	3
Present-Worth Cost	$0	$4,706,371	$4,740,027	$26,951,350	$28,258,025

[a] Preferred alternative will be contingent on confirmatory sampling.
[b] This criterion does not consider unrestricted land-use scenarios (e.g., residential farmer population) or related risks.
[c] Alternative does not meet this threshold criterion.
[d] Alternative meets this criterion.
Ranking is relative to the other alternatives, with a rank of "1" being best.
☑ Preferred alternative.
ARAR = applicable or relevant and appropriate requirement.
CERCLA = *Comprehensive Environmental, Response, Compensation, and Liability Act of 1980.*
N/A = not applicable.
SVE = soil-vapor extraction.

Table ES-4. Comparative Analysis of the 216-A-8 Trench Remedial Alternatives.

CERCLA Evaluation Criterion	Alternative 0	Alternative 1[a]	Alternative 2
		☑	
	No Action	Monofill Evapotranspiration Barrier	Partial Removal, Treatment and Disposal
Overall Protection of Human Health and the Environment [b]	c	1	2
ARARs	c	d	d
Long-Term Effectiveness and Permanence	N/A	2	1
Reduction of Toxicity, Mobility, or Volume through Treatment	N/A	N/A	2
Short-Term Effectiveness	N/A	1	2
Implementability	N/A	1	2
Present-Worth Cost	$0	$3,965,968	$51,396,466

[a] Preferred alternative will be contingent on confirmatory sampling.
[b] This criterion does not consider unrestricted land-use scenarios (e.g., residential farmer population) or related risks.
[c] Alternative does not meet this threshold criterion.
[d] Alternative meets this criterion.
Ranking is relative to the other alternatives, with a rank of "1" being best.
☑ Preferred alternative.
ARAR = applicable or relevant and appropriate requirement.
CERCLA = *Comprehensive Environmental, Response, Compensation, and Liability Act of 1980.*
N/A = not applicable.

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LIST OF TERMS

ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CCl_4	carbon tetrachloride
CCU	Cold Creek unit
CDF	controlled-density fill
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
COC	contaminant of concern
COPC	contaminant of potential concern
CPT	cone penetrometer
CWC	Central Waste Complex
DBBP	dibutyl butyl phosphonate
DOE	U.S. Department of Energy
DNAPL	dense, nonaqueous-phase liquid
DQO	data quality objective
DSA	documented safety analysis
Ecology	Washington State Department of Ecology
ECR	Ecological Compliance Review
EPA	U.S. Environmental Protection Agency
EPC	exposure-point concentration
ERAGS	*Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (Interim Final)* (EPA/540/R-97/006)
ERDF	Environmental Restoration Disposal Facility
ERH	electrical-resistance heating
ET	evapotranspiration
FS	feasibility study
GAC	granular activated carbon
GRA	general-response action
HAB	Hanford Advisory Board
Hanford NEPA	*Hanford Site National Environmental Policy Act (NEPA) Characterization* (PNNL-6415)
HEPA	high-efficiency particulate air (filter)
HHR	hydraulic hammer rig
HMS	Hanford Meteorological Station
IELUA	Industrial Exclusive Land-Use Area
Implementation Plan	*200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program* (DOE/RL-98-28)
IPF	intrusion-prevention feature
IRIS	*Integrated Risk Information System*
ISV	in situ vitrification
MCL	maximum contaminant level
MNA	monitored natural attenuation

National Contingency Plan	"National Oil and Hazardous Substances Pollution Contingency Plan" (40 CFR 300).
NCP	National Contingency Plan
ND	not detected
NEPA	*National Environmental Policy Act of 1969*
NPL	"National Priorities List" (40 CFR 300, Appendix B)
OU	operable unit
PCE	tetrachloroethylene
PFP (Complex)	Plutonium Finishing Plant
PNNL	Pacific Northwest National Laboratory
ppmv	parts per million by volume
PRG	preliminary remediation goal
PSVE	passive soil-vapor extraction
RAO	remedial-action objective
RBC	risk-based concentration
RCRA	*Resource Conservation and Recovery Act of 1976*
RECUPLEX	Recovery of Uranium and Plutonium by Extraction (Plant or process)
RESRAD	RESidual RADioactivity (dose model)
RI	remedial investigation
RI Report	*Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (DOE/RL-2006-51)
RI/FS	remedial investigation/feasibility study
RL	U.S. Department of Energy, Richland Operations Office
RME	reasonable maximum exposure
ROD	record of decision
RTD	removal, treatment, and disposal
SPV	Subsurface Planar Vitrification
SVE	soil-vapor extraction
SWB	standard waste box
TBP	tributyl phosphate
Tri-Parties	U.S. Department of Energy, U.S. Environmental Protection Agency, and Washington State Department of Ecology
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TSD	treatment, storage, and/or disposal (unit)
UPR	unplanned release
VOC	volatile organic compound
WIDS	*Waste Information Data System* database
WIPP	Waste Isolation Pilot Plant
PW Work Plan	*Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit RI/FS Work Plan, Includes: 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (DOE/RL-2001-01)

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If you know	*Multiply by*	*To get*	*If you know*	*Multiply by*	*To get*
Length			**Length**		
inches	25.40	millimeters	millimeters	0.0394	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles (statute)	1.609	kilometers	kilometers	0.621	miles (statute)
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.0929	sq. meters	sq. meters	10.764	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.591	sq. kilometers	sq. kilometers	0.386	sq. miles
acres	0.405	hectares	hectares	2.471	acres
Mass (weight)			**Mass (weight)**		
ounces (avoir)	28.349	grams	grams	0.0353	ounces (avoir)
pounds	0.453	kilograms	kilograms	2.205	pounds (avoir)
tons (short)	0.907	ton (metric)	ton (metric)	1.102	tons (short)
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.034	ounces (U.S., liquid)
tablespoons	15	milliliters	liters	2.113	pints
ounces (U.S., liquid)	29.573	milliliters	liters	1.057	quarts (U.S., liquid)
cups	0.24	liters	liters	0.264	gallons (U.S., liquid)
pints	0.473	liters	cubic meters	35.315	cubic feet
quarts (U.S., liquid)	0.946	liters	cubic meters	1.308	cubic yards
gallons (U.S., liquid)	3.785	liters			
cubic feet	0.0283	cubic meters			
cubic yards	0.764	cubic meters			
Temperature			**Temperature**		
Fahrenheit	(°F-32)*5/9	Centigrade	Centigrade	(°C*9/5)+32	Fahrenheit
Radioactivity			**Radioactivity**		
picocurie	37	millibecquerel	millibecquerel	0.027	picocurie

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1.0 INTRODUCTION

The Hanford Site, managed by the U.S. Department of Energy (DOE), encompasses approximately 1,517 km^2 (586 mi^2) in the Columbia Basin of south-central Washington State. In 1989, the U.S. Environmental Protection Agency (EPA) placed the 100, 200, 300, and 1100 Areas of the Hanford Site on the 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan" (National Contingency Plan [NCP]), Appendix B, "National Priorities List" (NPL), pursuant to the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). The process for characterization and remediation of waste sites at the Hanford Site is addressed in the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989), commonly referred to as the Tri-Party Agreement. Submittal of this feasibility study (FS) for the Plutonium/Organic-Rich Group OU waste sites by September 30, 2007, will meet Tri-Party Agreement Milestone M-015-45B.

The 200 Areas NPL site is in a region referred to as the Central Plateau and consists of the 200 West Area and 200 East Area (Figure 1-1). The 200 Areas contain approximately 700 waste sites that include waste management facilities and inactive irradiated nuclear-fuel reprocessing facilities. These sites are managed by the DOE, Richland Operations Office (RL), excluding sites assigned to the Tank Farms Waste Management Area. Several waste sites in the 600 Area, located near the 200 Areas, also are included in the 200 Areas NPL.

In 2002, RL, EPA, and Washington State Department of Ecology (Ecology) conducted a thorough review of the cleanup approach that was being applied through DOE/RL-98-28, *200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program* (Implementation Plan) and identified improvements to accelerate cleanup of these waste sites. As part of this improved approach to accelerating waste-site cleanup, these three agencies (the Tri-Parties) agreed to consolidate the 23 process-based operable units (OU) into 12 groups based on similarities between contaminant sources (Tri-Party Agreement Milestones M-13-02-01 and M-15-02-01, approved in June 2002). As a result of this process, the Plutonium/Organic-Rich Process Condensate/Process Waste Group OU (200-PW-1 OU), the Organic-Rich Process Condensate/Process Waste Group OU (200-PW-3 OU), and the Plutonium Process Condensate/Process Waste Group OU (200-PW-6 OU) were consolidated into one group – the Plutonium/Organic-Rich Group OU – because the waste sites in all three OUs received plutonium- and/or organic-rich process condensates and process wastes. All of the Plutonium/Organic-Rich Group OU waste sites are located in the 200 East and 200 West Areas (Figures 1-2 through 1-4) within the industrial-exclusive land-use boundary identified in DOE/EIS-0222-F, *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (Figure 1-1).

The Plutonium/Organic-Rich Group OU consists of 17 CERCLA past-practice liquid-waste disposal sites and areas where carbon tetrachloride (CCl_4) has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU. Ten of these waste sites are cribs, two are settling tanks, and there is one each of the following waste sites: tile field, french drain, injection/reverse well, covered trench, and an unplanned release. Table 1-1 identifies the 17 waste sites in the Plutonium/Organic-Rich Group OU.

During the remedial investigation (RI), reported in DOE/RL-2006-51, *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (RI Report), data were collected in accordance with DOE/RL-2001-01, *Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit RI/FS Work Plan, Includes: 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (PW Work Plan) to characterize the nature and extent of chemical and radiological contamination and physical conditions in the vadose zone underlying two representative waste sites: the 216-Z-9 Trench and the 216-A-8 Crib. During the data quality objective (DQO) process used to develop the PW Work Plan, sufficient data were determined to be available to support the evaluation of remedial alternatives for two other representative waste sites: the 216-Z-1A Tile Field and the 241-Z-361 Settling Tank. Historical data available for two waste sites, the 216-Z-8 French Drain and the 216-Z-10 Injection/Reverse Well, also were considered to be sufficient to support the evaluation of remedial alternatives for these sites (DOE/RL-2006-51, RI Report). Data from representative waste sites are used to evaluate remedial alternatives and to identify a preferred alternative(s) to apply to the representative waste site and waste sites determined to be analogous to the representative waste site. Although a degree of uncertainty exists in employing the analogous waste-site concept, substantial benefit is realized in the early identification of a preferred alternative that allows early cleanup actions.

The scope of the RI Report (DOE/RL-2006-51) included surface radiological surveys, borehole drilling, soil and soil-vapor sampling, dense, nonaqueous-phase liquid (DNAPL) characterization, and borehole geophysical surveys. The RI Report includes the results of these investigations as well as the investigation of a possible dispersed CCl_4 vadose-zone plume in the 200-PW-1 OU. The data from the representative and unique waste sites support the evaluation of remedial alternatives for all 17 waste sites in the Plutonium/Organic-Rich Group OU.

1.1 PURPOSE

The purpose of this FS is to develop and evaluate alternatives for remediation of the waste sites in the Plutonium/Organic-Rich Group OU and for the CCl_4 that has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU. This FS refines preliminary applicable or relevant and appropriate requirements (ARAR), remedial-action objectives (RAO), and general-response actions (GRA) initially identified in the Implementation Plan (DOE/RL-98-28). Technology screening and development of alternatives initially performed in the Implementation Plan have been reviewed and refined, as necessary, based on the site-specific data reported in the RI Report (DOE/RL-2006-51) and other sources of existing information. The alternatives considered provide a range of potential response actions (e.g., no action; maintain existing soil cover with institutional controls; capping; partial removal, treatment, and disposal (RTD) with capping; in situ treatment or containment) that are appropriate to address site-specific conditions. The alternatives are evaluated against the two threshold and five balancing CERCLA evaluation criteria (EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final*, OSWER 9355.3-01). The two modifying criteria will be evaluated through the public review process (EPA/540/G-89/004) of the proposed plan (DOE/RL-2007-40, *Proposed Plan for the*

Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units).

For the CERCLA balancing criterion of cost – all costs in this FS report are presented as present-net-worth values and are not rounded per standard cost-estimating practice. The present-net-worth value method is used to evaluate costs that occur during different time periods and allows for cost comparisons of alternatives based on a single cost number for each alternative.

The FS alternatives evaluation serves as the basis for identifying a preferred alternative(s) remedy consistent with CERCLA. A preferred alternative (or alternatives) will be presented to the public for review and comment in the proposed plan (DOE/RL-2007-40). Following public review, the EPA will prepare a CERCLA record of decision (ROD) that identifies the remedial alternative(s) to be implemented for the Plutonium/Organic-Rich Group OU waste sites and for the CCl_4 that has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU.

1.2 SCOPE

This FS focuses on the evaluation of remedial alternatives for the four representative waste sites (the 216-Z-1A Tile Field, 216-Z-9 Trench, 241-Z-361 Settling Tank, and 216-A-8 Crib) and two unique waste sites (the 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well) shown in Figures 1-2 through 1-4. The evaluation of remedial alternatives for the remaining 11 analogous waste sites and the CCl_4 that has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU will be presented in the proposed plan for the Plutonium/Organic-Rich Group OU. All of the waste sites, and the CCl_4 that has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU, are within the industrial-exclusive land-use boundary (Figure 1-1).

Remediation of the Plutonium/Organic-Rich Group OU waste sites, and the CCl_4 that has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU, is a source-control action that addresses contaminated soil and structures (e.g., concrete pads, pipes) associated with cribs, settling tanks, a tile field, a french drain, an injection/reverse well, a covered trench, and an unplanned release. Other than the requirement for source-control action to be protective of groundwater and surface water, the scope of this FS does not include remediation of groundwater beneath these sites.

Because three of the 200-PW-1 OU waste sites (the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-18 Crib) were the primary sources of the CCl_4 contamination in the 200-ZP-1 Groundwater OU, the FS reports for both the Plutonium/Organic-Rich Group OU and the 200-ZP-1 Groundwater OU were prepared by a common project team to ensure that the baseline risk assessment was integrated and that identification of the preferred remedial alternatives in both FS reports addressed contingencies with regard to contaminated soil, contaminant migration to groundwater, and groundwater contamination. As shown on Figure 1-5, other waste sites also overlie the 200-ZP-1 Groundwater OU; some of these waste sites may be sources for the other contaminants found in the groundwater. These other waste sites are being addressed by the CERCLA remedial investigation/feasibility study (RI/FS) process for other OUs in the 200 West

Area or under the *Resource Conservation and Recovery Act of 1976* (RCRA) for the applicable treatment, storage, and/or disposal (TSD) units. The RI for the 200-ZP-1 Groundwater OU was completed in 2006, and the 200-ZP-1 Groundwater OU FS will be submitted in 2007.

The 200-PW-3 OU waste sites are located in the 200 East Area (Figure 1-3). Contaminated groundwater beneath these waste sites is being addressed by the 200-PO-1 Groundwater OU.

1.3 REGULATORY STATUS

1.3.1 Hanford Federal Facility Agreement and Consent Order

The Tri-Parties undertook the task of developing a framework to support risk assessments in the Central Plateau. This included a series of workshops completed in 2002 with representatives from DOE, EPA, Ecology, the Hanford Advisory Board (HAB), the Tribal Nations, the State of Oregon, and other interested stakeholders. The workshops focused on the different programs involved in activities in the Central Plateau and the need for a consistent application of risk-assessment assumptions and goals. The results of the risk framework are documented in letter HAB 132, "Exposure Scenarios Task Force on the 200 Area"; in the Tri-Parties' response (Klein et al., 2002, "Consensus Advice #132: Exposure Scenarios Task Force on the 200 Area") to that letter; and in the final report, *Report of the Exposure Scenarios Task Force* (HAB, 2002). This guidance has been followed in the preparation of the 200-PW-1, 200-PW-3, and 200-PW-6 OUs baseline risk assessment.

The characterization and remediation of waste sites at the Hanford Site are addressed in the Tri-Party Agreement (Ecology et al., 1989, as amended). This agreement addresses the integration of cleanup programs under CERCLA and RCRA to provide a standard approach to directing cleanup activities and to ensure that applicable regulatory requirements are met. Details of this integration for the 200 Areas are presented in the Implementation Plan (DOE/RL-98-28).

The land surrounding the 200 East and 200 West Areas was designated as industrial-exclusive in DOE/EIS-0222-F. All of the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites are within the industrial-exclusive land-use area (Figure 1-1).

1.3.2 Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Process

The RI Report (DOE/RL-2006-51) and the PW Work Plan (DOE/RL-2001-01) summarize and reference the CERCLA and related documents and activities for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The references include descriptions of the expedited response action that was undertaken for the CCl_4 that has migrated beyond the boundaries of the known CCl_4 disposal sites in the 200-PW-1 OU. These documents were considered in the preparation of this FS.

1.3.3 Facility Ownership

The Hanford Site land holdings consist of three different real-property classifications: (1) lands acquired in fee by DOE or its predecessor agencies, (2) U.S. Bureau of Land Management public domain lands withdrawn from the public domain for use as part of the Hanford Site, and (3) lands that the U.S. Bureau of Reclamation withdrew from the public domain or acquired in fee as part of the Columbia Basin Project. All lands in the Hanford Site area were ceded to the United States by the Treaties of 1855, and these treaties contain reserved rights for perpetuity. All Federal agencies and projects, including the U.S. Bureau of Reclamation and the U.S. Bureau of Land Management, have a Federal trust responsibility to protect the rights of the Indian Tribes.

The U.S. Bureau of Reclamation agreed in a memorandum of agreement to transfer custody, possession, and use of certain acquired and withdrawn lands situated within the control zone of the Hanford Works to the U.S. Atomic Energy Commission on February 27, 1957. The U.S. Bureau of Reclamation retained the right to construct, operate, and maintain the Wahluke Canal and related facilities and any necessary waste ways and drainage ways through the Wahluke Slope in connection with irrigation of lands outside of the control zone. These lands were included in the South Columbia Basin Irrigation District and the East Columbia Basin Irrigation District at the time of district formation. In the memorandum of agreement, the U.S. Bureau of Reclamation identified a continued interest in development of irrigable lands on the Wahluke Slope as part of the Columbia Basin Project. The U.S. Atomic Energy Commission acknowledged the interest of the U.S. Bureau of Reclamation and reaffirmed a policy of keeping DOE land ownership and restrictions of land use on the Wahluke Slope to a minimum (DOE/EIS-0222-F).

1.4 FEASIBILITY STUDY REPORT ORGANIZATION

This FS report includes all of the required elements suggested in EPA/540/G-89/004. The report contains the following chapters and supporting appendices.

- Chapter 1.0 presents the purpose, scope, and regulatory framework for the FS, as well as this overview of report organization.
- Chapter 2.0 presents descriptions of the physical setting, waste sites, site contamination, and fate and transport and explains the process used to assign analogous waste sites to the representative waste sites.
- Chapter 3.0 discusses land-use assumptions, summarizes the risk assessments, summarizes the evaluation of groundwater protection, identifies the contaminants of concern (COC), and develops the overall cleanup objectives and media-specific goals for the waste sites.
- Chapter 4.0 refines the remediation or contaminant technologies identified for these OUs and waste sites in the Implementation Plan (DOE/RL-98-28) by evaluating new information on existing technologies or promising and relevant emerging technologies.

The technologies were broadly screened for applicability to the waste sites in the FS. Screening considerations include effectiveness (likelihood of meeting RAOs for the specific contaminants present at a site), implementability relative to specific site conditions, status of technology development, and relative cost.

- Chapter 5.0 describes the remedial-alternative development process, initially conducted as part of the Implementation Plan (DOE/RL-98-28) development, and uses that information in concert with site-specific data from the RI to refine the remedial alternatives retained for the detailed and comparative analyses.
- Chapter 6.0 presents a detailed analysis of each of the remedial alternatives against seven of the nine CERCLA evaluation criteria (overall protection of human health and the environment; regulatory compliance; long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost) as defined in EPA/540/G-89/004. This chapter also assesses each alternative relative to the *National Environmental Policy Act of 1969* (NEPA) values, as required by DOE policy.
- Chapter 7.0 presents the comparative analysis of the remedial alternatives and identifies relative advantages and disadvantages, based on seven of the nine CERCLA evaluation criteria. The results of this analysis provide a basis for identifying a preferred alternative for each representative and unique waste site.
- Chapter 8.0 provides a summary of the key uncertainties of all analyses included in this report so that their impact on the evaluations is explicitly presented and discussed.
- Chapter 9.0 summarizes the conclusions of the FS. This chapter also identifies the preferred alternatives for the six representative and unique waste sites and the path forward for remediation of the Plutonium/Organic-Rich Group OU waste sites.
- Chapter 10.0 provides the references for the main text of the report; each appendix contains its own reference section.
- Appendix A presents the integrated 200-PW-1, 200-PW-3, and 200-PW-6 OUs and 200-ZP-1 Groundwater OU human-health risk evaluations for the representative and unique waste sites, including the methodology, results, and uncertainties.
- Appendix B presents the ecological risk evaluations for all of the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites, including the methodology, results, and uncertainties.
- Appendix C presents an analysis of regulatory requirements and available guidance with respect to the Plutonium/Organic-Rich Group OU waste sites.
- Appendix D presents the basis for the comparative cost estimates.
- Appendix E presents the evaluation of groundwater protection.
- Appendix F presents the evaluation of risk reduction and cost for various soil-removal alternatives at the 216-Z-9 Trench and the 216-Z-1A Tile Field.

Figure 1-1. Location of the Hanford Site.

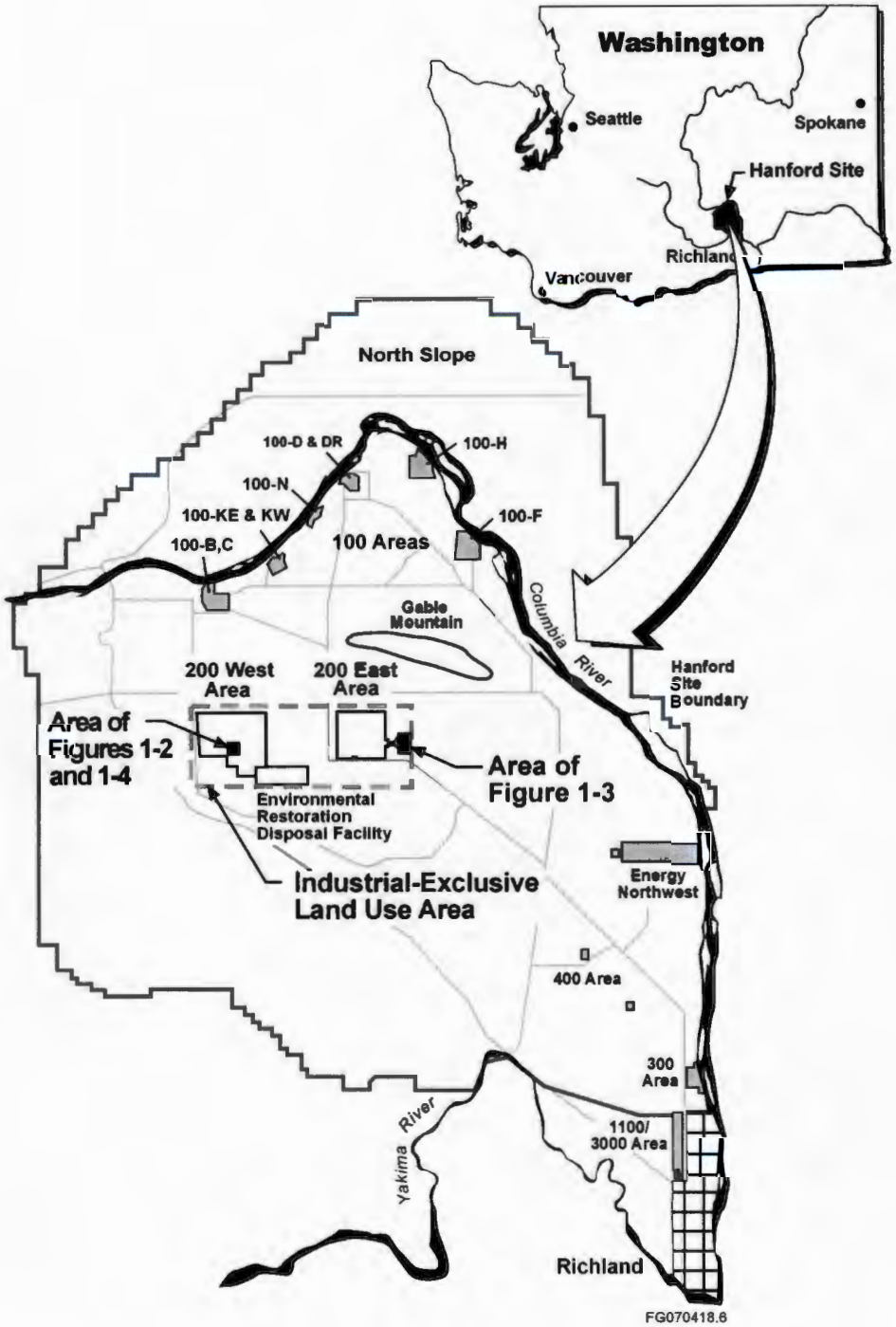


Figure 1-2. 200-PW-1 Operable Unit Waste Sites in the 200 West Area.

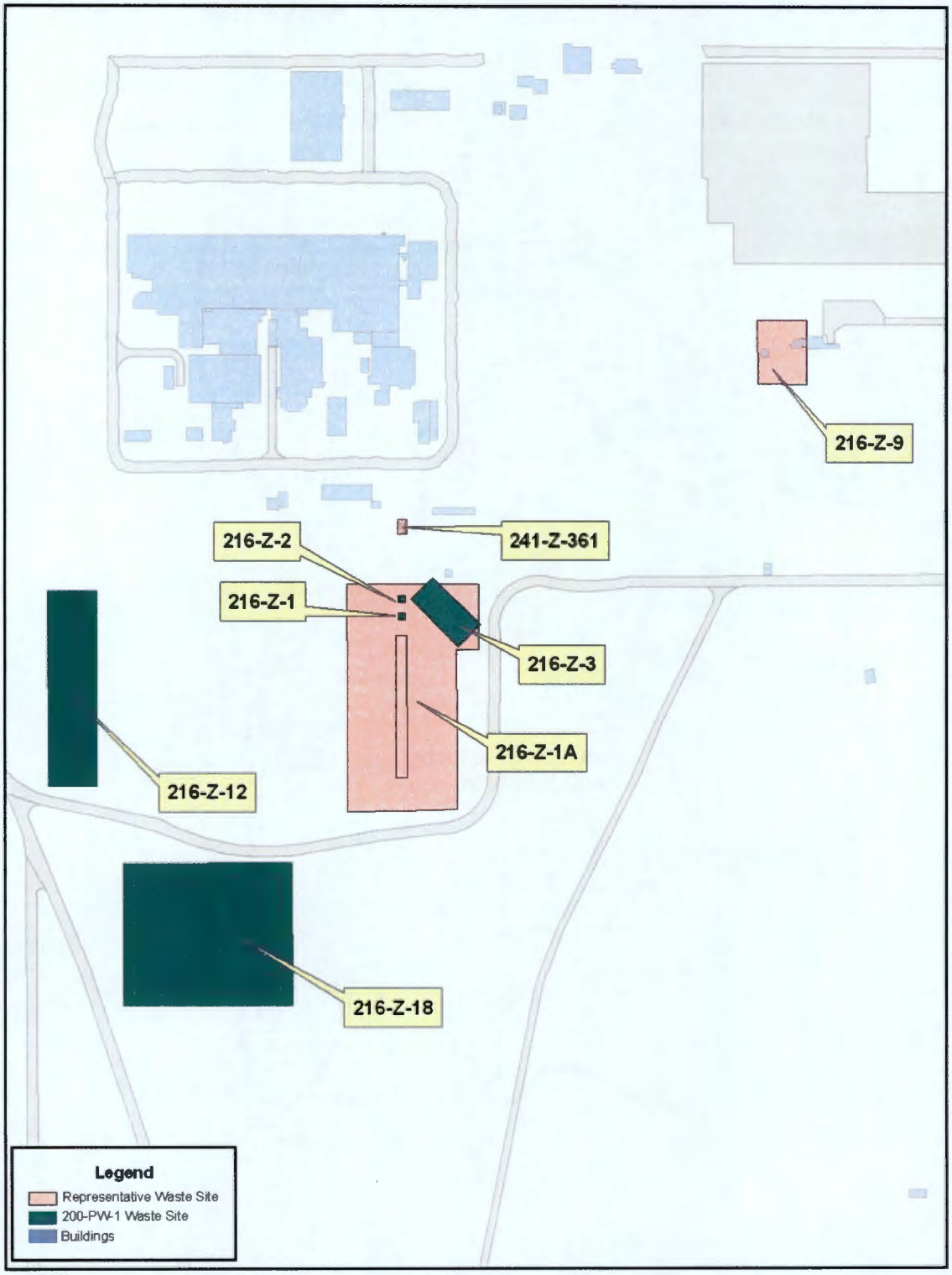


Figure 1-3. 200-PW-3 Operable Unit Waste Sites in the 200 East Area.

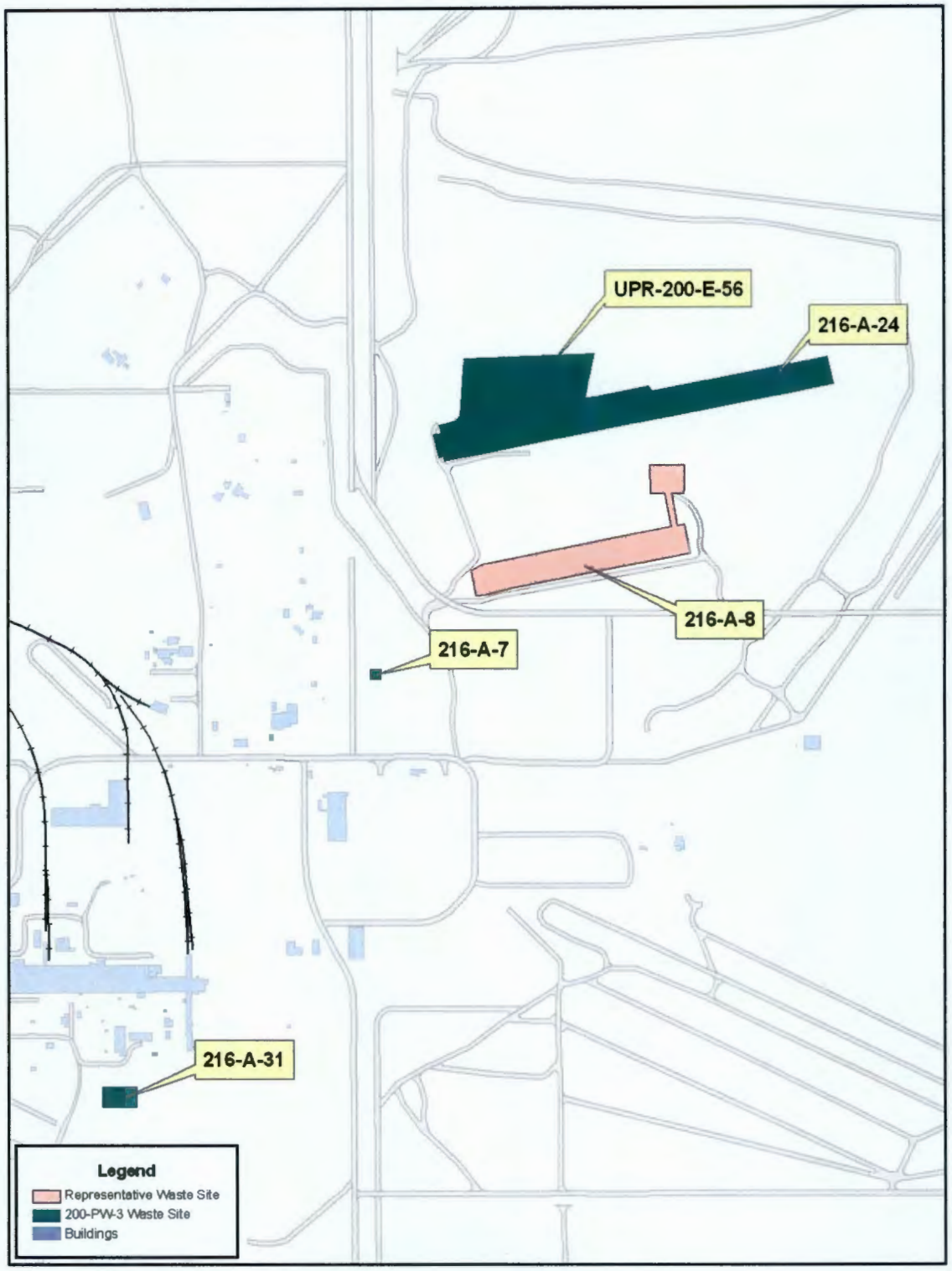


Figure 1-4. 200-PW-6 Operable Unit Waste Sites in the 200 West Area.

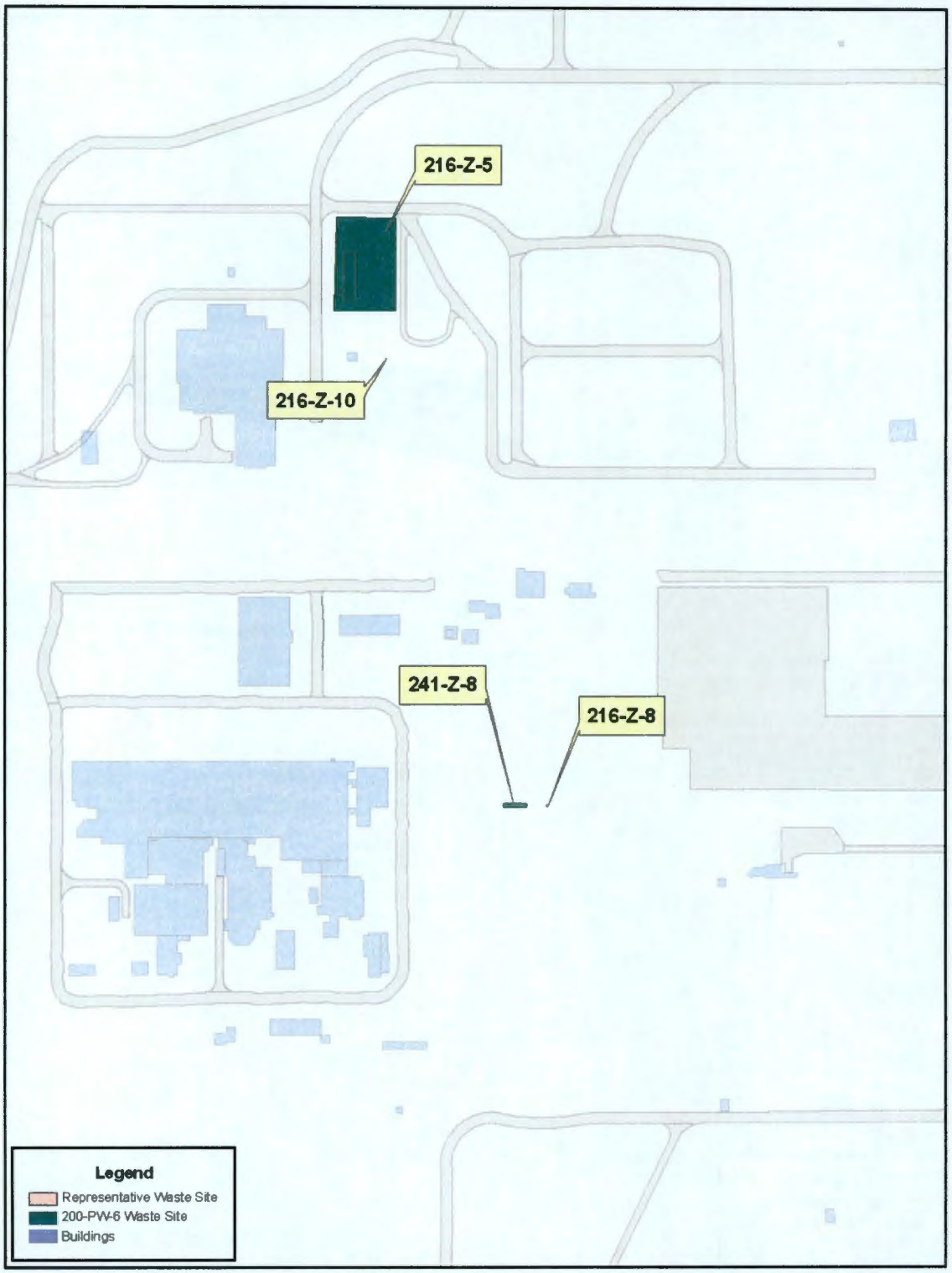


Figure 1-5. Relationship of the 200-PW-1 and 200-PW-6 Operable Unit Waste Sites to the 200-ZP-1 Groundwater Operable Unit and Other Waste Sites in the 200 West Area.

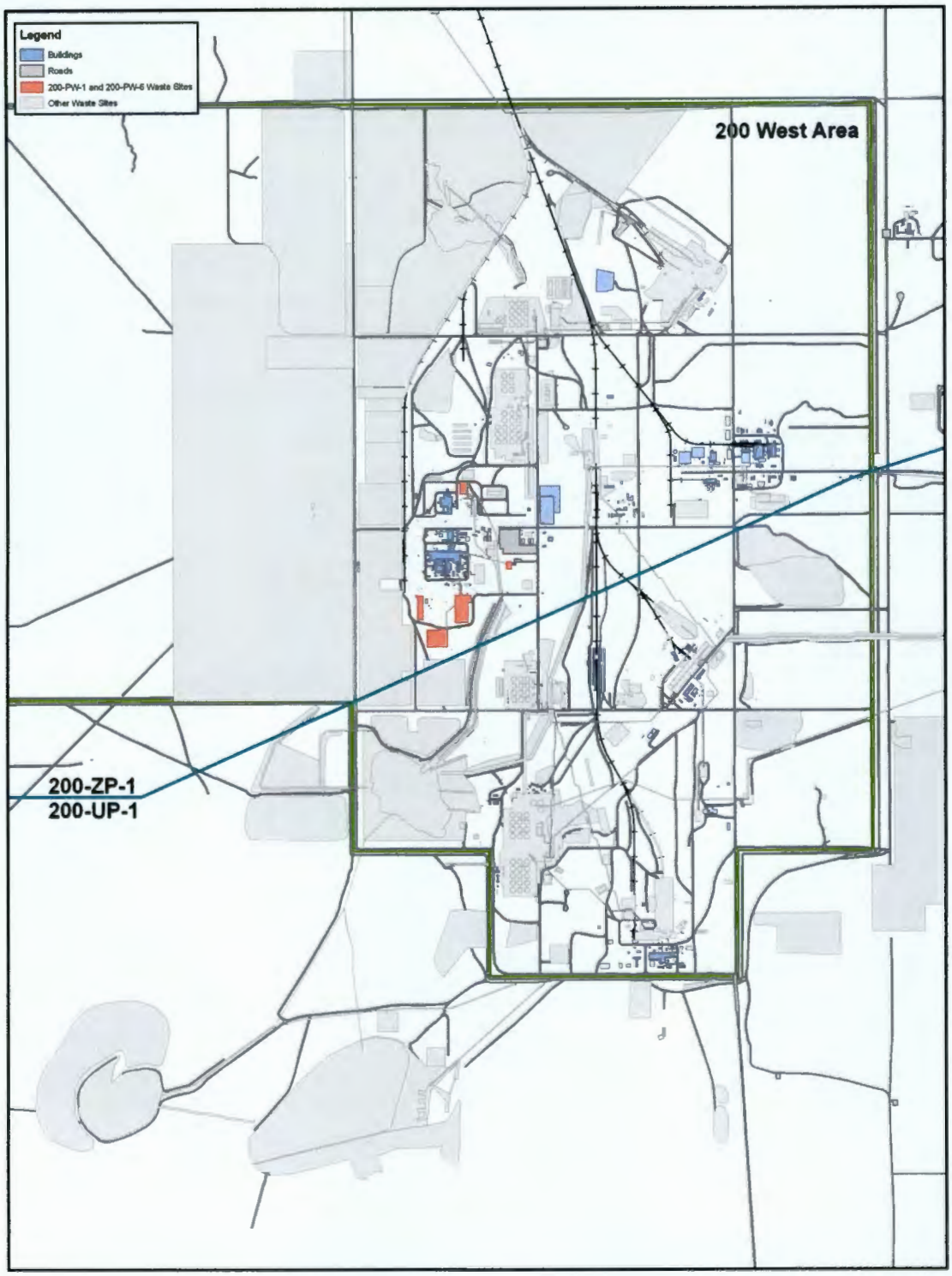


Table 1-1. Alignment of 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units Representative or Unique and Analogous Waste Sites.

Representative or Unique Waste Site	Analogous Waste Site
216-Z-1A Tile Field[a]	216-Z-1 Crib[a]
	216-Z-2 Cribs[a]
	216-Z-3 Crib[a]
	216-Z-5 Crib[c]
	216-Z-12 Crib[a]
	216-Z-18 Crib[a]
216-Z-8 French Drain[c]	None
216-Z-9 Trench[a]	None
216-Z-10 Injection/Reverse Well[c]	None
241-Z-361 Settling Tank[a]	241-Z-8 Settling Tank[c]
216-A-8 Crib[b]	216-A-7 Crib[b]
	216-A-24 Crib[b]
	216-A-31 Crib[b]
	UPR-200-E-56 unplanned release[b]

[a] 200-PW-1 Operable Unit waste site.
[b] 200-PW-3 Operable Unit waste site.
[c] 200-PW-6 Operable Unit waste site.

2.0 BACKGROUND INFORMATION

This chapter discusses the background and history of waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The information includes OU background and history; physical setting; natural resources; representative waste site description, characterization, and contamination; and an evaluation of analogous waste sites (i.e., sites not identified as representative waste sites within the OUs).

2.1 CERCLA STRATEGY USED FOR 200-PW-1, 200-PW-3, AND 200-PW-6 OPERABLE UNITS

The waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs were aligned with representative waste sites based on similarities between their contaminant distribution models (Section 2.5). This analogous waste-site approach, which is fundamental to the approach established for remedy development, recognizes that data collected from representative waste sites can be extrapolated to similar or analogous waste sites to support identification of a preferred alternative (Implementation Plan, DOE/RL-98-28, Section 2.5.1).

For the analogous waste-site approach, waste sites are combined into groups of sites with similar features such as location, geology, waste site history, contaminants, and potential remedies (Implementation Plan, DOE/RL-98-28, Section 2.5.1). Within each group, one or more representative waste sites was selected for comprehensive field investigations, with the intent that remedies developed for representative waste sites would be likely to apply to other sites in the waste group that were not as fully characterized.

However, there are some situations where greater flexibility may be required to ensure implementation of the most appropriate remedy for the analogous waste site. This is the case where there is significant uncertainty associated with the remedy selection. In such situations, the proposed plan will identify potential significant differences between the analogous waste site and its representative waste site that might cause a different remedy decision to be made for the analogous waste site. In such situations, the proposed plan may draw on the analysis from the FS to identify a remedy that is more appropriate to the analogous waste site that resolves the issue arising from the difference. As part of the implementation of the remedy, additional site-specific information may be collected to distinguish between the original remedy developed for the representative waste site or as a contingency remedy described in the proposed plan. The ROD will contain the metrics required to distinguish between the original remedy and the contingency. The contingent remedy would be available if the selected remedy were determined to be inappropriate for a waste site.

For this FS, the evaluation focuses on the representative and unique waste sites but is acknowledged to extend to other sites in the OUs. In the proposed plan, a preferred remedial alternative is identified for all of the waste sites in the group, based on the evaluation of the preferred remedial alternative identified for the representative waste site and details of each analogous waste site.

2.2 OPERABLE UNITS BACKGROUND AND HISTORY

The 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites are located within the 200 Areas industrial-exclusive land-use area (see Figure 1-1). This section summarizes the background and history of these OUs.

2.2.1 200-PW-1 Operable Unit

The 200-PW-1 OU includes three representative waste sites and five analogous waste sites that received mostly acidic aqueous and organic (mostly CCl_4, tributyl phosphate [TBP], and lard oil) process and laboratory wastes containing large amounts of americium and plutonium and some uranium. The waste discharged to the soil column in this OU was generated at the Z Plant complex (now referred to as the Plutonium Finishing Plant or PFP Complex) from 1949 through 1973.

Three waste sites were selected as representative waste sites in the 200-PW-1 OU. The 216-Z-1A Tile Field was selected as the "typical" representative source-term waste site because of its plutonium and CCl_4 inventory and its current level of characterization. This waste site is associated with the analogous waste sites 216-Z-1 Crib, 216-Z-2 Crib, 216-Z-3 Crib, 216-Z-5 Crib, 216-Z-12 Crib, and 216-Z-18 Crib. The 216-Z-9 Trench was selected as the "worst case" representative source-term waste site, because it has the highest plutonium inventory and a high CCl_4 inventory in terms of the volume of CCl_4 released, compared to the infiltration area of the receiving site. In the evaluation presented in Section 2.6, there are no associated analogous waste sites to the 216-Z-9 Trench. The 241-Z-361 Settling Tank was selected as a representative waste site, because it has a high plutonium inventory not released to the environment and because of its current level of characterization (RI Report, DOE/RL-2006-51). The associated analogous waste site is the 241-Z-8 Settling Tank in the 200-PW-6 OU.

Since 1992, an expedited response action in the 200-PW-1 OU has used soil-vapor extraction (SVE) to minimize the migration of CCl_4 in the vadose zone away from several 200-PW-1 OU waste sites. Initial CCl_4 concentrations in extracted soil vapor were approximately 30,000 parts per million by volume (ppmv) at the 216-Z-9 Trench and 1,500 ppmv at the 216-Z-1A Tile Field and 216-Z-18 Crib in 1993. In contrast, CCl_4 concentrations in extracted soil vapor were approximately 21 ppmv at the 216-Z-9 Trench in September 2006 and 10 ppmv at the 216-Z-1A Tile Field and 216-Z-18 Crib in July 2006. The remaining CCl_4 mass likely is held in fine-grained layers in the vadose zone, where it is less likely to be removed by the SVE system.

Carbon tetrachloride vapor concentrations measured near the groundwater during the 1996-1997 200-PW-1 OU rebound study were compared to groundwater-concentration data collected from nearby groundwater wells as part of the 200-ZP-1 Groundwater OU pump-and-treat-project. At both the 216-Z-9 Trench and the 216-Z-1A Tile Field, the measured vapor concentrations were an order of magnitude less than the equilibrium vapor concentrations predicted using Henry's Law and site groundwater concentrations. Based on this comparison, the CCl_4 concentration gradient in 1997 would drive the contaminant from the groundwater to the vadose zone.

Between 1990 and 2006, the CCl_4 concentrations at the top of the unconfined aquifer underlying the primary CCl_4 source sites also have been reduced. This reduction likely has resulted from the dual application of SVE remediation in the vadose zone and the 200-ZP-1 Groundwater OU pump-and-treat interim remedy in the groundwater in the vicinity of the source waste sites (the 216-Z-9 Trench, 216-Z-1A Tile Field, and 216-Z-18 Crib).

The reduction of CCl_4 vapor concentrations in the area remediated using SVE has reduced the threat to groundwater, based on calculations using Henry's Law. However, as CCl_4 concentrations in both groundwater and the vadose zone change, the direction of movement between these media may change based on the CCl_4 concentration gradients (SGW-33746, *Performance Evaluation Report for Soil Vapor Extraction Operations at the 200-PW-1 Carbon Tetrachloride Site, Fiscal Year 2006*).

The 14.2 m^3/min (501.5 ft^3/min) SVE system was the only SVE unit operated during fiscal years 1998, 1999, 2001, 2002, 2003, 2004, 2005, and 2006. The system typically operated from April through September and alternated between the 216-Z-9 Trench and the 216-Z-1A Tile Field/ 216-Z-18 Crib waste sites for approximately 3-month periods. The system was maintained in standby mode from October through March to allow time for CCl_4 vapor to diffuse into soil pores from the remaining CCl_4 mass sorbed to fine-grained soil. System operation was suspended during the entire period of fiscal year 2000 as a result of higher priority remediation activities that competed for limited funding. Passive SVE systems were installed on eight wells in fiscal year 1999 and operated from fiscal year 2000 through fiscal year 2006. Passive SVE is a natural process driven by barometric pressure fluctuations and often is referred to as "barometric pumping." The eight wells are located in the 216-Z-1A Tile Field/216-Z-18 Crib Well Field (RI Report, DOE/RL-2006-51).

2.2.2 200-PW-3 Operable Unit

The 200-PW-3 OU includes one representative waste site and four analogous waste sites. The 200-PW-3 OU waste sites received organic-rich wastes (primarily refined kerosene [normal paraffin hydrocarbon], TBP, and butanol) from A Plant (Plutonium-Uranium Extraction Plant). The waste can be classified as ranging from acidic to basic with moderate amounts of uranium and plutonium and small amounts of fission products (except the 216-A-8 and 216-A-24 Cribs, which received larger amounts of fission products).

One waste site was selected as a representative waste site. The 216-A-8 Crib was selected as the "worst case" representative waste site in the 200-PW-3 OU, because it has a relatively high fission product inventory compared to other waste sites in the Plutonium/Organic-Rich Group OU and was believed to have received a significant inventory of organic solvents including compounds other than CCl_4. However, as part of the RI, no significant concentrations of organics were detected at the 216-A-8 Crib (RI Report, DOE/RL-2006-51). The associated analogous waste sites are the 216-A-7 Crib, 216-A-24 Crib, and 216-A-31 Crib, and the UPR-200-E-56 unplanned release site.

2.2.3 200-PW-6 Operable Unit

The 200-PW-6 OU includes two unique waste sites and two analogous waste sites. The waste sites received neutral/basic process wastes from the Plutonium Isolation Facility, which operated from approximately 1945 to 1949, and silica gel waste from back flushes of the feed filters from the Recovery of Uranium and Plutonium by Extraction (RECUPLEX) process, which recovered plutonium from Z Plant liquid and solid scraps from 1955 to 1962. The 200-PW-6 OU waste sites received plutonium-rich wastes from the PFP Complex, but did not receive organic-rich wastes (RI Report, DOE/RL-2006-51).

The alignment of representative or unique and analogous waste sites presented in the PW Work Plan (DOE/RL-2001-01, Table 1-1) was reevaluated in support of the RI/FS process. Two additional unique waste sites with sufficient existing characterization data to support remedial decisions were identified during this reevaluation (see Section 2.6). Two waste sites were selected as unique waste sites in the 200-PW-6 OU, the 216-Z-10 Injection/Reverse Well and the 216-Z-8 French Drain. The 216-Z-5 Crib and 241-Z-8 Settling Tank are analogous waste sites to the representative waste sites in the 200-PW-1 OU (see Section 2.2.1).

2.3 PHYSICAL SETTING

The following sections briefly describe the meteorology, topography, and hydrogeologic setting in the vicinity of the 200-PW-1, 200-PW-3, and 200-PW-6 OUs.

2.3.1 Meteorology

The Hanford Site lies within the semiarid shrub-steppe Pasco Basin of the Columbia Plateau in south-central Washington State. Climatological data for the Hanford Site are compiled at the Hanford Meteorological Station (HMS), which is located on the Hanford Site's Central Plateau, just outside the northeast corner of the 200 West Area and about 4 km (3 mi) west of the 200 East Area.

The prevailing surface winds on Hanford's Central Plateau are from the northwest, and occur most frequently during the winter and summer. The HMS reported wind speeds, from 1945 through 2004, at 15.2 m (50 ft) above the ground that are lower during the winter months, averaging 2.7 to 3.1 m/s (6 to 7 mi/h), and faster during the spring and summer, averaging 3.6 to 4.0 m/s (8 to 9 mi/h).

Based on data collected from 1946 through 2004, the average monthly temperatures at the HMS range from a low of -0.7 °C (31 °F) in January to a high of 24.7 °C (76 °F) in July. The record maximum temperature, 45 °C (113 °F) occurred at the HMS on July 13, 2002, and August 4, 1961. The record minimum temperature, -31 °C (-23 °F) occurred on February 1 and 3, 1950. The annual average relative humidity at the HMS is 55 percent. The annual average dew point temperature at the HMS is 1 °C (34 °F).

Average annual precipitation at the HMS is 17 cm (6.8 in.). Most precipitation occurs during the late autumn and winter, with more than half of the annual amount occurring from November through February. Average snowfall ranges from 0.25 cm (0.1 in.) during October to a

maximum of 13.2 cm (5.2 in.) during December and decreases to 1.3 cm (0.5 in.) during March. Snowfall accounts for about 38 percent of all precipitation from December through February.

Concerns about severe weather usually center on hurricanes, tornadoes, and thunderstorms. Washington does not experience hurricanes; and tornadoes are rare and generally small in the northwestern portion of the United States. The estimated probability of a tornado striking a point on the Hanford Site is 9.6×10^{-6}/yr. The average occurrence of thunderstorms near the HMS is 10 per year (PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*) (Hanford NEPA).

2.3.2 Topography

The 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites are located in the 200 East and 200 West Areas of the Hanford Site. The 200 Areas are located on a broad, relatively flat area that constitutes a local topographic high commonly referred to as the 200 Areas Plateau. The plateau is a giant flood bar (Cold Creek Bar) that was formed during cataclysmic ice-age floods from glacial Lake Missoula. The flood bar may have started forming during the earliest floods 1 to 2 million years ago. The Cold Creek Bar trends generally east-west, with elevations between 197 and 225 m (647 to 740 ft). The plateau drops off rather steeply to the north and east into a former flood channel that runs east-southeast, with elevation changes of between 15 and 30 m (50 and 100 ft). The plateau gently decreases in elevation to the south into the Cold Creek valley. Most of the 200 West Area and the southern half of the 200 East Area are situated on the Cold Creek Bar, while the northern half of the 200 East Area lies on the edge of a former flood channel. A secondary flood channel running south from the main channel bisects the 200 West Area. More detail on the physical setting of the 200 Areas and vicinity is provided in the Implementation Plan, Appendix F (DOE/RL-98-28).

Waste sites in the 200 West Area are situated on a relatively flat area within the secondary flood channel that bisects the 200 West Area. Surface elevations range from approximately 201 to 217 m (660 to 712 ft). Waste-site surface elevations in the 200 East Area range from about 189 m (620 ft) in the northern portion to about 220 m (720 ft) in the southern portion. The ground surface in the 200 East Area slopes gently to the northeast.

2.3.3 Geology

The 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites are located in the Pasco Basin, one of several structural and topographic basins of the Columbia Plateau. Basalts of the Columbia River Basalt Group and a sequence of suprabasalt sediments underlie the representative and unique waste sites. From oldest to youngest, the major geologic units of interest are the Elephant Mountain Member of the Saddle Mountains Basalt Formation, Columbia River Basalt Group, the Ringold Formation, the Cold Creek unit (CCU), the Hanford formation, and surficial deposits. The stratigraphy of the 200 Areas and the major units of interest are shown in Figures 2-1 and 2-2.

Elephant Mountain Member. The Elephant Mountain Member of the Saddle Mountains Basalt Formation is the uppermost basalt unit (i.e., bedrock) in the 200 Areas (Implementation Plan, DOE/RL-98-28, Appendix F). Except for a small area north of the 200 East Area boundary

where it has been eroded away, the Elephant Mountain Member is laterally continuous throughout the 200 Areas. The RI field investigations for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs did not penetrate to the basalt.

Ringold Formation. The Ringold Formation consists of an interstratified fluvial-lacustrine sequence of unconsolidated to semiconsolidated clay, silt, sand, and granule-sized gravel to cobbles that were deposited by the ancestral Columbia River (PNNL-12261, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*, and PNNL-13858, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford Site, Washington*). These sediments, shown in Figure 2-2, consist of four major units (from oldest to youngest): the fluvial gravel and sand of Unit 9 (basal coarse); the buried soil horizons, overbank, and lake deposits of Unit 8 (lower mud); the fluvial sand and gravel of Unit 5 (upper coarse); and the lacustrine mud of Unit 4 (upper fines). Units 9 and 5 consist of silty-sandy gravel with secondary lenses and interbeds of gravelly sand, sand, and muddy sands to silt and clay. Unit 8 (lower mud) consists mainly of silt and clay. Unit 4 (upper fines) consists of silty over-bank deposits and fluvial sand. Units 6 and 7 are not present beneath the 200 West and East Areas; Unit 4 is not present in the 200 East Area, and it is discontinuous in the 200 West Area (PNNL-12261 and PNNL-13858). The two RI boreholes at the 216-Z-9 Trench penetrated into the Ringold Formation Unit 5. The RI borehole at the 216-A-8 Crib penetrated into Ringold Unit 9. Boreholes drilled as part of the CCl_4 dispersed-plume investigation also penetrated into the Ringold Formation Unit 5.

Cold Creek unit. The CCU includes several post-Ringold Formation and pre-Hanford formation units present beneath a portion of the 200 East and West Areas (DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Post-Ringold Formation Sediments Within the Central Pasco Basin*). The CCU includes the sediments formerly identified as the Plio-Pleistocene unit, caliche, early Palouse soil, pre-Missoula gravels, and sidestream alluvial facies in previous site reports. The CCU has been divided into five lithofacies: fine-grained, laminated to massive (fluvial-overbank and/or eolian deposits, formerly the early Palouse soil); fine- to coarse-grained, calcium-carbonate cemented (calcic paleosol, formerly the caliche); coarse-grained, multilithic (mainstream alluvium, formerly the pre-Missoula gravels); coarse-grained, angular, basaltic (colluvium); and coarse-grained, rounded, basaltic (sidestream alluvium, formerly sidestream alluvial facies; DOE/RL-2002-39). The two RI boreholes at the 216-Z-9 Trench penetrated the CCU. At the 216-Z-9 Trench, the CCU is present from about 33 to 36 m (108 to 118 ft) depth and comprises two distinct layers. The upper silt layer is about 2.5 m (8 ft) thick, and the lower calcic paleosol layer is about 0.5 m (2 ft) thick and is composed of a variable mixture of gravel, sand, and silt with a calcium carbonate cemented matrix. The RI borehole drilled to investigate the 216-A-8 Crib did not encounter the CCU, because it is not present in the vicinity of the 216-A-8 Crib.

Hanford formation. The Hanford formation is the informal stratigraphic name used to describe the Pleistocene cataclysmic flood deposits in the Pasco Basin (DOE/RL-2002-39). The Hanford formation consists predominantly of unconsolidated sediments that range from boulders to gravel, sand, silty sand, and silt. The sorting ranges from poorly sorted (for gravel facies) to well sorted (for fine sand and silt facies). The Hanford formation is divided into three main facies associations: interbedded sand- to silt-dominated (formerly called the Touchet beds or slackwater facies); sand-dominated (formerly called the sand-dominated flood facies); and

gravel-dominated (formerly called the Pasco gravels), which have been further subdivided into 11 textural-structural lithofacies (DOE/RL-2002-39). Beneath the representative and unique waste sites and the adjacent areas, the Hanford formation includes all three facies associations. The gravel-dominated facies are cross-stratified, coarse-grained sands and granule-size gravel to boulders. The gravel is uncemented and matrix-poor. The sand-dominated facies are well-stratified fine- to coarse-grained sand and granule gravel. Silt in these facies is variable and may be interbedded with the sand. Where the sand and silt content is low in the gravel-dominated facies, an open-framework texture is common. Clastic dikes are common in the Hanford formation but rare in the Ringold Formation (Implementation Plan, DOE/RL-98-28, and DOE/RL-2002-39). They appear as vertical to subvertical sediment-filled structures, especially within sand- and silt-dominated units (Figure 2-1). The two RI boreholes at the 216-Z-9 Trench and the RI borehole at the 216-A-8 Crib penetrated the Hanford formation. In general, from shallowest to deepest, the Hanford formation units encountered beneath the 200 West Area included an upper fines unit (Hanford formation upper fines), the upper gravel-dominated sequence (H1), a sand-dominated sequence (H2), and a lower gravel-dominated sequence (H3). Not all of these units are laterally continuous beneath the waste sites.

The cataclysmic floodwaters that deposited sediments of the Hanford formation locally reshaped the topography of the Pasco Basin. The floodwaters deposited a thick sand and gravel bar (Cold Creek Bar) that constitutes the higher southern portion of the 200 Areas, informally known as the 200 Areas Plateau. In the waning stages of the ice-age floods, these floodwaters also eroded a channel north of the 200 Areas in the area currently occupied by West Lake and the former Gable Mountain Pond. The pre-Hanford formation erosion and the floodwaters removed all of the Ringold Formation from this area and deposited Hanford formation sediments directly over basalt.

Surficial Deposits. Surficial deposits include Holocene eolian sheets of sand that form a thin veneer over the Hanford formation across the site, except in localized areas where the deposits are absent. Surficial deposits consist of very fine- to medium-grained sand to occasionally silty sand. Fill material was placed in and over some waste sites during construction and for contamination control. The fill consists of reworked Hanford formation sediments and/or surficial sand and silt.

2.3.4 Hydrostratigraphy

The focus of this FS is the vadose zone beneath the representative and unique waste sites. Vadose-zone hydrostratigraphic units in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs include the Ringold Formation, the CCU, the Hanford formation, and surficial deposits. The base of the unconfined aquifer typically is the top of the Ringold Formation Unit 8 (lower mud) within the 200 West Area and the top of the basalt (Elephant Mountain Member) in the 200 East Area.

Vadose Zone. The vadose zone is the unsaturated interval between the ground surface and the water table. The vadose zone is approximately 104 m (340 ft) thick in the southern section of the 200 East Area and thins to the north to as little as 0.3 m (1 ft) near West Lake. Sediments in the vadose zone are dominated by the Hanford formation, although the CCU and part of the Ringold

Formation are above the water table in the 200 West Area. Because erosion during cataclysmic flooding removed much of the Ringold Formation north of the central part of the 200 East Area, the vadose zone predominantly comprises Hanford formation sediments between this area and Gable Mountain to the north. Basalt also projects above the water table in the northern part of the 200 East Area.

In the 200 West Area, the vadose-zone thickness ranges from 40 to 75 m (132 to 246 ft). Sediments in the vadose zone are the Ringold Formation, the CCU, and the Hanford formation. Erosion during cataclysmic flooding removed some of the CCU and the Ringold Formation, especially in the northern part of the 200 West Area.

Historically, and as recently as the early 1990s, perched water has been documented above the CCU at locations in the 200 West Area. While liquid-waste disposal facilities were operating, localized areas of saturation or near saturation were created in the soil column. With the reduction of artificial recharge from disposal facilities in the 200 Areas in 1995, downward flux of liquid in the vadose zone beneath these waste sites has been decreasing.

Unconfined Aquifer. The top of the unconfined aquifer in the 200 Areas occurs within the Ringold Formation, the CCU, or the Hanford formation, depending on location. The base of the unconfined aquifer is the top of the Ringold Formation Unit 8 (lower mud), or the top of the basalt where Unit 8 is absent at the 200 West Area, and the top of the basalt in the 200 East Area. Groundwater in the unconfined aquifer flows from recharge areas where the water table is higher (west of the Hanford Site) to areas where it is lower, near the Columbia River (PNNL-16346, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*). In the northern half of the 200 East Area, the water table is present within the Hanford formation, except in areas where basalt extends above the water table. In the central and southern parts of the 200 East Area, the water table is located near the contact between the Ringold Formation and the Hanford formation. Depth to groundwater in the 200 East Area and vicinity ranges from about 54 m (177 ft) near the former B Pond area to about 104 m (340 ft) near the southern boundary of the 200 East Area. The water table across the 200 East Area is very flat, making it difficult to determine groundwater flow direction based on water-level measurements from monitoring wells. The configuration of contaminant groundwater plumes, however, indicates that groundwater flows to the northwest in the northern half of the 200 East Area and to the east/southeast in the southern half of the 200 East Area. Identifying the specific location of the groundwater divide between the northern and southern sections is difficult because of the flat water table. The highly transmissive Hanford formation sediments are the cause of the flat water table in the 200 East Area.

The water table has been declining since surface-liquid discharges were terminated in the 200 East Area in the mid-1990s. In the 200 East Area, the elevation of the water table declined by an average of 0.07 m (0.2 ft) from March 2005 to April 2006. This is less than the previous annual decline (0.13 m [0.4 ft] from March 2004 to March 2005, PNNL-15670, *Hanford Site Groundwater Monitoring for Fiscal Year 2005*), and is below the average rate of decline observed from June 1997 to March 2002 (0.17 m/yr [0.56 ft/yr]) (PNNL-16346).

Groundwater beneath the 200 West Area occurs primarily in the Ringold Formation. Depth to water varies from about 40.2 m (132 ft) to greater than 75 m (246 ft). In the 200 West Area,

groundwater in the unconfined aquifer typically flows from west to east. The surface elevation of the water table beneath the 200 West Area currently is declining at a average rate of 0.31 m/yr (1 ft/yr) in those areas not influenced by the 200-ZP-1 Groundwater OU pump-and-treat remediation system (PNNL-16346).

Recharge to the unconfined aquifer in the 200 Areas is from artificial sources and, less significantly, from natural precipitation. According to estimates, 1.7 trillion liters (450 billion gal) of liquid waste, some containing radionuclides and hazardous chemicals, have been released to the ground at the Hanford Site since 1944. Much of this contamination remains in the vadose zone above the water table, but some of the more mobile contaminants have reached groundwater (DOE/RL-2002-68, *Hanford's Groundwater Management Plan: Accelerated Cleanup and Protection*). Most sources of artificial recharge were terminated in 1995. The current artificial recharge is limited to liquid discharges from sanitary sewers, two state-approved land-disposal structures (one east of the 200 East Area and one north of the 200 West Area), and 140 small-volume, uncontaminated miscellaneous liquid discharge streams.

2.4 NATURAL RESOURCES

Natural resources in the vicinity of the 200-PW-1, 200-PW-3, and 200-PW-6 OUs include vegetation and wildlife resources. The wildfire in 2000, in and around the Hanford Site, did not affect any waste sites considered in this FS.

Biological and ecological information aids in evaluating impacts to the environment from contaminants in the soils, including potential effects of implementing remedial actions and identification of sensitive habitats and species. This section also considers cultural and aesthetic resources and socioeconomics associated with activities in the 200 Areas.

2.4.1 Vegetation

PNNL-6415 (Hanford NEPA) reports that the undisturbed portions of the 200 Areas are characterized by sagebrush/cheatgrass or sagebrush/Sandberg's bluegrass communities. The dominant plants on the 200 Areas Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass. Of the vegetation types found on the Hanford Site adjacent to the 200-PW-1, 200-PW-3, and 200-PW-6 OUs, those with a shrub component (i.e., big sagebrush, threetip sagebrush [*Artemisia tripartita*], bitterbrush [*Purshia tridentata*], gray rabbitbrush [*Ericameria nauseousa* previously *Chrysothamnus nauseosus*], green rabbitbrush [*Chrysothamnus viscidiflorus*], black greasewood [*Sarcobatus vermiculatus*], winterfat [*Krascheninnikovia (Ceratoides) lanata*], snow buckwheat [*Eriogonum niveum*], and spiny hopsage [*Grayia (Atriplex) spinosa*] are considered shrub-steppe. These stands typically have an understory dominated by bunchgrasses such as bluebunch wheatgrass (*Pseudoroegnaria spicata* previously *Agropyron spicatum*), Sandberg's bluegrass (*Poa sandbergii [secunda]*), needle-and-thread grass (*Hesperostipa comata* previously *Stipa comata*), Indian ricegrass (*Achnatherum hymenoides* previously *Oryzopsis hymenoides*), bottlebrush squirreltail (*Elymus elymoides* previously *Sitanion hysterix*), and prairie junegrass (*Koeleria cristata*), as well as a number of broad-leaf forbs. Heavily grazed or disturbed areas on the Hanford Site often have an understory dominated by cheatgrass.

Disturbance and active management have either completely denuded or significantly reduced the species more typical of undisturbed sites in the 200 Areas at each of the representative and unique waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs.

Before RI field activities began, excavation permits were obtained for the 216-Z-9 Trench, 216-Z-1A Tile Field, and 216-A-8 Crib. As part of the excavation-permit process for site investigation activities, Ecological Compliance Reviews (ECR) were issued by Pacific Northwest National Laboratory (PNNL) for the 216-Z-9 Trench (ECR#2006-200-031, *Biological Review of the Stage 5 VET Probes Project, 200W Area*) on April 13, 2006; the 216-Z-1A Tile Field (ECR#2005-200-045, *Biological Review of the Cone Penetrometer Probes South of 234-5Z Project, 200 W Area*) on May 19, 2005; and the 216-A-8 Crib (ECR#2004-200-048, *Biological Review of the Borehole and Geoprobe Casings Installation at 216-A-8 Project, 200W Area*) on February 26, 2004. The ECR consisted of a biological review to determine the occurrence in the project area of plant species protected under the *Endangered Species Act of 1973*; candidates for protection; and species listed as threatened, endangered, candidate, sensitive, or monitored by the State of Washington. The ECR survey methods consisted of pedestrian visual reconnaissance at the 216-Z-9 Trench and 216-Z-1A Tile Field and knowledge of priority habitats and species of concern for each respective site documented by the Washington State Department of Fish and Wildlife and the Washington State Department of Natural Resources. Lists of plant species considered endangered, threatened, proposed, or candidate by the U.S. Fish and Wildlife Service are maintained in 50 CFR 17.12, "Endangered and Threatened Wildlife and Plants, "Endangered and Threatened Plants." The survey results at the 216-Z-9 Trench found that the area was highly disturbed with an essentially barren sand and gravel ground surface. The ECR found no plant species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered near the 216-Z-9 Trench. Ground surface conditions at the 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well are considered similar to those at the 216-Z-9 Trench. The 241-Z-361 Settling Tank is located inside the PFP and thus is located in a highly disturbed environment and considered similar to that of the 216-Z-9 Trench. The survey results at the 216-Z-1A Tile Field found the area highly disturbed by windblown sand, resulting in the elimination of most forbs and grasses. The area was dominated by gray rabbitbrush (*Ericameria nauseousa*) with little understory. The ECR found no plant species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered near the 216-Z-1A Tile Field. The survey results at the 216-A-8 Crib reported that the site had been revegetated with crested wheatgrass (*Agropyron cristatum*) and maintained free of broadleaf plants with regular herbicide applications. The ECR found no plant species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered near the 216-A-8 Crib.

2.4.2 Wildlife

The shrub and grassland habitat of the Hanford Site supports many groups of terrestrial wildlife. Species may include large animals like Rocky Mountain elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*); predators such as coyote (*Canis latrans*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus*); and herbivores including deer mice (*Peromyscus maniculatus*), harvest

mice (*Riethrodontonomys megalotis*), ground squirrels (*Spermophilus* spp.), voles (*Lagurus* spp., *Microtus* spp.), and black-tailed jackrabbits (*Lepus californicus*). The most abundant mammal on the Hanford Site is the Great Basin pocket mouse (*Perognathus parvus*). Many of the rodent species and some predators (badgers) construct burrows on the site. Other nonburrowing animals including cottontails (*Sylvilagus nutalli*), jackrabbits, snakes, and burrowing owls (*Athene cunicularia*) may use abandoned burrows of other animals.

The largest mammal potentially frequenting the 200-PW-1, 200-PW-3, and 200-PW-6 OUs is the mule deer. Mule deer collect around the 200 Areas, away from the river, and constitute a grouping named the Central Population. The Rattlesnake Hills herd of elk inhabiting the Hanford Site primarily occupies the Fitzner-Eberhardt Arid Lands Ecology Reserve and private lands adjoining the reserve to the south and west. They occasionally are seen on the 200 Areas Plateau.

Common upland gamebird species in shrub and grassland habitat include chukar (*Alectoris chukar*), partridge (*Perdix perdix*), California quail (*Callipepla californica*), and ring-necked pheasant (*Phasianus colchicus*). Chukars are most numerous in the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountains, and Gable Mountain areas of the Hanford Site. Less common species include greater sage grouse (*Centrocercus urophasianus*), and scaled quail (*Callipepla squamata*). Greater sage grouse historically were abundant on the Hanford Site; however, populations have declined since the early 1800s.

Among the more common raptor species to use shrub and grassland habitat are the ferruginous hawk (*Buteo regalis*), Swainson's hawk (*B. swainsoni*), and red-tailed hawk (*B. jamaicensis).* Northern harriers (*Circus cyaneus)*, sharp-shinned hawks (*Accipiter striatus)*, rough-legged hawks (*B. lagopus)*, and golden eagles (*Aquila chrysaetos*) also occur in this habitat, although infrequently.

The side-blotched lizard (*Uta stansburiana*) is the most abundant reptile species occurring on the Hanford Site. Short-horned (*Phrynosoma douglassii*) and sagebrush (*Sceloporus graciosus*) lizards are found on the Hanford Site but occur infrequently. The most common snake species include gopher snake (*Pituophis melanoleucus*), yellow-bellied racer (*Coluber constrictor*), and western rattlesnake (*Crotalus viridis*).

Many species of insects occur throughout habitats on the Hanford Site. Butterflies, grasshoppers, and darkling beetles are among the most conspicuous of the about 1,500 species of insects identified from specimens collected on the Hanford Site. The actual number of insect species occurring on the Hanford Site may reach as high as 15,500 (PNNL-6415).

An inventory was performed on the representative waste sites to evaluate occurrences of potential Hanford Site fauna; specifically, the ECRs issued for the 216-Z-9 Trench, the 216-Z-1A Tile Field, and the 216-A-8 Crib also considered wildlife resources. The PNNL biological review in the project area determined the occurrence of wildlife species protected under the *Endangered Species Act of 1973*; candidates for protection; species listed as threatened, endangered, candidate, sensitive, or monitored by the State of Washington; and species protected under the *Migratory Bird Treaty Act of 1918*. The survey methods consisted of pedestrian visual reconnaissance at the 216-Z-9 Trench and the 216-Z-1A Tile Field and

knowledge of priority habitats and species of concern documented for each respective site by the Washington Department of Fish and Wildlife. Lists of wildlife species considered endangered, threatened, proposed, or candidate by the U.S. Fish and Wildlife Service are maintained in 50 CFR 17.12, and the list of birds protected under the *Migratory Bird Treaty Act of 1918* are maintained in 50 CFR 10.13, "General Provisions," "List of Migratory Birds." The survey results at the 216-Z-9 Trench found no migratory birds observed nesting in the vicinity of the site. The ECR found no wildlife species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered observed in the vicinity of the 216-Z-9 Trench. Ground surface conditions at the 216-Z-8 French Drain and 216-Z-10 Injection/Reverse well are similar to those at the 216-Z-9 Trench. The 241-Z-361 Settling Tank is located inside the PFP and is located in a highly disturbed environment, similar to that of the 216-Z-9 Trench. The survey results at the 216-Z-1A Tile Field reported that no migratory birds were observed nesting in the vicinity of the site. The ECR also found no wildlife species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered in the vicinity of the 216-Z-1A Tile Field. The survey results at the 216-A-8 Crib reported that there was a possibility of migratory birds nesting at the site. Nevertheless, the ECR found no wildlife species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered in the vicinity of the 216-A-8 Crib.

2.4.3 Species of Concern

The Hanford Site is home to a number of species of concern, but many of these are associated with the Columbia River and its shoreline or steel transmission-line towers. No Federal- or state-listed endangered or threatened mammals, reptiles, amphibians, or invertebrates are on the Hanford Site, but three species of fish, five species of birds, and 11 species of plants are listed as threatened or endangered by either the state or the Federal Government outside of the waste-site areas (PNNL-6415). The RI investigation ECRs specifically found no plant or wildlife species protected under the *Endangered Species Act of 1973*, no candidates for such protection, and no species listed by Washington State as threatened or endangered in the vicinity of the 216-Z-9 Trench, 216-Z-1A Tile Field, or 216-A-8 Crib. These conditions are considered to be similar at the highly disturbed sites of the 216-Z-8 French Drain, 216-Z-10 Injection/Reverse well, and 241-Z-361 Settling Tank.

2.4.4 Cultural Resources

Much of the 200 Areas has been altered by Hanford Site operations. The Hanford Cultural Resources Laboratory conducted a comprehensive archaeological resources survey of the fenced portions of the 200 Areas during 1987 and 1988. The results do not indicate evidence of cultural resources associated with the Native American cultural landscape, early settlers/farming landscape, or archaeological discoveries associated with the 200-PW-1, 200-PW-3, and 200-PW-6 OUs (PNNL-6415).

As part of the excavation permit process for RI field activities, NPCE#2006-200-031, *Cultural Resource Review Notices to Proceed* [Rodriguez, 2006], was obtained to determine the potential

of the RI activities to have an impact on cultural resources. At the 216-Z-9 Trench, planned RI characterization activities were determined by the DOE Cultural and Historic Resource Program on June 8, 2006, to not have an effect on cultural resources (NPCE#2006-200-031). Review of historic properties by aerial and recent photographs of the 216-Z-9 Trench confirmed ground-surface disturbance of the waste site. At the 216-Z-1A Tile Field, planned RI characterization activities were determined by DOE Cultural and Historic Resource Program on May 16, 2005, to not have an effect on historic properties (HCRC#2005-200-045, *Cultural Resource Review Notices to Proceed* [McFarland, 2005]). The survey consisted of a literature review indicating that the 216-Z-1A Tile Field had little potential to contain cultural resources.

The *National Historic Preservation Act of 1966* requires agencies to consult with the State Historic Preservation Officer and the Advisory Council on Historic Preservation to ensure that all potentially significant cultural resources, including structures and associated sites, were adequately identified, evaluated, and considered in planning for a proposed undertaking (e.g., remediation, renovation, or demolition) (DOE/RL-97-56, *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan*). The representative and unique waste sites do not contain any representative examples of buildings or structures associated with the Manhattan Project and Cold War landscape that are eligible for the National Register as contributing properties within the Historic District requiring individual documentation (PNNL-6415). Historic preservation requirements are not applicable for the 216-Z-1A Tile Field, 216-Z-8 French Drain, 216-Z-9 Trench, 216-Z-10 Injection/Reverse Well, 216-A-8 Crib, or 241-Z-361 Settling Tank, upon evaluation and classification as noncontributing/exempt from documentation requirements as historical properties (DOE/RL-97-56).

2.4.5 Aesthetics, Visual Resources, and Noise

With the exception of Rattlesnake Mountain, the land near the Hanford Site generally has little relief. Rattlesnake Mountain, rising to 1,060 m (3,477 ft) above mean sea level, forms the western boundary of the Hanford Site. Gable Mountain and Gable Butte are the highest landforms within the Site. The Columbia River and Rattlesnake Mountain generally are considered scenic.

Studies of the propagation of noise at the Hanford Site have been concerned primarily with occupational noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford Site activities and isolation from receptors covered by Federal or state statutes. Most industrial facilities on the Hanford Site are located far enough away from the Hanford Site boundary that noise levels at the boundary are not measurable or are barely distinguishable from background noise levels (PNNL-6415).

2.4.6 Socioeconomic

As reported in PNNL-6415, activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities (i.e., the cities of Pasco, Richland, and Kennewick, Washington) and other parts of Benton and Franklin Counties. The agricultural community also has a significant effect on the local economy. Any major changes in Hanford Site activity would potentially affect the Tri-Cities and other areas of Benton and Franklin Counties.

Contractors to the DOE comprise the largest single source of employment in the Tri-Cities. During fiscal year 2004, an average of 10,247 employees were employed by the DOE, Office of River Protection and its prime contractor CH2M HILL Hanford Group, Inc.; and by RL and its prime contractors Fluor Hanford, Inc.; Bechtel Hanford, Inc.; AdvanceMed Hanford; and PNNL, which is operated by Battelle for the DOE Office of Science's Pacific Northwest Site Office. The fiscal year 2004 year-end employment for DOE contractors was 10,225, which was down slightly from 10,288 at the end of fiscal year 2003. In addition to these totals, Bechtel National, Inc. and its subcontractors, including prime subcontractor Washington Group International, employed 3,780 employees at the end of fiscal year 2004. Washington Closure Hanford, LLC is a partnership consisting of Washington Group International, Inc.; Bechtel National, Inc.; and CH2M HILL, Inc. During December 2000, the DOE, Office of River Protection awarded a contract directly to Bechtel National, Inc. to design, build, and start up waste treatment facilities for the glassification of liquid radioactive waste.

The Hanford Site represents 14 percent of the total jobs in the local economy. Total employment in the Tri-Cities metropolitan statistical area averaged 99,900 during 2004, up from 96,400 in 2003. Based on employee records as of February 2005, 91 percent of the direct employees of the Hanford Site live in Benton and Franklin Counties. Approximately 73 percent of Hanford Site employees reside in Richland, Pasco, or Kennewick. More than 36 percent are Richland residents, 10 percent are Pasco residents, and 26 percent live in Kennewick. Residents of other areas of Benton and Franklin Counties (including West Richland, Benton City, and Prosser) account for approximately 17 percent of the total Hanford Site employment. The remaining 10 percent reside in surrounding counties.

In addition to the Hanford Site, other key employers in the area are as follows:

- Energy Northwest
- ConAgra/Lamb Weston
- Tyson Fresh Meats
- Boise Cascade Corporation Paper and Corrugated Container Divisions
- AREVA NP, Inc.
- Wal-Mart.

Tourism and government transfer payments to retirees in the form of pension benefits also are important contributors to the local economy.

An estimated total of 155,100 people lived in Benton County and 57,000 lived in Franklin County during 2004, totaling 212,100, which is an increase of almost 11 percent from the census count for the year 2000. According to the 2000 census, population totals for Benton and Franklin Counties were 142,475 and 49,347, respectively. Both Benton and Franklin Counties grew at a faster pace than Washington did as a whole during the 1990s. The population of Benton County grew 26.6 percent, up from 112,560 during 1990. The population of Franklin County grew 31.7 percent, up from 37,473 during 1990.

Based on the 2000 census, the 80 km (50-mi) radius area surrounding the Hanford Site had a total population of 482,300 and a minority population of 178,500. The ethnic composition of the minority population is primarily white Hispanic (24 percent), self-designated "other and multiple races" (63 percent), and Native American (6 percent). Asians and Pacific Islanders (4 percent) and African Americans (3 percent) make up the remainder of the population in the area. The Hispanic population resides predominantly in Franklin, Yakima, Grant, and Adams Counties. Native Americans within the 80 km (50-mi) area reside primarily on the Yakama Reservation and upstream of the Hanford Site near the town of Beverly, Washington.

2.5 REPRESENTATIVE AND UNIQUE WASTE-SITE DESCRIPTION, CHARACTERIZATION, AND CONTAMINATION

This section describes the six representative and unique waste sites selected for characterization to support development of contaminant distribution models, to evaluate risk, and to provide a baseline for implementing the analogous waste-site approach in support of the RI/FS process. The contaminant distribution models for the six representative and unique waste sites are presented in Figures 2-3 to 2-8.

2.5.1 216-Z-9 Trench

The 216-Z-9 Trench is about 213 m (700 ft) east of the 234-5Z Building in the 200 West Area of the Hanford Site. The surface elevation of this site is approximately 201 m (660 ft).

Groundwater beneath the 216-Z-9 Trench was about 68 m (223 ft) below ground surface (bgs) in April 2005, at nearby well 299-W15-46 (WMP-26264, *Borehole Summary Report for Well 299-W15-46 (C3426) Drilled at the 216-Z-9 Trench*).

The 216-Z-9 Trench consists of a 6.1 m (20-ft)-deep open excavation with a 36.5 by 27.4 m (120 by 90 ft) concrete cover. The walls of the trench slope inward and downward to the 18 by 9 m (60 by 30 ft) floor space, which has a slight slope to the south. The underside of the concrete cover was paved with acid-resistant brick/tiles. The cover of the trench is supported by six concrete columns.

The 216-Z-9 Trench received approximately 4.1 million L (1.1 Mgal) of high-salt, acidic, aqueous, and organic liquid waste from the RECUPLEX process. Material discharged to the trench included 130,000 to 480,000 kg (286,600 to 1,058,219 lb) of CCl_4, 2.5 kg (1.1 lb) of Am-241, and 885,800 kg (1.95 million lb) of nitrate (see Figure 2-3). The CCl_4 was discharged to the 216-Z-9 Trench as a small entrained fraction of process aqueous wastes and as DNAPL.

When the 216-Z-9 Trench was retired in 1962, it had received approximately 50 to 150 kg (110 to 330 lb) of plutonium. Mining took place at the 216-Z-9 Trench in 1976 and 1977 to remove plutonium. The upper 0.3 m (1 ft) of soil was removed from the floor of the trench. The mining operation removed an estimated 58 kg (128 lb) of plutonium. Based on data acquired during the mining operation, an estimated 38 to 48 kg (84 to 106 lb) of plutonium

remains in the 216-Z-9 Trench (RHO-ST-21, *Report on Plutonium Mining Activities at 216-Z-9 Enclosed Trench*). The 6.4 m (21-ft)-deep open space beneath the concrete cover over the 216-Z-9 Trench remains void of soil and contains only the mining equipment (DOE/RL-91-58, *Z Plant Source Aggregate Area Management Study Report*; RHO-ST-21; ARH-2915, *Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench*). The concrete cover has an uncertain life-span, which is one of the reasons that remedial action is needed at this site.

The RI Report (DOE/RL-2006-51) provides details of the past investigations and the RI results, including soil, soil-vapor, borehole geophysical logging, and other investigations. The significant RI findings for the 216-Z-9 Trench are summarized below.

- For most of the radionuclides detected above background levels in soil samples (Np-237, Pu-238, Ra-226, Ra-228, Sr-90, Tc-99, Th-232, U-234, U-235), all of the highest concentrations were at a depth of 14 m (46 ft) bgs or deeper (i.e., deeper than initially postulated in the preliminary contaminant distribution model). The maximum concentrations of Pu-239/240 and Am-241, the primary radionuclides at the site, were near the base of the trench, at 18 to 19 m (59 to 62 ft) bgs and at 31 to 33 m (102 to 108 ft) bgs. Radioactive contamination was identified in several boreholes using geophysical logging methods. Contamination (Am-241, Pa-233, Pu-239, Pu-241) was detected to a maximum depth of 59.4 m (195 ft) bgs. Radioactive contamination in soil samples (predominantly Am-241 and Pu-239/240) was detected to a maximum depth of 37.2 m (122 ft) bgs. The highest concentrations of plutonium and americium are located at the trench floor and generally decrease with depth below the floor.

- Soil-vapor samples collected from boreholes drilled in the vicinity of the trench revealed CCl_4 at concentrations up to 28,500 ppmv in 1993. This is approximately 23 percent of the soil-vapor concentration, indicating CCl_4 saturation in the vadose zone.

- Soil samples from boreholes near the 216-Z-9 Trench revealed CCl_4 DNAPL in soil of up to 380,000 µg/kg in well 299-W15-46 from 19.4 to 20.1 m (63.5 to 66 ft bgs). At adjacent HHR push location Borehole C5336 (P66), the maximum CCl_4 detected in soil was 390,000 µg/kg in the same silt lens (Figure 2-9). These represent the first detections of DNAPL at any location in the subsurface of the 200 West Area since the beginning of the CCl_4 contamination investigation in the early 1990s.

- An SVE system has been operated near the 216-Z-9 Trench as an expedited response action. Between April 1991 and September 2006, 54,280 kg of CCl_4 were removed by the SVE system.

- In general, the highest concentrations of contaminants of potential concern (COPC) detected in the vadose-zone soils have been in fine-grained layers (i.e., silts and the CCU).

- A higher percentage of the CCl_4 inventory than previously estimated likely was lost to the atmosphere through evaporation during disposal. A higher percentage of the CCl_4 inventory than previously estimated is present in the unconfined aquifer.

- Based on evaluation of new geophysical logging, Am-241 previously was misidentified in spectral gamma logs as Cs-137.

- At the 216-Z-9 Trench, the discharged effluent volume was greater than soil-column pore volume, which indicates that the volume of effluent released was sufficient to reach the unconfined aquifer during operation of this waste site. However, based on currently available site data including soil-moisture-content measurements, the 216-Z-9 Trench is not considered to be a significant current source of groundwater contamination.

The maximum concentrations of radionuclide COPCs in soil samples at the 216-Z-9 Trench are summarized below.

Radionuclide Contaminant of Potential Concern	Maximum Concentration (pCi/g)	Depth Interval (ft bgs)		Location*
		Top	Bottom	
Americium-241	43,478,261	22	22.3	216-Z-9 Trench floor (1973)
Neptunium-237	28.9	109.5	112	299-W15-46 well
Plutonium-238	3,680	70	72	299-W15-48 well
Plutonium-239/240	404,347,826	22	22.3	216-Z-9 Trench floor (1973)
Radium-226	2.16	131.5	133	299-W15-48 well
Radium-228	2.79	109.5	112	299-W15-46 well
Strontium-89,90	13.4	63.5	66	299-W15-46 well
Technetium-99	272	70	72	299-W15-48 well
Thorium-232	1.89	135	140	299-W15-48 well
Uranium-234	11.8	48.5	50	299-W15-46 well
Uranium-235	0.13	119.5	122	299-W15-46 well

*299-W15-48 Depth Interval = downhole depth (not converted to vertical depth).

The maximum concentrations of nonradionuclide COPCs in soil samples at the 216-Z-9 Trench are summarized below (2 pages).

Nonradionuclide Contaminant of Potential Concern	Maximum Concentration (mg/kg)	Depth Interval (ft bgs)		Location*
		Top	Bottom	
1,1-Dichloroethane	0.0011	115	117.5	299-W15-46 well
Acetone	2.9	131.5	133	299-W15-48 well
Ammonium ion	192	109.5	112	299-W15-46 well
Aroclor-1248	1.6	63.5	66	299-W15-46 well
Arsenic	11	47.5	50	299-W15-46 well
Benzene	0.0037	70	72	299-W15-48 well
Bismuth	156	135	140	299-W15-48 well
Cadmium	118	122.5	124.5	299-W15-48 well
Carbon Tetrachloride (CCl_4)	390	64	66	C5336 Borehole
Chlorobenzene	0.00098	115	117.5	299-W15-46 well
Chloroform	4.9	63.5	66	299-W15-46 well
Chromium	162	119.5	122	299-W15-46 well
Copper	26.3	119.5	122	299-W15-46 well

Nonradionuclide Contaminant of Potential Concern	Maximum Concentration (mg/kg)	Depth Interval (ft bgs)		Location*
		Top	Bottom	
Ethylbenzene	0.0008	73	75	299-W15-48 well
Fluoride	51.4	118.5	120.5	299-W15-48 well
Hexavalent Chromium	0.75	63.5	66	299-W15-46 well
Hydraulic Fluids (Grease)	2,440	70	72	299-W15-48 well
Normal Paraffins (greases and cutting oils)				299-W15-48 well
Lead	620	115	117.5	299-W15-46 well
Mercury	1.02	174	176.5	299-W15-46 well
Methyl Ethyl Ketone	1.7	122.5	124.5	299-W15-48 well
Methyl Isobutyl Ketone	0.0012	117	119.5	299-W15-46 well
Methylene Chloride	0.14	100	102	299-W15-48 well
Nickel	72.9	119.5	122	299-W15-46 well
Nitrate	6,990	100	102	299-W15-48 well
Nitrite	12.1	47.5	50	299-W15-46 well
Oil and Grease	2,400	63.5	66	299-W15-46 well
Phosphate	3.9	135	140	299-W15-48 well
Selenium	3.76	119.5	122	299-W15-46 well
Silver	2.88	174	176.5	299-W15-46 well
Sulfate	456	63.5	66	299-W15-46 well
Tetrachloroethene	17	63.6	66	299-W15-46 well
Toluene	0.0038	131.5	133	299-W15-48 well
Tributyl phosphate	3,000	70	72	299-W15-48 well
Trichloroethene	0.0013	73	75	299-W15-48 well
Xylene	0.003	73	75	299-W15-48 well

*299-W15-48 Depth Interval = downhole depth (not converted to vertical depth).

As reported in DOE/RL-2006-24, *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit*, no radioactive plumes (or contaminants) above maximum contaminant levels (MCL) have been identified in the groundwater area of the 216-Z-9 Trench. Currently there are seven nonradioactive groundwater plumes in the vicinity of the trench: (CCl_4) chloroform, trichloroethylene, nitrate, chromium (total), tetrachloroethylene (PCE), and methylene chloride. Technetium-99 also has been detected, but not above the MCL. The presence of these groundwater contaminants is attributed to past waste-disposal practices at the 216-Z-9 Trench as well as at other adjacent facilities. Because the 216-Z-9 Trench received large inventories of CCl_4 and nitrate, it is considered a major contributor of groundwater contamination in the 200 West Area for these two compounds.

Soil samples were collected in 2005 from Borehole C3426 (completed as well 299-W15-46) for laboratory analyses of soil-moisture content. Measured soil-moisture contents in samples from the Hanford formation ranged from 4.2 to 4.4 percent. Measured moisture contents in the CCU ranged from 19.1 to 23.6 percent, and moisture content in the Ringold Formation ranged from 2.8 to 6 percent. These values of soil-moisture content for the granular soils of the Hanford formation and Ringold Formation, and for the more porous silt unit of the CCU, indicate that the vadose-zone soils beneath the trench are unsaturated. Considering the current unsaturated vadose-zone conditions, as well as the operation of the SVE system in the vicinity of the 216-Z-9 Trench since 1993, which further decreases soil-moisture content, it is not likely that the

remaining COPCs in the vadose zone are a significant current source of groundwater contamination. The contaminant distribution model for the 216-Z-9 Trench is presented in Figure 2-3.

2.5.2 216-Z-1A Tile Field

The 216-Z-1A Tile Field is located in the 200 West Area about 153 m (500 ft) south of the 234-5Z Building and immediately south of the 216-Z-1 and 216-Z-2 Cribs, and is adjacent to the 216-Z-3 Crib. The surface elevation around this site is approximately 207 m (679 ft). Groundwater beneath the 216-Z-1A Tile Field is approximately 71 m (234 ft) bgs, based on nearby well 299-W18-16 on March 20, 2005.

The tile-field piping consists of 20 cm (8 in.)-diameter perforated vitrified clay pipeline placed on a 1.5 m (5 ft) deep gravel bed. The piping consists of a 79 m (260 ft)-long north-south trunk or main pipeline with seven pairs of 21 m (70 ft) laterals spaced at 11 m (35 ft) intervals in a centered, herringbone pattern. The piping system was overlaid with 15 cm (6 in.) of cobbles and 1.5 m (5 ft) of sand and gravel.

The tile field was used in this configuration from 1949 to 1959. The waste stream discharged to the adjacent 216-Z-1 and 216-Z-2 Cribs (1949-1952) and the 216-Z-3 Crib (1952-1959), overflowed to the tile field, and consisted of neutral to basic (pH 8 to 10) process waste and analytical and development laboratory waste from the Z Plant via the 241-Z-361 Settling Tank. The total volume of waste discharged from 1949 to 1959 was approximately 1 million L (264,172 gal).

Before the 216-Z-1A Tile Field was reactivated in 1964, a sheet of 0.05 cm (0.02 in.)-thick polyethylene and a 30 cm (1 ft)-thick layer of sand and gravel were added, and the liquid waste discharge piping was routed directly to the central distributor pipe in the tile field. Between 1964 and 1969, a 5 cm (2 in.)-diameter stainless steel pipe was progressively inserted inside the central distributor pipe to divide the tile field into three operational sections (216-Z-1AA, 216-Z-1AB, and 216-Z-1AC) (RHO-LD-114, *Existing Data on the 216-Z Liquid Waste Sites*).

From 1964 to 1969, the 216-Z-1A Tile Field received approximately 5.2 million L (1.37 Mgal) of liquid waste from 234-5Z (PFP), the 236-Z Plutonium Reclamation Facility, the 242-Z Waste Treatment Facility, and miscellaneous laboratory waste. Material discharged to the tile field reportedly included 57 kg (126 lb) of plutonium, 270,000 kg (594,000 lb) of CCl_4, 30,000 kg (66,000 lb) of TBP, 20,300 kg (44,800 lb) of dibutyl butyl phosphonate (DBBP), 3,885 Ci of Am-241, and 1,320,000 kg (2,904,000 lb) of nitrate. The CCl_4 was discharged to the 216-Z-1A Tile Field in combination with other organics, as a small entrained fraction of process aqueous wastes, and as DNAPL.

The RI report (DOE/RL-2006-51) provides details of the past investigations and RI results, including soil, soil-vapor, borehole geophysical logging, and other investigations. The significant RI findings for the 216-Z-1A Tile Field are summarized below.

- The highest concentrations of radionuclides (Pu-239/240 and Am-241) in sediments are located immediately beneath the tile field, below the distribution pipe.

- The maximum vertical extent of radiological contamination (predominantly Am-241, Pa-233, Pu-239) detected in soil, as detected by borehole geophysical logging, is 37 m (121 ft).

- The maximum vertical extent of radioactive contamination detected above background levels in soil samples (Am-241, Np-237, Pu-239/240, Pa-233) from the tile field area was 46.8 m (153.5 ft).

- Soil samples from the tile field area revealed a maximum CCl_4 concentration of 6,561 mg/kg in the CCU in 1993.

- An SVE system has been operated near the tile field. Between April 1991 and September 2006, 24,604 kg of CCl_4 was removed by the SVE system.

- The 216-Z-1A Tile Field has not been considered to be a past source of groundwater contamination, because the effluent volume discharged at this site was much less than the soil-column pore volume. However, based on the dispersed CCl_4 vadose-zone plume data presented in the RI, there are significant concentrations of CCl_4 in the vadose zone adjacent to this site, so it is possible that this site was a past source of groundwater contamination, but it is not a significant current source.

The refinements to the 216-Z-9 Trench contaminant distribution model regarding the presence of discontinuous silt layers and the previous misidentification of Am-241 as Cs-137 apply to the 216-Z-1A Tile Field contaminant distribution model as well.

The maximum concentrations of radionuclide COPCs in soil samples at the 216-Z-1A Tile Field are summarized below.

Radionuclide Contaminant of Potential Concern	Maximum Concentration (pCi/g)	Well Number	Depth Interval (ft bgs)	
			Top	Bottom
Americium-241	2,590,000	299-W18-149	11.2	11.2
Neptunium-237	40	299-W18-174	48.0	48.0
Plutonium-239/240	38,200,000	299-W18-149	11.2	11.2
Protactinium-233	36.7	299-W18-174	14.6	14.6

The maximum concentrations of nonradionuclide COPCs in soil samples at the 216-Z-1A Tile Field are summarized below (2 pages).

Nonradionuclide Contaminant of Potential Concern	Maximum Concentration (mg/kg)	Depth Interval (ft bgs)	
		Top	Bottom
Chromium (III)	19	118.5	118.5
Copper	24	56.0	56.0
Lead	11	124.9	125.4
Fluoride	16	124.9 and 128.9	124.9 and 128.9

Nonradionuclide Contaminant of Potential Concern	Maximum Concentration (mg/kg)	Depth Interval (ft bgs)	
		Top	Bottom
Nitrate	250	56.0	56.0
Phosphate	1	56.0	56.0
Chloroform	0.135	131.0	131.0
Carbon Tetrachloride (CCl_4)	6,561	127.1	127.1
Methyl ethyl ketone	0.180	56.0	56.0
Methyl isobutyl ketone	0.156	74.5	74.5
Tetrachloroethylene	0.050	128.9	128.9
Toluene	0.040	71.5	71.5
Trichloroethylene	0.068	128.9	128.9

The total effluent volume (6.2 million L [1.6 Mgal]) discharged to the 216-Z-1A Tile Field over its period of operation is about 12 percent of the estimated soil-pore volume. As reported in DOE/RL-2006-24, no radioactive plumes (or contaminants) above MCLs have been identified in the area of the 216-Z-1A Tile Field. The lack of radiological groundwater contamination is consistent with the contaminant profiles in RHO-ST-17, *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: A Status Report*, and more recent geophysical logs. As indicated in RHO-ST-17, the maximum vertical extent of radiological contamination in the vadose zone is approximately 30 m (100 ft) bgs. However, geophysical logging suggests that Pa-233 extends to 37 m (121 ft) bgs.

Based on the dispersed CCl_4 vadose-zone plume data presented in the RI Report (DOE/RL-2006-51), there are significant concentrations of CCl_4 in the vadose zone adjacent to this site, so it is possible that this site was a past source of groundwater contamination. The operation of the SVE system in the vicinity of the 216-Z-1A Tile Field since 1993 has further decreased soil moisture in the vadose zone, so it is not likely that the remaining COPCs in the vadose zone are a significant current source of groundwater contamination. The contaminant distribution model for the 216-Z-1A Tile Field is presented in Figure 2-4.

2.5.3 241-Z-361 Settling Tank

The 241-Z-361 Settling Tank is located approximately 35 m (115 ft) north of the 216-Z-1A Tile Field in the 200 West Area, within the boundary of the PFP Complex. The surface elevation and hydrogeologic conditions at this representative waste site are the same as those for the adjacent 216-Z-1A Tile Field.

The 241-Z-361 Settling Tank is an underground reinforced-concrete structure 8.5 m (28 ft) long and 4.5 m (15 ft) wide, with a 1 cm (3/8 in.)-thick steel liner. The tank has inside dimensions of 7.9 by 4.0 m (26 by 13 ft) with 0.3 m (1 ft)-thick walls. The bottom slopes, resulting in an internal height variation between 5.2 and 5.5 m (17 and 18 ft). The top is 0.6 m (2 ft) below grade. Two 15 cm (6 in.)-diameter stainless steel inlet pipes from the 241-Z Facility enter the

settling tank from the north. A single 20 cm (8 in.)-diameter stainless steel pipe exits the tank from the south. Several risers are visible above grade.

The tank served as the primary solids settling tank for liquid waste from the 234-5Z, 236-Z, and 242-Z Buildings from 1949 to 1973. Effluent in the tank was discharged to the 216-Z-1A Tile Field and the 216-Z-1, 216-Z-2, and 216-Z-3 Cribs. When the tank was in use, the contents were neutralized by adding fly ash, and later sodium hydroxide, to raise the pH to the 8 to 10 range. Liquid samples collected in March 1975, however, had a pH as low as 4. Before this characterization, it was assumed that the pH was greater than 2, which renders the plutonium mostly insoluble (HNF-8735, *241-Z-361 Tank Characterization Report*).

Details of the tank investigations and characterization activities are provided in the RI Report (DOE/RL-2006-51). The significant RI findings for the 241-Z-361 Settling Tank are summarized below.

- The settling tank currently contains approximately 75 m^3 of sludge. The sludge is contaminated with radionuclides (primarily Pu-239), metals (cadmium, chromium, lead, mercury, silver, arsenic, barium, nickel, zinc), organics (1-butanol, acetone, benzene, methylene chloride, toluene), and polychlorinated biphenyls.

- Helical piers installed to support tank sampling were surveyed when removed. No radiological contamination was detected.

- The lack of detected radiological contamination on the piers installed beneath the depth of the tank bottom, and the apparent stability in the tank sludge level since 1975, suggests that there has been no leak of tank contents to the soil column.

- All available information indicates that the 241-Z-361 Settling Tank has not leaked, so this site is not considered to be a past or current source of groundwater contamination.

The contaminant distribution model for the 241-Z-361 Settling Tank is presented in Figure 2-5.

2.5.4 216-A-8 Crib

The 216-A-8 Crib is located approximately 177 m (580 ft) east of the A Tank Farm in the 200 East Area, at a surface elevation of approximately 198 m (650 ft). Groundwater beneath the 216-A-8 Crib was about 80 m (261.7 ft) bgs at Borehole C4545.

The bottom dimensions of the crib are 259 by 6 m (850 by 20 ft). The long axis of the crib trends to the east-northeast. A 61 cm (24 in.)-diameter, schedule 20, perforated distribution line extends the length of the crib and rests on a 2 m (6.5 ft)-thick layer of rock capped by a 30 cm (12 in.)-thick layer of gravel. The gravel fill is mounded over the distribution line. Two layers of Sisalkraft paper[10] cover the gravel and prevent overlying native sand backfill from filling the

[10] Sisalkraft (paper) is a trademark of Fortifiber Corporation, Los Angeles, California.

void space. The crib floor was excavated to a uniform elevation of 195 m (639.5 ft). The depth of the excavation varied from 4.9 to 5.8 m (16 to 19 ft.) below the 1955 ground surface. The site was surface stabilized in September 1990 by the addition of 0.6 m (2 ft) of clean fill (DOE/RL-92-04, *PUREX Plant Source Aggregate Area Management Study Report*). Water entered the crib through the 216-A-508 Diversion Box, located due west of the crib. The crib was permanently isolated in April 1995 by filling the 216-A-508 Diversion Box with concrete.

Over its operational life, the 216-A-8 Crib received an estimated 1.15 billion L (303.8 Mgal) of process effluent, which is estimated to be greater than 30 times the pore volume beneath the site (DOE/RL-92-04; DOE/RL-96-81, *Waste Site Grouping for 200 Areas Soil Investigations*). The estimated discharged inventory for the 216-A-8 Crib included 390.8 kg (861 lb) of uranium, 2,410 Ci of Cs-137, 128,600 kg (283,500 lb) of TBP, 55,110 kb (121,500 lb) of normal paraffin hydrocarbon, and 24,561 Ci of tritium (see Figure 2-6). However, the RI activities detected no organics (DOE/RL-2006-51).

The RI Report (DOE/RL-2006-51) provides details of the RI results, including soil, soil-vapor and borehole geophysical logging. The significant RI findings for the 216-A-8 Crib are summarized below.

- The highest radioactive contamination (Cs-137) associated with the crib and detected during the RI was within 8 m (25 ft) of the ground surface.
- The maximum extent of radioactive contamination (Cs-137) detected near the crib, by geophysical logging techniques, was 76.5 m (251 ft) bgs. However, the source of the contamination at this depth is not known.
- Radioactive COPCs were detected above background levels in soil samples (C-14, Cs-137, Eu-155, Pu-239/240, Tc-99, Sr-90, H-3) beneath the 216-A-8 Crib to total depth (80 m [264.5 ft] bgs).
- At the 216-A-8 Crib, the discharged effluent volume was greater than the soil-column pore volume, which indicates that the volume of effluent released was sufficient to reach the unconfined aquifer during operation of this waste site. However, based on currently available site data, including soil-moisture-content measurements, the 216-A-8 Crib is not considered a significant current source of groundwater contamination.

The maximum concentrations of radionuclide COPCs in soil samples at the 216-A-8 Crib are summarized below (2 pages).

Radionuclide Contaminant of Potential Concern	Maximum Concentration (pCi/g)	Depth Interval (ft bgs)	
		Top	Bottom
Carbon-14	89.7	27.5	30
Cesium-137	877,000	19	21.5
Europium-155	0.055	49	51.5
Plutonium-239/240	55.7	19	21.5
Technetium-99	79.6	19	21.5

Radionuclide Contaminant of Potential Concern	Maximum Concentration (pCi/g)	Depth Interval (ft bgs)	
		Top	Bottom
Total Radioactive Strontium	4,380	19	21.5
Tritium	8.5	234	236.5

The maximum concentrations of nonradionuclide COPCs in soil samples at the 216-A-8 Crib are summarized below.

Nonradionuclide Contaminants of Potential Concerns	Maximum Concentration (mg/kg)	Depth Interval (ft bgs)	
		Top	Bottom
Cadmium	0.240	104	106.5
Chromium (III)	41.8	178	180.5
Hexavalent Chromium	0.278	27.5	30
Selenium	1.8	19	21.5
Acetone	0.019 J	19	21.5
Acetonitrile	0.012 J	25	27.5
Ethyl acetate	0.023	25	27.5
Decane	0.5 J	104	106.5
Nonadecane	1.6 J	104	106.5
Di-n-butylphthalate	0.69	178	180.5
Aroclor-1254	0.039	234	236.5

J = laboratory-estimated value.

The large waste-stream volumes discharged to the 216-A-8 Crib are known to have impacted groundwater, but it has not been determined whether the contaminant transport occurred uniformly through the soil column or if poor seals in nearby monitoring wells provided a preferential migration pathway. Short-lived beta emitters were detected in groundwater at the crib within 13 months of the start of operations, but longer lived beta and gamma emitters that were predicted to arrive in January 1958 apparently did not.

Soil samples were collected in 2005 from Borehole C4545 for laboratory analysis of soil-moisture content. Soil-moisture content ranged from 2.3 to 9.4 percent in the vadose zone beneath the crib. These values of soil-moisture content for the granular soils of the Hanford formation and Ringold Formation beneath the crib indicate that the vadose zone beneath the crib is unsaturated. Therefore, the remaining COPCs in the vadose zone are unlikely to be a significant current source of groundwater contamination.

The 216-A-8 Crib overlies a known groundwater contamination plume of I-129 and is within a few hundred meters of known plumes of tritium and chromium. PNNL-16346 does not report any current impacts to groundwater from the 216-A-8 Crib. The contaminant distribution model for the 216-A-8 Crib is presented in Figure 2-6.

2.5.5 216-Z-8 French Drain

The 216-Z-8 French Drain is located east of the 234-5Z Building, and approximately 94 m (308 ft) northwest of the 216-Z-9 Trench in the 200 West Area. The surface elevation and hydrogeology of the 216-Z-8 French Drain are similar to those of the adjacent 216-Z-9 Trench.

The french drain bottom dimensions form a 1.5 by 1.5 m (5 by 5 ft) square with angled walls. The bottom 0.9 m (3 ft) of the excavation is backfilled with clean, graded gravel. A seal of building paper was laid over the gravel with a 0.9 m (3-ft-) diameter hole to match the two sections of a 0.9 m (3-ft) vitrified clay pipeline placed end-to-end over the hole. A concrete collar was poured around the bottom of the clay pipeline, on the top of the building paper. The clay pipeline was filled with gravel and capped with building paper and a wire-mesh-reinforced concrete slab to seal the top of the structure. The overflow pipe from the 241-Z-8 Settling Tank entered through the center of the french drain's concrete cap. Woven wire mesh was placed at the opening of the pipe into the French drain to ensure a void space at the waste inlet. The entire structure was backfilled, resulting in the top of the structure being 2.5 m (8 ft) below grade. Waste overflow entered the gravel-filled excavation at 4.4 m (14 ft) below grade from the 241-Z-8 Settling Tank. The total volume filled with gravel in the french drain was more than 4 m^3 (141 ft^3). The french drain was designed assuming a net porosity of 30 percent, such that more than 1,000 L (265 gal) of solution could be accommodated. This was sufficient capacity to permit the waste solution to percolate into the sediments beneath the French drain between batch discharges of waste and rinse water from the 241-Z-8 Settling Tank (RHO-RE-EV-46P, *216-Z-8 French Drain Characterization Study*).

The 216-Z-8 French Drain received low-level plutonium-contaminated waste from the 234-5Z Building from 1955 to 1962. No organic waste was discharged to the 216-Z-8 French Drain. The waste stream was dilute and nearly neutral, with no fission or activation product content, and was relatively low in both disposal rate and total disposal volume. It is estimated that 9,590 L (2,530 gal) of liquid waste containing an estimated 48.2 g (1.7 oz) of plutonium overflowed from the 241-Z-8 Settling Tank to the 216-Z-8 French Drain by the time it was retired in 1962 (RHO-RE-EV-46P).

A characterization well (299-W15-202) was drilled in 1980, and soil samples were collected to define the plutonium and americium distribution beneath the 216-Z-8 French Drain (RHO-RE-EV-46P). The well was located less than 1 m (3 ft) south of the 216-Z-8 French Drain, and was drilled to 53.6 m (176 ft) bgs. A maximum value of 457 pCi/g of Am-241 was reported at 6.1 m (20 ft) bgs, near the bottom of the 216-Z-8 French Drain. A maximum Pu-239 value of 4,620 pCi/g was reported at 7.6 m (25 ft) bgs. Results indicate that plutonium and americium were sorbed onto sediments within a few meters beneath the french drain. Based on these results, the nature and extent of contamination are suspected to be confined to a shallow vadose-zone region directly adjacent to the 216-Z-8 French Drain. The probability of waste from the 216-Z-8 French Drain having reached groundwater is unlikely. The contaminant distribution model for the 216-Z-8 French Drain is presented in Figure 2-7.

2.5.6 216-Z-10 Injection/Reverse Well

The 216-Z-10 Injection/Reverse Well is approximately 30.5 m (100 ft) east of the 231-Z Building in the 200 West Area. The 216-Z-10 Injection/Reverse Well also has been known as the 231-W Reverse Well, 231-W-151 Dry Well or Reverse Well, 231-Z Well, 299-W15-51, 231-W-150, and 216-Z-2. The surface elevation of the well is approximately 204 m (670 ft). Groundwater beneath the 216-Z-10 Injection/Reverse Well was approximately 58.8 m (193 ft) bgs at nearby well 299-W15-1 in 1945, and was 68.6 m (225 ft) bgs at Borehole C4183 in April 2005.

The 216-Z-10 Injection/Reverse Well was drilled in September 1944. The well was 0.15 m (6 in.) in diameter and constructed of Schedule 40 steel pipe. The drilling log reported depth to bottom at 45.7 m (150 ft) bgs, with a capped flange extending approximately 0.31 m (1 ft) above grade. Three inlet pipes enter the well at 1.5 m (5 ft), 1.8 m (6 ft), and 2.1 m (7 ft) bgs. Historical drawings suggest that a 1.3 cm (0.5-in.) copper tube extends from ground surface to 0.6 m (2 ft) bgs, where it enters the 216-Z-10 Injection/Reverse Well, and may extend to the well bottom. The well was perforated from 36 to 45.7 m (118 to 150 ft) bgs, with a cement plug in the bottom. On November 24, 1944, the well was tested with 7,571 L (2,000 gal) of water pumped into the well at a rate of 379 L/min (100 gal/min). The results of this test showed no static water 5 minutes after pumping had stopped (HW-9671, *Underground Waste Disposal at Hanford Works*).

The 216-Z-10 Injection/Reverse Well received process and laboratory waste from the 231-Z Building via the 231-Z-151 Sump between February and June of 1945. It is estimated that 988,000 L (260,000 gal) of liquid containing up to 50 g (1.6 oz) of plutonium was discharged to the well at approximately 76 L/min (20 gal/min). No other radionuclides were reported to have been released to the 216-Z-10 Injection/Reverse Well (HW-9671). During drilling of nearby well 299-W15-42, it was estimated that the depth to the highest recorded water table in the area of the 216-Z-10 Injection/Reverse Well was 58 m (191 ft) bgs. This suggests that the water table did not rise near the 216-Z-10 Injection/Reverse Well perforated interval in later years.

The well plugged with sludge in June 1945 and subsequently was deactivated by capping the pipeline to the 216-Z-10 Injection/Reverse well west of the 231-W-151 Diversion Box (231-Z-151 Sump). The rapid reduction in effectiveness has been attributed to the long perforation depth subjecting the well to washing in of sand, silt, and clay during the discharge of wastes and effectively sealing the well (*Waste Information Data System* [WIDS] database and HW-9671).

In 1947, three monitoring wells (299-W15-59, 299-W15-60, and 299-W15-61) were drilled 4.6 m (15 ft) from the 216-Z-10 Injection/Reverse Well for the collection of characterization soil samples (HW-9671). The wells were drilled to 53.3 m (175 ft) bgs, which was 7.6 m (25 ft) below the bottom of the reverse well.

Characterization soil samples were collected at a minimum frequency of every 1.5 m (5 ft), and every 0.3 m (1 ft) where contamination was suspected to exist. A total of 210 soil samples from the three monitoring wells were collected, including field duplicates, and analyzed in the lab using an alpha counter (HW-9671). HW-9671 did not report the method reporting limit used;

therefore, the method reporting limit from HW-23769, *Calculation Constants Used by Regional Survey, Part II, Alpha Sample Counting Rate Conversion Factors*, of 0.15 pCi/g was used as a surrogate value. Contamination, specifically plutonium, was not detected in any of the soil samples. In 2005, passive-neutron logging to detect alpha contamination was conducted at this site, and the results confirm the HW-9671 findings that plutonium has not moved 4.6 m (15 ft) laterally from the injection/reverse well toward the soil borings (completed as vadose-zone wells 299-W15-59, 299-W15-60, and 299-W15-61). At well 299-W15-59, Cs-137, Co-60, and Eu-154 were the man-made radionuclides detected in this borehole. Cesium-137 was detected near the ground surface at approximately 1 pCi/g and at 24 m (80 ft) near its minimum detection level of approximately 0.2 pCi/g. Cobalt-60 was detected between 40 and 41 m (131 and 134 ft) at concentrations less than 0.2 pCi/g. Europium-154 was detected between 29 and 30 m (96 and 98 ft). The maximum Eu-154 concentration was approximately 0.25 pCi/g. At well 299-W15-60, Cs-137 was the only man-made radionuclide detected. Cesium-137 was detected at a few locations near its minimum detection level of approximately 0.2 pCi/g. At well 299-W15-61, Cs-137 and Eu-154 were the man-made radionuclides detected. Cesium-137 was detected near the ground surface and at a few locations near its minimum detection level of approximately 0.2 pCi/g. Europium-154 was detected at 28 and 35 m (92.5 and 114.5 ft) near its minimum detection level of approximately 0.6 pCi/g (DOE-EM/GJ918-2005, *Log Data Report for 299-W15-59 [A7360]*; DOE-EM/GJ919-2005, *Log Data Report for 299-W15-60 (A7361)]*; and DOE-EM/GJ920-2005, *Log Data Report for 299-W15-61 (A7362)*). The nature and extent of remaining contamination at the 216-Z-10 Injection/Reverse Well are expected to be confined within the 9.1 m (30-ft) diameter lateral circle formed by the three vadose-zone wells and to near the vertical perforated zone of the injection/reverse well. The contaminant distribution model for the 216-Z-10 Injection/Reverse Well is presented in Figure 2-8.

2.6 EVALUATION OF ANALOGOUS WASTE SITES

2.6.1 Approach Used for Assignment of Analogous Waste Sites

The analogous waste-site approach relies on grouping waste sites with similar location, geology, waste site history, inventory, and contaminant distribution and then choosing one or more representative waste sites from each grouping to use in the analysis. The analogous waste-site approach was established in the Implementation Plan (DOE/RL-98-28, Section 2.5) as an appropriate approach for dealing with the large number of individual sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The analogous waste-site approach offers advantages both in schedule, as it streamlines the investigation process and will arrive at earlier decisions and remedial action, and in reducing investigation costs. The realized savings during investigation activities can be focused on remediation. If existing field data at a representative waste site are not sufficient to support a remedial decision for that site, comprehensive field investigations are conducted at the representative waste site during the RI. Findings from site investigations at representative waste sites are extended to analogous waste sites in the waste group that are not characterized as part of the RI. Sites for which field data have not been collected are assumed to have contamination characteristics similar to those sites characterized. Confirmatory

investigations of limited scope, rather than full characterization, can be conducted at the analogous waste sites after the ROD is issued to confirm the analogy and the remedial alternative.

If a waste site is significantly different from, and fails to meet, the contaminant distribution model, and the identified preferred alternative is not appropriate, the site will be reevaluated based on available information. The reevaluation could result in a decision to use a contaminant distribution model established for a different OU or to conduct additional confirmatory sampling. Changes to the preferred alternative would be evaluated as needed, based on confirmatory data, and a contingent remedy may be needed.

Selection of representative waste sites is fundamental to the implementation of the analogous waste-site approach. These sites often are indicative of worst case and typical conditions in an OU and, in some cases, have been characterized extensively. Four representative waste sites evaluated in the RI Report as being representative of sites within their OU in the 200 Areas Implementation Plan (DOE/RL-98-28, Appendix G) and during the OU consolidation process were confirmed through the DQO process (CP-15371, *Remedial Investigation Data Quality Objectives Summary Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit Representative Waste Sites*). Following are the four representative waste sites:

- 216-A-8 Crib
- 216-Z-1A Tile Field
- 216-Z-9 Trench
- 241-Z-361 Settling Tank.

The alignment of representative and analogous waste sites presented in the PW Work Plan (DOE/RL-2001-01, Table 1-1) was reevaluated in support of the RI/FS process. In addition, several waste sites recently were transferred out of these OUs, based on the need for additional characterization or for consistency with newly created OUs (*Federal Facility Agreement and Consent Order Change Control Form Transfer Waste Sites from 200-PW-1 and 200-PW-3 OU to Other OU*, Change Request C-07-01 [RL 2007]). Two additional sites with sufficient existing field data to support remedial decisions were identified during this reevaluation and are evaluated in the RI report:

- 216-Z-8 French Drain
- 216-Z-10 Injection/Reverse Well.

Therefore, data collected from these six waste sites and the resulting contaminant distribution models are anticipated to be representative of the analogous waste sites in the OUs.

2.6.2 Process for Assignment of Analogous Waste Sites

Because there are no analogous waste sites for which sufficient data are available for a site-specific risk assessment, all 11 analogous waste sites were evaluated against the six representative and unique waste sites.

The rationale used to assign the analogous waste sites to representative waste sites compares the following representative and analogous waste-site characteristics:

- Constituent inventory (the types and amounts of constituents received)
- Site configuration, site construction
- Site dimensions
- Depth of discharge
- Source facility and waste-stream information
- Geologic characteristics (information about the soil column beneath the site)
- Depth to groundwater (from the surface)
- Proximity to other structures and waste sites
- Contaminant distribution within the vadose zone
- Potential for groundwater impact
- Effluent volume
- Soil-pore volume (the volume of porosity between the base of the site and groundwater)
- Ratio of effluent volume to (soil) pore volume.

These characteristics are used to compare each analogous waste site to the representative waste sites in a three-step approach. In the first step constituent inventory is compared, in the second step all other site characteristics are compared, and in the third step the comparisons are combined and used to assign each analogous waste site to a representative waste site.

Step 1 – Inventory Comparison

Inventory values for each analogous waste site were compared to the representative waste site inventory values. Inventory values were taken from RPP-26744, *Hanford Soil Inventory Model, Rev. 1*, with three exceptions. The exceptions were the 241-Z-361 Settling Tank, the 241-Z-8 Settling Tank, and UPR-200-E-56 unplanned release, none of which are included in RPP-26744. The inventory for the 241-Z-361 Settling Tank was calculated from information in HNF-8735. The inventory for the 241-Z-361 Settling Tank was obtained by multiplying the average specific gravity from 13 samples by the mean concentration of constituents, as determined by laboratory analysis of core samples, and this, in turn, was multiplied by the volume of sludge remaining in the tank. No inventories were available for the other two analogous waste sites, so inventories from RPP-26744 for waste streams similar to those associated with the sites were assumed. In these cases, the specific contaminant species probably represent the analogous waste sites fairly accurately, but the total mass or total curies are less likely to be representative. The inventory for the 216-Z-8 French Drain was used for the 241-Z-8 Settling Tank; and the inventory for the 216-A-24 Crib was used for UPR-200-E-56 (DOE/RL-2006-51).

RPP-26744 contained data for 28 chemicals and elements and 47 radionuclides. The inventory for these 75 contaminants in the analogous waste sites were compared to the inventory in each representative waste site, and a 'best fit' representative waste site was selected for each analogous waste site. (Note: Only four organic compounds are included in RPP-26744, so the organic inventory may not be well represented.) An additional consideration was important in the review. High levels of certain constituents (> 5 Ci of plutonium or Am-241, > 10 Ci of Ci-137 and Sr-90) can present potential near-surface hazards, and this was considered in

assigning analogous waste sites to representative waste sites. In addition, high levels of mobile constituents (> 500 kg of nitrate, > 10 Ci of tritium, and > 0.01 Ci of Tc-99) are potential threats to groundwater, and this was considered in assigning representative waste sites.

The inventories for analogous waste sites 216-A-24 Crib, 216-A-31 Crib, and UPR-200-E-56 compare favorably with the inventory for the 216-A-8 Crib representative waste site. The inventories for analogous waste sites 216-Z-1, 216-Z-2, 216-Z-3, and 216-Z-18 Cribs compare favorably with the inventory for the 216-Z-1A Tile Field representative waste site.

Step 2 – Comparison of Site Characteristics

Construction Design Comparison. The site configuration, site construction, and depth of discharge were considered in this comparison. The information needed to make the comparison was obtained primarily from WIDS; DOE/RL-91-58; DOE/RL-92-04; DOE/RL-91-61, *T Plant Source Aggregate Area Management Study Report*; DOE/RL-91-60, *S Plant Source Aggregate Area Management Study Report*; and DOE/RL-92-18, *Semiworks Plant Source Aggregate Area Management Study Report*; and site-specific reports.

The 216-Z-1A Tile Field and the 216-A-8 Crib are similar in that they both discharged liquids in the subsurface at less than about 4.6 m (15 ft) bgs. Analogous waste sites 216-Z-1, 216-Z-2, 216-Z-3, and 216-Z-12 Cribs also discharged liquids at shallow depths and were considered comparable to the 216-Z-1A Tile Field; analogous waste sites 216-A-7 and 216-A-24 Cribs were considered comparable to the 216-A-8 Crib. The 216-Z-8 French Drain discharged liquids in the subsurface at a depth greater than 4.6 m (15 ft) bgs, as did analogous waste sites 216-Z-5, 216-Z-18, and 216-A-31 Cribs. The 216-Z-9 Trench consists of a 6.1 m (20-ft-) deep open trench, albeit covered but not backfilled, into which liquid was discharged near the ground-surface level of the trench cover. No analogous waste sites discharged liquids into an open structure comparable to the 216-Z-9 Trench. The 216-Z-10 Injection/Reverse Well was designed for waste liquids to discharge into the deep vadose zone from 36.0 to 45.7 m (118 to 150 ft) bgs. The 241-Z-361 Settling Tank is an enclosed structure designed to hold solids and pass liquids to other waste sites, but not to discharge the liquids beneath the tank. Analogous waste site 241-Z-8 Settling Tank was considered comparable to the 241-Z-361 Settling Tank based on similar closed construction. Only one waste site, the UPR-200-E-56 unplanned release, was not considered comparable to any of the representative waste sites for construction design.

Site Size (Area) Comparison. An analogous waste site was considered comparable to a representative waste site if its area was between one half and two times the size of the representative waste site, although this rule was relaxed slightly for analogous waste sites near the limits of the representative waste sites. Data on site size were taken from the same sources as the construction data. Several of the analogous waste sites (e.g., 216-Z-1, 216-Z-2, 216-Z-3, 216-Z-5, 216-A-7, 216-A-31 Cribs) are relatively small cribs with areas much smaller than the four representative waste sites designed to discharge liquids to the shallow vadose zone. These cribs have areas within the size limits for the 241-Z-361 Settling Tank but, although the settling tank is representative of their size, the tank is not considered representative of the cribs.

General Waste-Stream Characteristic Comparison. This comparison related the general waste stream received at the analogous waste sites to the waste streams received at the

representative waste sites. Two representative waste sites, the 216-Z-9 Trench and the 216-Z-1A Tile Field, received high-salt, acidic, high-organic waste from the RECUPLEX process (216-Z-9 Trench) or the replacement Plutonium Reclamation Facility (216-Z-1A Tile Field). The 241-Z-361 Settling Tank received high-salt, acidic, high-organic, and plutonium waste originating mostly from the Plutonium Reclamation Facility (236-Z Building) and dilute, neutral/basic, low-organic, and low-plutonium waste from the PFP (234-5Z Building). The 216-A-8 Crib received low-salt, neutral/basic condensate from the A, AX, AY, and AZ Tank Farms. The 216-Z-10 Injection/Reverse Well received process and laboratory waste from the 231-Z Plutonium Isolation Facility. The 216-Z-8 French Drain received acidic liquids from backflushes of feed filters that were used in the RECUPLEX process.

An analogous waste site was considered comparable to a representative waste site if both received waste streams with the same general characteristics. The general waste-stream characteristics of 9 of the 11 analogous waste sites are represented by the general characteristics of representative waste-site waste streams. The characteristics of waste streams discharged to analogous waste sites 216-A-7 and 216-Z-5 Cribs did not match the general characteristics of waste streams discharged to representative waste sites.

Geologic Information Comparison. This comparison combined information related to the site proximity, geologic data (stratigraphy and lithology), and depth to groundwater. Emphasis was placed on the geologic characteristics. It was assumed that sites adjacent to each other have similar stratigraphy. Little emphasis was placed on depth to groundwater, because the depth to groundwater in each of the two general areas under consideration (central 200 West Area and east-central 200 East Area) does not vary significantly, although the depth to groundwater at the 200 West Area and the 200 East Area is significantly different. The geology is significantly different in the 200 East and 200 West Areas, such that comparison of sites from the two areas is not representative regardless of the depth to groundwater. An analogous waste site was considered geologically comparable to a representative waste site if it is adjacent to the representative waste site or if all the major geologic units are present at approximately the same thicknesses in both the analogous and the representative waste sites. The comparison of unit thicknesses was subjective and based on professional judgment. All of the analogous waste sites were considered geologically comparable to at least one of the representative waste sites.

Extent of Contamination Comparison. The comparison of the extent of vadose-zone contamination at analogous waste sites and representative waste sites included consideration of borehole geophysical logging results, available characterization (laboratory) data, and general migration characteristics of the major COPCs (transuranics, mobile constituents, and organics). For those analogous waste sites with very little actual characterization data or no geophysical-log data, the volume of effluent and the general contaminant migration characteristics were considered.

Two additional aspects were considered while comparing the extent of contamination. First was whether or not high levels of certain relatively immobile contaminants (specifically plutonium, americium, cesium, and strontium) are present. These can present potential near-surface hazards that must be taken into consideration when relating analogous waste sites to representative waste sites for remediation purposes. Second was whether high levels of very mobile contaminants

(nitrate, tritium, and Tc-99) are present. These can impact groundwater and must be considered in the identification of a preferred alternative.

An analogous waste site was considered comparable to a representative waste site if the general distribution of contaminants was similar for both sites and if both sites received comparable volumes of effluent, such that they both did or did not impact groundwater. The comparison of geophysical log results and the expected impacts of disposal of liquid volumes are subjective and based on professional judgment. All but three of the analogous waste sites compared favorably with representative waste sites.

Analogous waste site 216-A-7 Crib contained a very low inventory of transuranic radionuclides compared to the representative waste sites, such that the overall vadose-zone contaminant distribution may not be comparable to the representative waste sites. The extent of contamination at two analogous waste sites is not considered to be comparable to the representative waste sites. One of these is an unplanned release associated with an excavation (UPR-200-E-56); none of the representative waste sites are excavations. The volume of effluent disposed to one analogous waste site (216-A-31 Crib) is extremely small compared to the volumes for the representative waste sites. The vadose-zone contamination associated with this site is expected to be localized and not comparable to the representative waste sites.

Step 3 – Assignment of Analogous Waste Sites to Representative Waste Sites.

The overall purpose of the representative waste-site strategy is to identify the preferred remedial alternative for the representative waste site and assume that this remedial alternative is appropriate for the analogous waste sites, subject to confirmatory sampling. Thus, the contaminants associated with a waste site (contaminant inventory and general waste-stream characteristics) and the distribution of contaminants in the vadose zone (and groundwater) are deemed more important than construction details, waste-site size, and hydrogeologic characteristics when identifying a preferred remedial alternative for past-practice disposal facilities. Further, for most contaminants, the distribution of contaminants in the vadose zone was considered more important than waste-stream characteristics or inventory for this evaluation.

Accordingly, the assignment of an analogous waste site to a representative waste site looked first to the similarities in inventory, general waste-stream characteristics, and contaminant distribution between the analogous waste site and the six representative and unique waste sites. The construction, hydrogeology, and waste-site size attributes were used as secondary considerations if an analogous waste site was similar to two representative waste sites based on waste characteristics and contaminant distribution.

The following guidelines were used.

- If the inventory, the general waste characteristics, and the distribution of contaminants in the vadose zone were similar for an analogous waste site and a representative waste site, the correspondence between the two was considered **very good**.

- If the inventory and the distribution of contaminants in the vadose zone were similar for an analogous waste site and a representative waste site, the correspondence between the two was considered **good**.

- If the general waste-stream characteristics and the distribution of contaminants in the vadose zone were similar for an analogous waste site and a representative waste site, the correspondence between the two was considered **good**.

- If the distribution of contaminants in the vadose zone was similar for an analogous waste site and a representative waste site, the correspondence between the two was considered **probable**.

- If inventory was similar for an analogous waste site and a representative waste site, the correspondence between the two was considered **possible**. Some characterization of the distribution of contaminants at the analogous waste site may be needed.

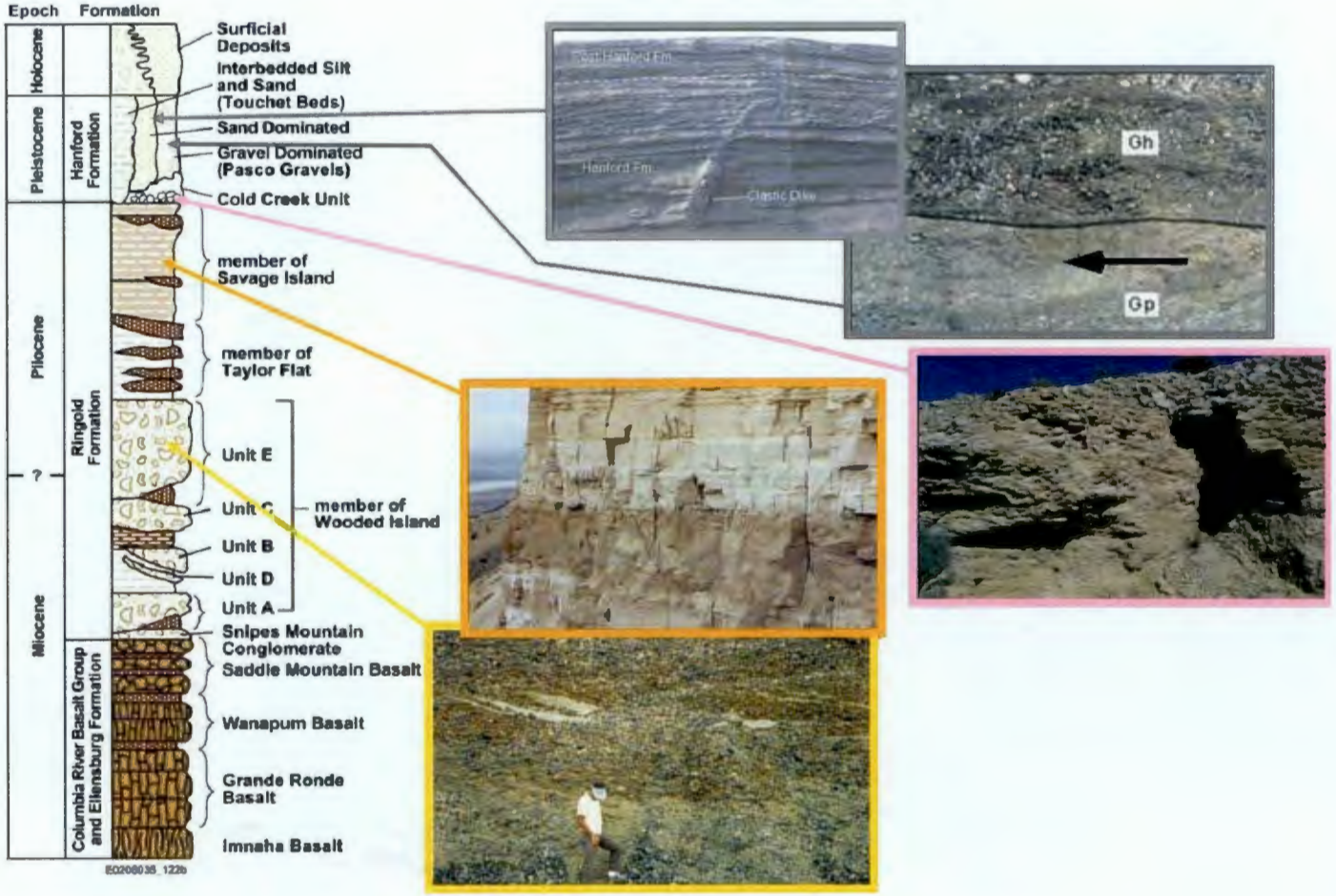
- If the general waste-stream characteristics were similar for an analogous waste site and a representative waste site, the correspondence between the two was considered **possible**. Some characterization of the distribution of contaminants at the analogous waste site may be needed.

- If neither the inventory, general waste-stream characteristics, nor the distribution of contaminants in the vadose zone were similar for an analogous waste site and any of the representative waste sites, the analogous waste site is not considered to be represented by any representative waste site.

The correspondence between the analogous 216-A-24 Crib and the representative 216-A-8 Crib and between the analogous 216-Z-18 Crib and the representative 216-Z-1A Tile Field site was very good. The correspondence between the analogous 216-Z-3 Crib and the 216-Z-12 Crib and the representative 216-Z-1A Tile Field site was good. The correspondence between four analogous waste sites (216-Z-1, 216-Z-2, and 216-Z-5 Cribs, and the 241-Z-8 Settling Tank) and the respective representative waste sites was considered probable. The correspondence between the analogous 241-Z-8 Settling Tank and the 241-Z-361 Settling Tank was considered probable. The correspondence between analogous waste sites 216-A-7 and 216-A-31 Cribs and UPR-200-E-56 and the representative waste site 216-A-8 Crib was considered possible.

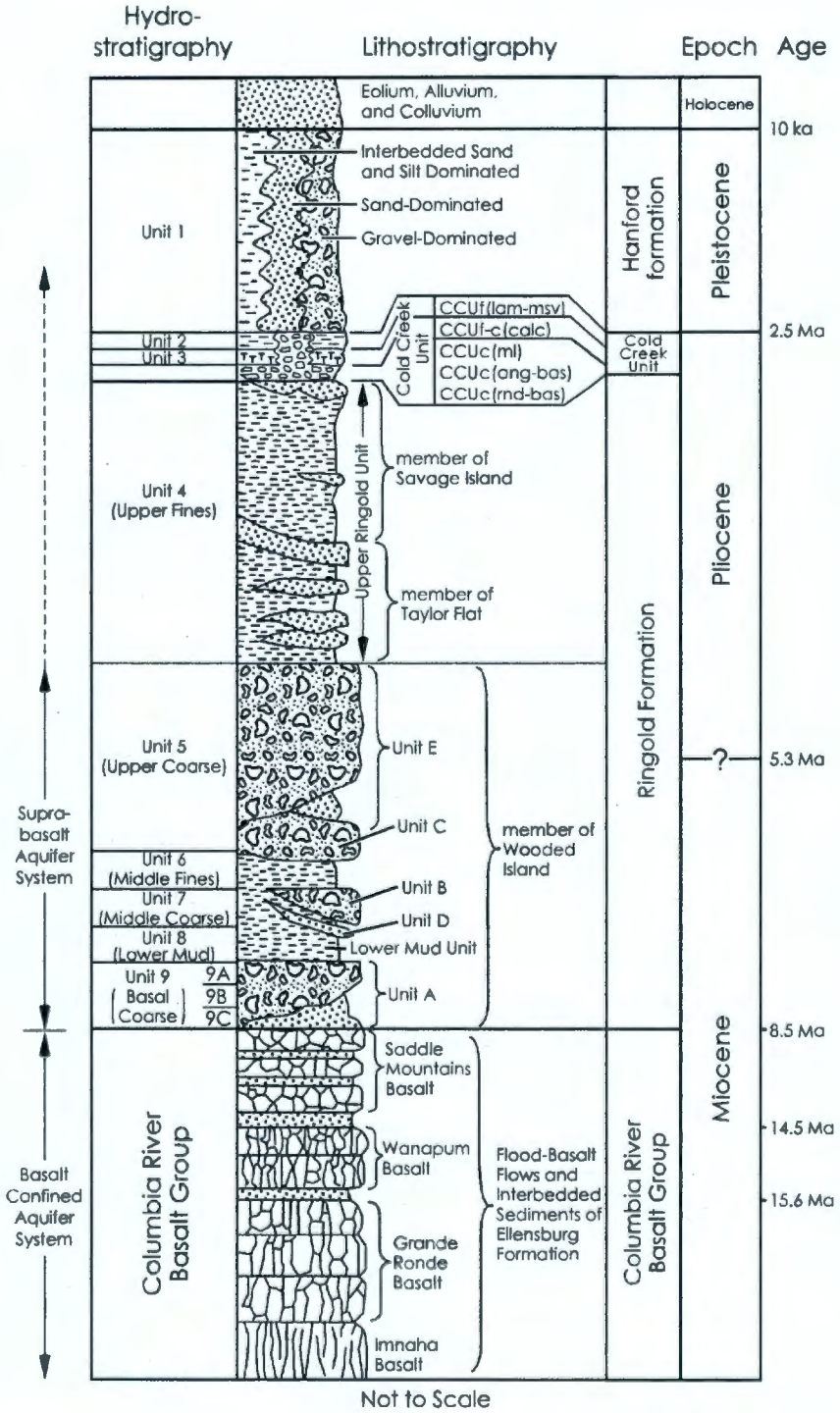
The results of the comparison of analogous waste sites with the representative waste sites for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are summarized in Table 2-1.

Figure 2-1. Major Geologic Units of Interest in the 200 Areas (from DOE/RL-2006-51).



Note: Gh = horizontally bedded, Gp = Foreset-Bedded

Figure 2-2. Generalized Stratigraphic Column for the 200 Areas.



After WHC-MR-0391, *Field Trip Guide to the Hanford Site*; PNL-8971, *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 93 Status Report*; BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*; PNNL-12261; and DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Post-Ringold Formation Sediments Within the Central Pasco Basin*.

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Figure 2-3. Contaminant Distribution Model, 216-Z-9 Trench.

200-PW-1 Operable Unit
Waste Type: Process Waste

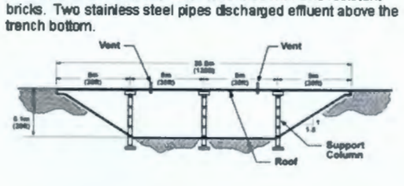
216-Z-9 Trench

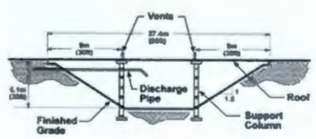
PFP Zone

History

The 216-Z-9 Trench is an enclosed, below-grade trench that was used from 1955 to 1962 for disposal of Z Plant RECUPLEX aqueous and organic liquid waste. Carbon tetrachloride was received in the aqueous phase liquid and, mixed with other organics, as a dense, non-aqueous phase liquid (DNAPL). In 1976 and 1977, the upper 0.3 m (1 ft) of the trench floor was mined to reduce the amount of plutonium in the trench; after mining, 38 to 48 kilograms (84 to 106 pounds) of plutonium were estimated to remain in the soils beneath the trench. Soil vapor extraction has been ongoing at the 216-Z-9 Trench since 1993 to remove carbon tetrachloride from the vadose zone.

CONSTRUCTION: The site is a rectangular, enclosed trench with a concrete cover supported by six columns. The trench is 18 by 9 m (60 by 30 ft) at the bottom and 6 m (21 ft) deep. The underside of the concrete cover was lined with acid resistant bricks. Two stainless steel pipes discharged effluent above the trench bottom.





WASTE VOLUME: 4,090,000 L (1,081,000 gal) (RHO-LD-114)

DURATION: 1955 to 1962

DISCHARGED INVENTORY:

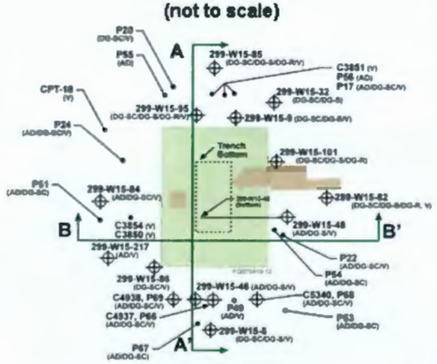
Plutonium	38-48 kg (remaining) (RHO-ST-21)
Americium-241	2.5 kg (RHO-LD-114)
Carbon tetrachloride	83,000 to 300,000 L (DOE/RL-91-32)
Tributyl phosphate	27,900 L (WHC-SD-EN-TI-248)
Dibutylbutyl phosphonate	46,500 L (WHC-SD-EN-TI-248)
Lard oil	9,300 L (WHC-SD-EN-TI-248)
Nitrate	1,361,000 kg (HNF-31792)

REFERENCES:
WIDS general summary reports
ARH-2915
RHO-ST-21
RHO-LD-114
PNNL-16103
PNNL-11978
DOE/RL-91-32
WHC-SD-EN-TI-248
BHI-00431
SGW-33746
HNF-31792

Basis of Knowledge (Data Types)

- Process History (PH)
- Downhole Geophysics - Spectral (DG-S)
- Downhole Geophysics - Scintillation (DG-SC)
- Downhole Geophysics - Radionuclide Logging System (DG-R)
- Soil Sampling Analytical Data (AD)
- Vapor Sampling Data (V)

Site Plan View
(not to scale)



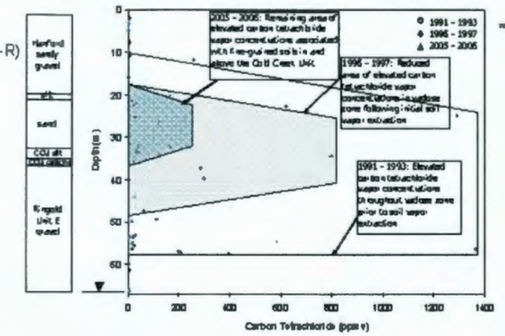
Characterization Summary

Wells were installed around the 216-Z-9 Trench beginning in the 1950s to monitor contaminant migration. Many of these wells have been geophysically logged. Characterization was conducted in 1961, 1963, and 1973 to evaluate the plutonium and americium in the trench (ARH-2915). Characterization was conducted in 1991 to 1993 to support soil vapor extraction activities. A DNAPL investigation conducted on the northeast corner of the 216-Z-9 Trench in 1995 detected no DNAPL in well 299-W15-32 (BHI-00431). Remedial investigation activities conducted at the trench included sampling from one deep well (299-W15-46) and one slant well (299-W15-48) and a phased carbon tetrachloride investigation. DNAPL was identified in a silt lens 20 m (65 ft) bgs south of the trench.

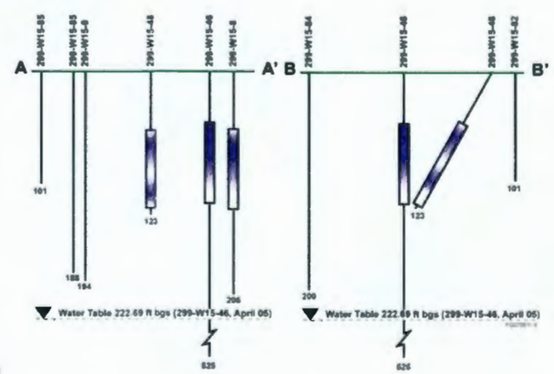
LEGEND
- Existing Borehole (data type)
- Water Table
- bgs = below ground surface

Site Section View Scale. Concentrations of plutonium; no color bar on Site Section View indicates no contamination was identified in available data.

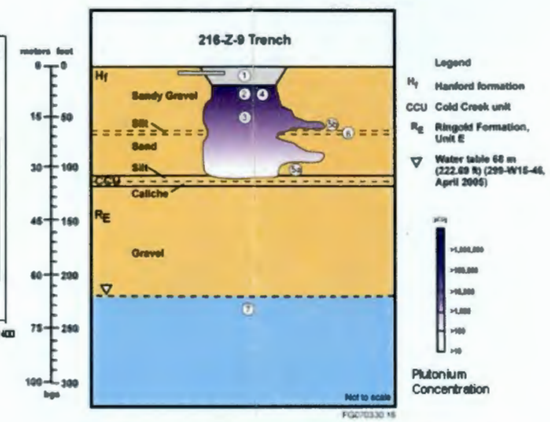
Carbon Tetrachloride Vapor Distribution



Site Section Views
(not to scale, units in feet bgs)



Contaminant Distribution Model



1. At the 216-Z-9 Trench, more than 4 million liters of plutonium/organic-rich process wastes were discharged between 1955 and 1962.
2. Effluent containing contaminants was discharged at the bottom of the unlined 216-Z-9 Trench. The trench floor slopes slightly to the south.
3. The wetting front and contaminants moved vertically beneath the trench. Lateral spreading of liquids is associated mainly with the Hanford gravel and sand contact, the Cold Creek unit, or fine-grained lenses in the Hanford or Ringold formations. In addition, vapor phase carbon tetrachloride migrated vertically and laterally beneath and around the trench, but has been considerably reduced by soil vapor extraction operations started in 1993 (see vapor distribution chart at left).
4. Constituents with large distribution coefficients, such as americium and plutonium, sorb to soils resulting in higher concentrations near the bottom of the trench. Concentrations generally decrease with depth. However, these contaminants were detected to depths up to 36.9 m (121 ft) bgs beneath the trench, indicating that plutonium and americium mobility was enhanced in the presence of the organic and acidic liquid wastes.
5. Carbon tetrachloride is present throughout the vadose zone beneath the 216-Z-9 Trench. As determined from sample data, carbon tetrachloride exists as vapor (5A), as a DNAPL near the Hanford gravel/sand contact on the south side (5B), and as a dissolved aqueous phase and/or sorbed phase in soil.
6. The highest concentrations of detected carbon tetrachloride are associated with silts in a thin lens at 20 m (65 ft) bgs.
7. Carbon tetrachloride has impacted the groundwater; impacts may have been associated with vapor, aqueous liquid, and/or organic liquid phases. In addition, carbon tetrachloride may have been dissolved in aqueous waste effluent from nearby facilities and subsequently been transported to groundwater. Plutonium and americium have been detected at low concentrations in the groundwater collected from one well near the trench. Older boreholes, and possibly clastic dikes, may have provided preferential pathways through the vadose zone.

200-PW-1FS.216-Z-9.08/28/07

Figure 2-4. Contaminant Distribution Model, 216-Z-1A Tile Field.

200-PW-1 Operable Unit
Waste Type: Process Waste

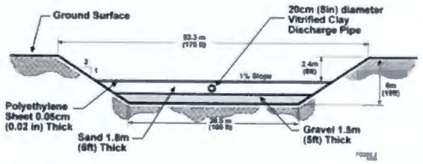
216-Z-1A Tile Field

PFP Zone

History

The 216-Z-1A Tile Field was a liquid waste site that was used to dispose of aqueous and organic liquid waste generated at the Plutonium Finishing Plant. The waste streams included overflow from the 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, which received process and laboratory waste from 1949 to 1959, and 236-Z plutonium recovery waste and 242-Z americium recovery waste discharged directly to the tile field from 1964 to 1969. Carbon tetrachloride was received in the aqueous phase liquid and, mixed with other organics, as a dense, non-aqueous phase liquid (DNAPL) from 1964 to 1969. The site was deactivated in 1969 by plugging facility discharge piping to the tile field when plutonium recovery waste was diverted to the 216-Z-18 Crib. Soil vapor extraction has been ongoing at the site since 1992 to remove carbon tetrachloride from the vadose zone.

CONSTRUCTION: The 216-Z-1A Tile Field consists of a 30 m (100 ft) wide, 79 m (260 ft) long, and 5.8 m (19 ft) deep excavation. The 20-cm (8-in) diameter vitrified clay distribution pipes lie on a 1.5-m (5-ft) thick gravel bed, 4.3 m (14 ft) bgs. The distribution pipes are covered with a 1.8-m (6-ft) thick sand layer. The central distribution pipe is a continuous line without perforations; the seven pairs of lateral pipes are divided into 0.3-m (1-ft) long segments.



WASTE VOLUME: 6,200,000 L (1,600,000 gal) (RHO-LD-114)

DURATION: 1949 to 1969

ESTIMATED DISCHARGED INVENTORY:

Plutonium	57 kg (RHO-LD-114)
Americium-241	1 kg (RHO-ST-17)
Carbon tetrachloride	270,000 kg (WHC-SD-EN-TI-248)
Tributyl phosphate	23,900 L (WHC-SD-EN-TI-248)
Dibutylbutyl phosphonate	27,500 L (WHC-SD-EN-TI-248)
Lard oil	11,000 L (WHC-SD-EN-TI-248)
Nitrate	3,000 kg (DOE/RL-91-58)

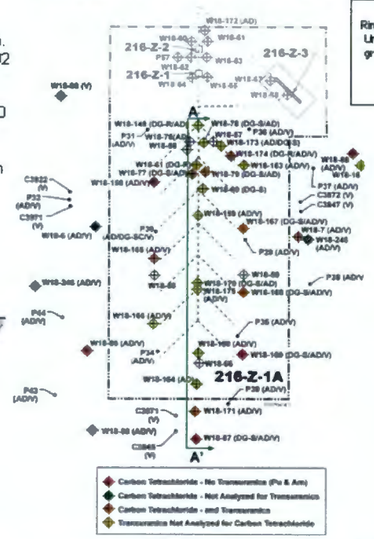
REFERENCES:
WIDS general summary reports
RHO-ST-17
RHO-LD-114
DOE/RL-91-32
WHC-SD-EN-TI-248
DOE/RL-91-58
SGW-33746
SGW-33829

Basis of Knowledge (Data Types)

- Process History (PH)
- Downhole Geophysics - Spectral (DG-S)
- Downhole Geophysics – Scintillation (DG-SC)
- Geologic Logs (GL)
- Soil Sampling Analytical Data (AD)
- Vapor Sampling Data (V)

Site Plan View

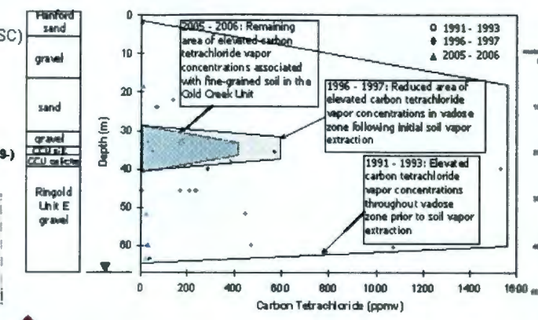
(not to scale; all well numbers prefixed with 299-)



Characterization Summary

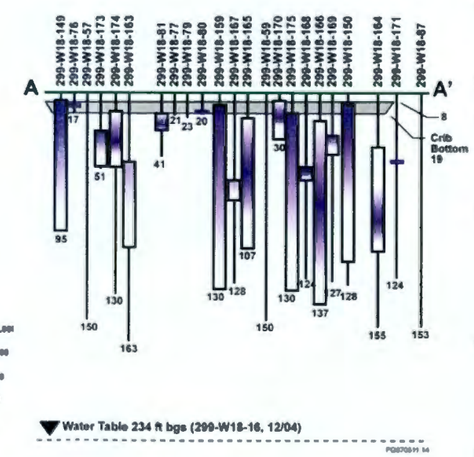
Data collection activities have been ongoing at the 216-Z-1A Tile Field since early operations. The distribution of plutonium and americium was characterized at 16 wells at this site in the 1970s (RHO-ST-17). Also, many of the wells in and around the tile field have been geophysically logged (ARH-ST-156, SGW-33829). Characterization was conducted in 1991-1993 to support soil vapor extraction, which has been ongoing at this site since 1992. As part of the remedial investigation, information from additional characterization boreholes was used to evaluate the distribution of carbon tetrachloride and other organic contaminants.

Carbon Tetrachloride Vapor Distribution



Site Section View

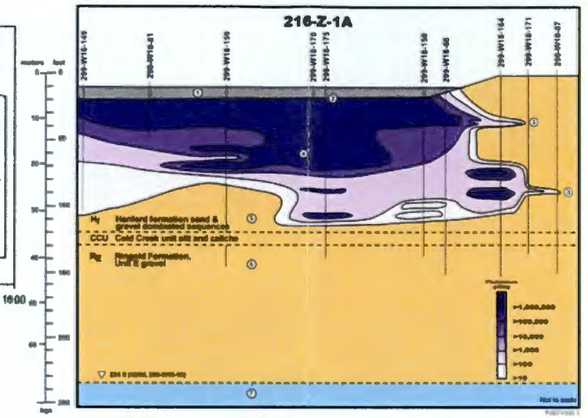
(not to scale; units in feet bgs)



Site Section View Scale. Concentrations of plutonium; no color bar on Site Section View indicates no contamination was identified in available data.

LEGEND
- Existing Borehole (data type)
- Water Table
- bgs = below ground surface

Contaminant Distribution Model



1. Between 1964 and 1969, the 216-Z-1A Tile Field received 5.2 million liters of high-salt, acidic liquid waste containing significant inventories of plutonium and carbon tetrachloride. From 1949 to 1959, the 216-Z-1A Tile Field received 1.0 million liters of slightly basic, aqueous waste.
2. Effluent and contaminants were released to the soil at the bottom of the tile field through a herringbone arrangement of pipes.
3. The wetting front and contaminants moved vertically beneath the tile field. Lateral spreading is mainly attributed to contact with the Cold Creek unit or fine-grained lenses in the Hanford or Ringold formations. Vapor phase carbon tetrachloride exists throughout the vadose zone in the source area.
4. Constituents such as plutonium (Pu) and americium (Am), which are generally immobile in soils, sorb readily to soils, resulting in higher concentrations directly beneath the tile field. The Am and Pu concentrations generally decrease with depth. However, radionuclides were detected to depths up to 37 m, indicating that Pu and Am mobility was enhanced in the presence of carbon tetrachloride, tributyl phosphate and derivatives, and acidic liquid wastes.
5. Carbon tetrachloride initially spread throughout the vadose zone beneath and around the 216-Z-1A Tile Field. However, soil vapor extraction operations started at the site in 1992 have considerably reduced the vadose zone carbon tetrachloride inventory (see vapor distribution chart at left). Dense non-aqueous phase liquid carbon tetrachloride was not identified during the remedial investigation.
6. The highest concentration of carbon tetrachloride is associated with the fine-grained sediments of the Cold Creek unit.
7. The effluent volume discharged to the tile field suggests that groundwater may not have been directly impacted by the wetting front unless a preferential pathway is present. Carbon tetrachloride in the soil vapor phase may have reached groundwater.

200-PW-1FS.216-Z-1A.08/30/07

Figure 2-5. Contaminant Distribution Model, 241-Z-361 Settling Tank.

200-PW-1 Operable Unit
Waste Type: Process Waste

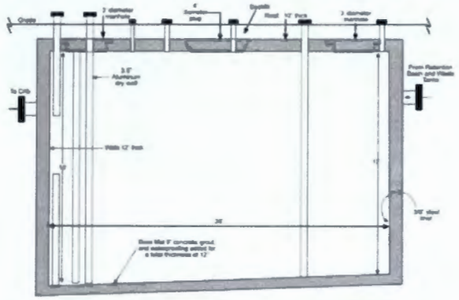
241-Z-361 Settling Tank

PFP Zone

History

The 241-Z-361 settling tank is an underground reinforced concrete structure that operated from 1949 to 1973 as a settling tank for neutralized 234-5Z, 242-Z and 236-Z liquid waste arriving from the 241-Z sump tanks. Settling tank supernatant was routed to numerous cribs, including the 216-Z-1, 216-Z-2, 216-Z-3, and 216-Z-12 cribs. The tank was isolated in 1973 and was partially pumped in May 1975 leaving approximately 800 L (210 gal) of liquid and 75 m^3 (82 yd^3) of sludge. The tank was evaluated in 1997 as part of a chemical hazard risk assessment. Characterization and analysis of the tank contents, completed in 2001, concluded that the tank contents posed no imminent threat to the environment (HNF-8735).

CONSTRUCTION: The tank interior is 7.9 by 4.0 m (26 by 13 ft) with 0.3-m (1-ft) thick walls and a sloping bottom resulting in an internal height varying between 5.2 and 5.5 m (17 and 18 ft). The top is 0.6 m (2 ft) below grade. There are two manhole covers and frames and several risers visible above grade. Waste entered the tank through two 15 cm (6 in) diameter stainless steel pipes; waste exited through a 20 cm (8 in) diameter stainless steel pipe.



WASTE VOLUME: 800 L of liquid and 75 m^3 of sludge are estimated to remain in the tank (HNF-8735)

DURATION: 1949 to 1973

REMAINING INVENTORY:
Plutonium 29 kg (HNF-8735)

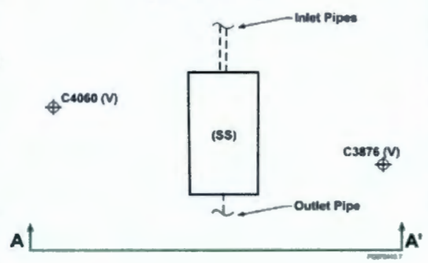
REFERENCES:
WIDS general summary reports
DOE/RL-2003-52
DOE/RL-2001-01
HNF-2867
HNF-8735
HNF-4371
FH-0002791

Basis of Knowledge (Data Types)

- Process History (PH)
- Vapor Sampling Data (V)
- Sludge Sampling Data (SS)

Site Plan View

(not to scale)

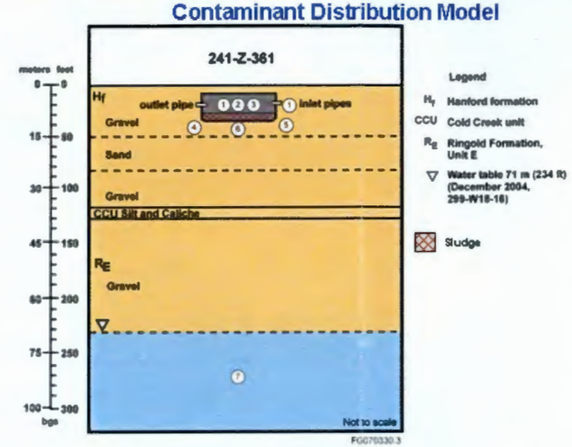


LEGEND
- Existing Borehole (data type)
- Water Table
- bgs = below ground surface

Characterization Summary

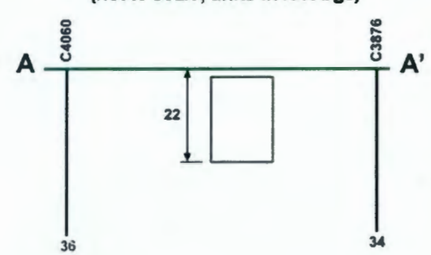
The 241-Z-361 Settling Tank and its contents were characterized from 1999 to 2001 in two phases. Phase I focused on opening the tank, characterizing the headspace vapor, and conducting a video camera survey of the tank interior (HNF-2867). Phase I identified volatile and semivolatile organics (HNF-8735). Phase II focused on characterizing the sludge (HNF-4371). Phase II identified approximately 75 m^3 (82 yd^3) of sludge with 29 kg of plutonium at concentrations of Pu-239 ranging from 428 ppm to 69 ppm and Pu-240 from 61 ppm to less than detectable. Metals (e.g., cadmium, chromium) and polychlorinated biphenyls (PCB) were detected in the sludge (HNF-8735). Helical piers installed to support tank sampling were surveyed when removed; no radiological contamination was detected (FH-0002791). Comparison of the 1999 camera survey to the 1975 photographs indicates the depth of the contents has not changed, signifying the tank has not leaked.

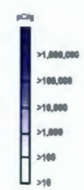
Contaminant Distribution Model



Site Section View

(not to scale, units in feet bgs)





Site Section View Scale. Concentrations of plutonium; no color bar on Site Section View indicates no contamination was identified in available data.

Water Table 234 ft bgs (299-W18-16, 12/04)

1. From 1949 to 1973, the settling tank was used to precipitate the heavier constituents from plutonium/organic rich process waste discharged to the tank.
2. After pumping in May 1975, a layer of sludge approximately 2.4 m (8 ft) thick remained with an estimated volume of 75 m^3 (82 yd^3) and containing approximately 29 kg of plutonium.
3. Characterization of the tank and its contents from 1999 to 2001 concluded that there are no imminent threats posed by the tank or its contents in their present condition and that the conditions are not likely to change in the near future. The sludge was identified as requiring remediation based on plutonium and toxic metals content.
4. Limited opportunistic survey of soils in the vicinity of the 241-Z-361 tank was conducted in 1999. Helical piers were installed and extended beneath the depth of the tank bottom within a meter from the tank. Some piers were removed and surveyed, and no radiological contamination was detected.
5. Potential leaks from this tank seem unlikely, based on comparisons of 1999 videos to 1975 still photographs showing the waste level remained unchanged and on the lack of radiological contamination from removed piers.
6. Although not expected, if tank leakage had occurred, immobile contaminants such as plutonium would be expected to sorb near the point of release. More mobile contaminants were mainly present in the remaining liquid in the tank, not in the sludge; most were removed with the supernatant.
7. Groundwater impact from this site is not expected. Evidence shows the tank likely did not leak and even had leakage occurred, the potential leak volume is much less than the soil column pore volume.

200-PW-1FS.241-Z-361.08/28/07

Figure 2-6. Contaminant Distribution Model, 216-A-8 Crib.

200-PW-3 Operable Unit
Waste Type: Process Waste

216-A-8 Crib

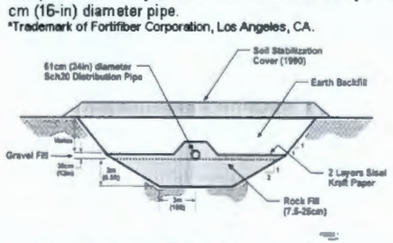
PUREX Zone

History

The 216-A-8 Crib was a liquid waste site used to dispose of vapor condensate and cooling water from operation of ventilation systems associated with the 241-A, 241-AX, 241-AY, and 241-AZ Tank Farms via the 216-A-508 Control Structure. In May 1958, when the crib approached its radionuclide capacity, the condensate was routed to the 216-A-24 Crib. Between 1966 and 1985, the 216-A-8 Crib intermittently received the vapor condensate waste. After 1985, all tank farm condensate waste was routed to the double-shell tank system. This site was surface stabilized in September 1990. The site was permanently isolated in April 1995 by filling the 216-A-508 Control Structure with concrete.

CONSTRUCTION: The 216-A-8 Crib is 6 by 259 m (20 by 850 ft) at the bottom, and ranges from 4.9 to 5.8 m (16 to 19 ft) deep. The crib was fed by a 61-cm (24 in) diameter, perforated distribution pipe located 2.6 to 3.5 m (8.5 to 11 ft) below original grade (1955) along the length of the crib on a 30-cm (12-in) thick bed of gravel. The gravel overlies 2.0 m (6.5 ft) of rock fill. The crib was covered with sisalkraft* paper and backfilled to grade. An overflow pond was excavated to the northeast of the crib. The pond was fed by a narrow ditch that was fed by a 41-cm (16-in) diameter pipe.

*Trademark of Fortifiber Corporation, Los Angeles, CA.



WASTE VOLUME: 1,150,000,000 liters (303,800,000 gal) (ARH-CD-745)

DURATION: 1955 to 1985

ESTIMATED DISCHARGED INVENTORY (RPP-26744, mean values; radionuclides decayed to 01/01/2001):

Cesium-137	2,410 Ci
Tritium	24,561 Ci
Uranium (total)	391 kg
Tributyl phosphate	128,582 kg
Normal paraffin hydrocarbon	55,107 kg
Butanol	1,364 kg

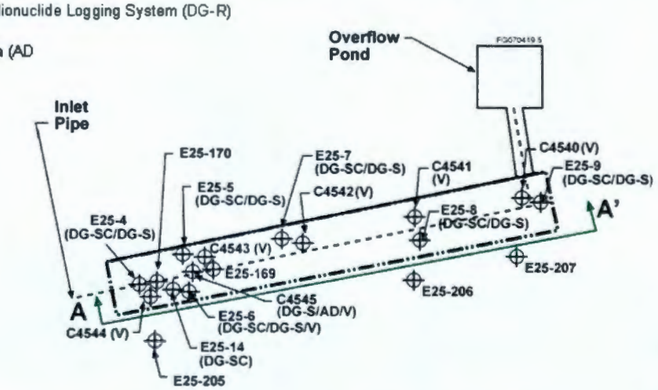
REFERENCES:
WIDS general summary reports
ARH-CD-745
RPP-26744
DOE/RL-2001-01
DOE/RL-92-04
WHC-EP-0287, Volume 3

Basis of Knowledge (Data Types)

- Process History (PH)
- Downhole Geophysics - Spectral (DG-S)
- Downhole Geophysics – Scintillation (DG-SC)
- Downhole Geophysics – Radionuclide Logging System (DG-R)
- Geologic Logs (GL)
- Soil Sampling Analytical Data (AD
- Vapor Sampling Data (V)

Site Plan View

(not to scale; all well numbers prefixed by 299-.)

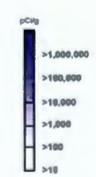


Characterization Summary

Characterization of the 216-A-8 Crib was performed during the remedial investigation. A deep borehole (C4545) was drilled, sampled, and geophysically logged at the head end of the crib (west end). Maximum cesium-137 concentrations were 877,000 pCi/g from 5.8 to 6.6 m (19 to 21.5 ft) bgs from soil sampling and 1.5 million pCi/g at 6 m (20 ft) bgs from geophysical logging. Additionally, 6 existing boreholes were geophysically logged to assess the distribution of gamma-emitting radionuclides. The highest cesium-137 concentration was 30,800 pCi/g in well 299-E25-5 at 7.6 m (25 ft) bgs. Sampling and geophysical data indicate higher contamination near the head end of the crib. An anticipated layer of organic contamination from the preliminary conceptual site model (DOE/RL-2001-01) was not observed, based on the borehole sampling.

LEGEND

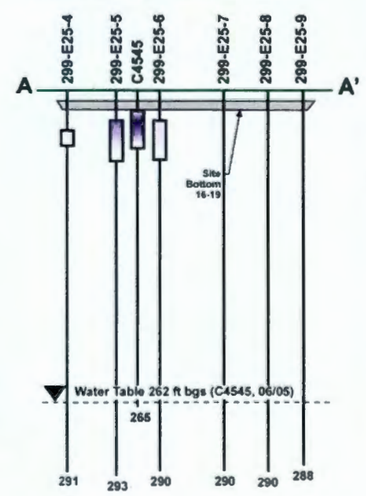
- Existing Borehole (data type)
- Water Table
- bgs = below ground surface



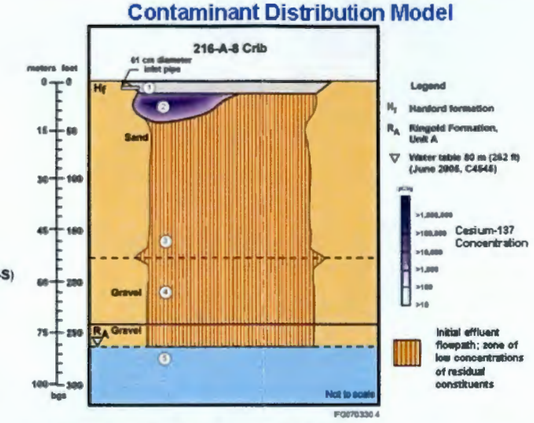
Site Section View Scale. Concentrations of cesium-137; no color bar on Site Section View indicates no contamination was identified in available data.

Site Section View

(not to scale, units in feet bgs)



Contaminant Distribution Model



1. The 216-A-8 Crib received liquid waste created by condensing vapors from self-boiling tanks in the 241-A, 241-AX, 241-AY, and 241-AZ Tank Farms. The crib received 1.15 billion liters from 1955 to 1985.
2. The more immobile radioactive contaminants (e.g., cesium-137, strontium-90) sorbed to soils at the bottom of the crib and concentrations decrease with depth. A zone of elevated cesium-137 concentrations exists between about 3.4 and 7.6 m (11 and 25 ft) bgs; concentrations in this zone range from 10 pCi/g to over 1 million pCi/g. Higher contamination is associated with the head end of the crib. Data from geophysical logging and vapor sampling show no contamination at the distal end of the crib.
3. The effluent and mobile contaminants traveled downward through coarser-grained material but tended to slow and spread at the intersection with finer-grained material. As the effluent traveled downward after discharge, contaminants may have been deposited along the top of these zones.
4. Waste water and mobile contaminants migrated downward through the vadose zone. These contaminants include both radioactive and nonradioactive constituents. A number of the radioactive constituents had short half lives and through time have decayed away. Nonradioactive constituents, especially the organics, have undergone vaporization, decay, and organic/metabolic processes that limit their persistence in the environment. The remedial investigation data indicate limited residual organic contamination in the vadose zone beneath the crib.
5. Groundwater in this area has been impacted by discharge to the crib. Based on the effluent volume and the tritium inventory for the 216-A-8 Crib, any future groundwater impacts are likely to be from tritium; however, future impacts are expected to be minimal due to the large effluent volume discharged, the mobility of tritium, and the short half life of tritium (12.3 years) (i.e., likely only a small inventory of tritium remains in the vadose zone).

200-PW-1FS.216-A-8.08/29/07

Figure 2-7. Contaminant Distribution Model, 216-Z-8 French Drain.

200-PW-6 Operable Unit
Waste Type: Process Waste

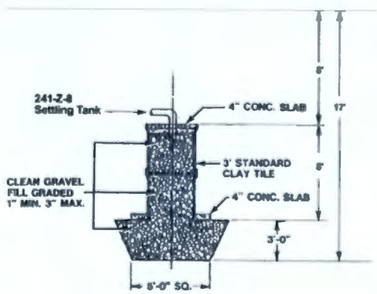
216-Z-8 French Drain

PFP Zone

History

The 216-Z-8 French drain is a liquid waste site that was used from 1955 to 1962 to dispose of overflow liquid waste from the 241-Z-8 Settling Tank. The tank was used as a solids settling tank for effluent waste from back flushes of the RECUPLEX feed filters. Tank waste flowed 11 m (36 ft) east to the French drain via a 10-cm (4-in) steel effluent pipe. Between 1957, when the tank first overflowed, and 1962, an estimated 9,590 L (2,530 gal) overflowed from the 241-Z-8 Settling Tank to the 216-Z-8 French drain. The drain ceased operations in 1962 when discharge piping in the 234-5Z Building was disconnected.

CONSTRUCTION: The 216-Z-8 French drain is constructed of two, 0.9-m (3-ft) long clay tile culverts, stacked vertically underground and filled with gravel. At the base of the culverts is a 10-cm (4-in) thick concrete collar that rests on a 1.5-m (5-ft) square by 0.9-m (3-ft) deep gravel bed that is approximately 5.6 m (17 ft) deep at the bottom.



WASTE VOLUME: 9,590 liters (2,530 gallons) (RHO-LD-114)

DURATION: 1955 to 1962

ESTIMATED DISCHARGED INVENTORY:

Plutonium 48.4 g (RHO-LD-114)

REFERENCES:
WIDS general summary reports
DOE/RL-91-58
RHO-RE-EV-46 P
RHO-LD-114

Basis of Knowledge (Data Types)

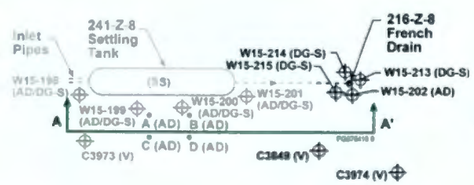
- Process History (PH)
- Downhole Geophysics - Spectral (DG-S)
- Downhole Geophysics – Scintillation (DG-SC)
- Downhole Geophysics – Radionuclide Logging System (DG-R)
- Geologic Logs (GL)
- Soil Sampling Analytical Data (AD)
- Vapor Sampling Data (V)

Characterization Summary

Characterization activities at the 216-Z-8 French drain consist of geophysical logging and soil sampling. A 1984 study focused on evaluating the distribution of transuranic constituents beneath the French drain. Samples were collected and analyzed from well 299-W15-202 (RHO-RE-EV-46 P). Maximum plutonium-239 and americium-241 concentrations were 4,620 and 457 pCi/g, respectively, located near the bottom of the drain structure. Geophysical logging in well 299-W15-213 in 2005 showed plutonium contamination up to 25,000 pCi/g near the bottom of the drain structure.

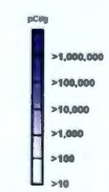
Site Plan View

(not to scale; all well numbers prefixed with 299-)



LEGEND

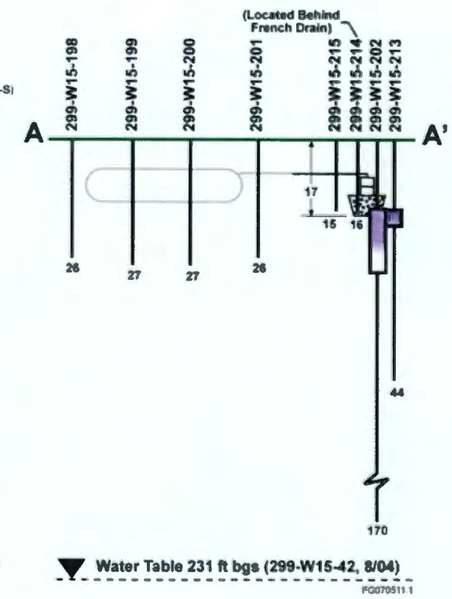
- Existing Borehole (data type)
- Water Table
- bgs = below ground surface



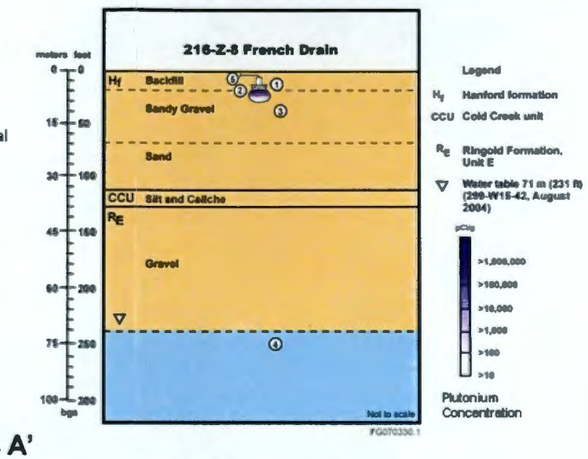
Site Section View Scale. Concentrations of plutonium; no color bar on Site Section View indicates no contamination was identified in available data

Site Section View

(not to scale; units in feet bgs)



Contaminant Distribution Model



1. Approximately 9,590 L (2,530 gal) of neutral to basic waste overflowed to the 216-Z-8 French drain from the 241-Z-8 Settling Tank between 1955 and 1962. (Note: the first overflow did not occur until 1957.)
2. Soil sampling data and geophysical logging data show an area of plutonium and americium contamination near the bottom of the French drain structure. Because of the affinity of plutonium for the vadose soils, little migration away from the disposal point, either laterally or vertically, was identified.
3. Data show the immobile contaminants plutonium and americium were sorbed onto the sediments within approximately 5 m (16 ft) below the gravel bottom of the drain. Contaminant concentrations decrease with depth and are less than 1 pCi/g near the bottom of this zone. Mobile contaminants were not identified in the inventory.
4. Waste discharged to the French drain likely did not impact groundwater because the discharge volume is very low, the contaminants disposed tend to sorb to soils at the discharge point, sampling data did not identify deeper contamination, and because of the significant depth to groundwater.
5. Leaks from the settling tank, if any, are not expected to impact soils away from the tank and would not have impacted contaminant distribution at the French drain.

200-PW-1FS.216-Z-8.06/28/07

Figure 2-8. Contaminant Distribution Model, 216-Z-10 Injection/Reverse Well.

200-PW-6 Operable Unit
Waste Type: Process Waste

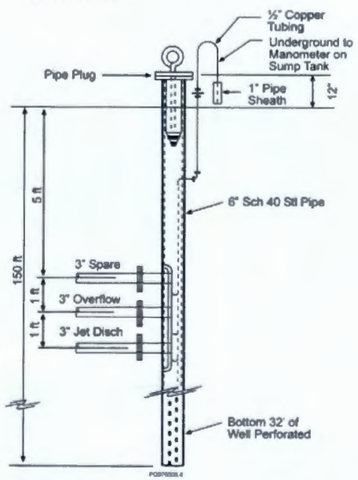
216-Z-10 Injection/Reverse Well

PFP Zone

History

The 216-Z-10 Injection/Reverse Well (well 299-W15-51) is a liquid waste disposal site that was used during 1945 to dispose of process and laboratory waste from the 231-Z building via the 231-W-151 Sump. The transuranic-contaminated process waste was discharged, at a rate of 76 L (20 gal) per minute, directly to the well through a 7.6 cm (3 in) diameter pipe from the 231-Z Building, entered the well about 1.5 m (5 ft) below grade, and was released to the soil through perforations in the well. The reverse well plugged after 4 months of use, after receiving 1,000,000 L (260,000 gal). The discharge line to the reverse well was capped and waste was diverted to the 216-Z-5 Crib.

CONSTRUCTION:



WASTE VOLUME: 1,000,000 L (260,000 gal) (HW-12468)

DURATION: February 1945 to June 1945

ESTIMATED DISCHARGED INVENTORY:
Plutonium 1 to 50 g (HW-12468)

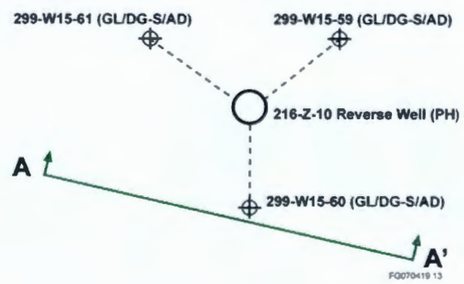
REFERENCES:
WIDS general summary reports
HW-12468
HW-9671
HW-23769
RHO-LD-114

Basis of Knowledge (Data Types)

- Process History (PH)
- Downhole Geophysics - Spectral (DG-S)
- Geologic Logs (GL)
- Soil Sampling Analytical Data (AD)

Site Plan View

(not to scale)



LEGEND
- Existing Borehole (data type)
- Perforated Zone
- Water Table

bgs = below ground surface

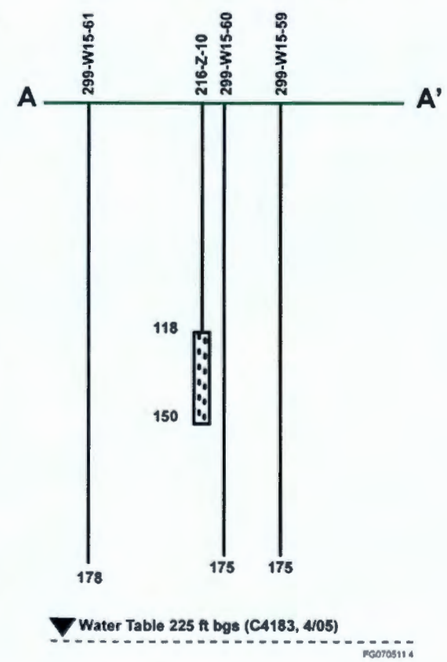
Site Section View Scale. Concentrations of plutonium; no color bar on Site Section View indicates no contamination was identified in available data.

Characterization Summary

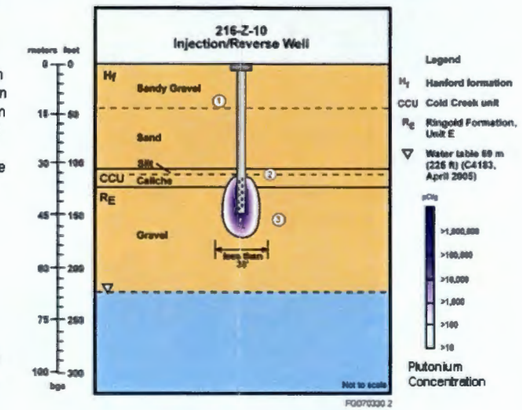
Operating history indicates plutonium (up to approximately 50 g) was the main contaminant released to the injection/reverse well. No organics are expected. Data include geophysical logging and analytical soil samples taken every 1.5 m (5 ft) in depth from three characterization wells surrounding the 216-Z-10 Injection/Reverse Well in an approximate 4.6-m (15-ft) radius and extending about 7.6 m (25 ft) deeper than the 216-Z-10 well. Soil samples did not identify plutonium contamination above a detection limit of approximately 0.15 pCi/g (HW-23769), indicating that waste spread laterally less than 4.6 m (15 ft) (HW-9671).

Site Section View

(not to scale, units in feet bgs)



Contaminant Distribution Model



1. Approximately 1 million liters of liquid waste containing up to approximately 50 g of plutonium and few other contaminants were discharged to the 216-Z-10 Injection/Reverse Well from February to June 1945.
2. Once discharged, the plutonium sorbed to soils around and below the perforations of the well. Only minor lateral spreading is expected because of the low volume of effluent discharged and the short operating period. Data show that migration is confined laterally to less than a 4.6-m (15-ft) radius around the well.
3. Downward migration is expected to be limited to within a few feet of the bottom of the well. Radionuclide impacts to groundwater are not expected. While no direct measurements of plutonium concentrations are available at the reverse well itself, concentrations are expected to be highest in the perforated well section (because the well plugged) and in the soils near the perforations. Concentrations are expected to decrease quickly with depth and with distance from the reverse well, based on the low plutonium inventory discharged, low volume of effluent discharged, and the short length of the perforated casing that distributed the waste over 10 m (32 ft) of soil column.

200-PW-1FS:216-Z-10:08/26/07

Figure 2-9. Approximate Extent of Carbon Tetrachloride Dense Nonaqueous-Phase Liquid in Silt Lens at 19.8 m (65 ft) Below Ground Surface Adjacent to the 216-Z-9 Trench.

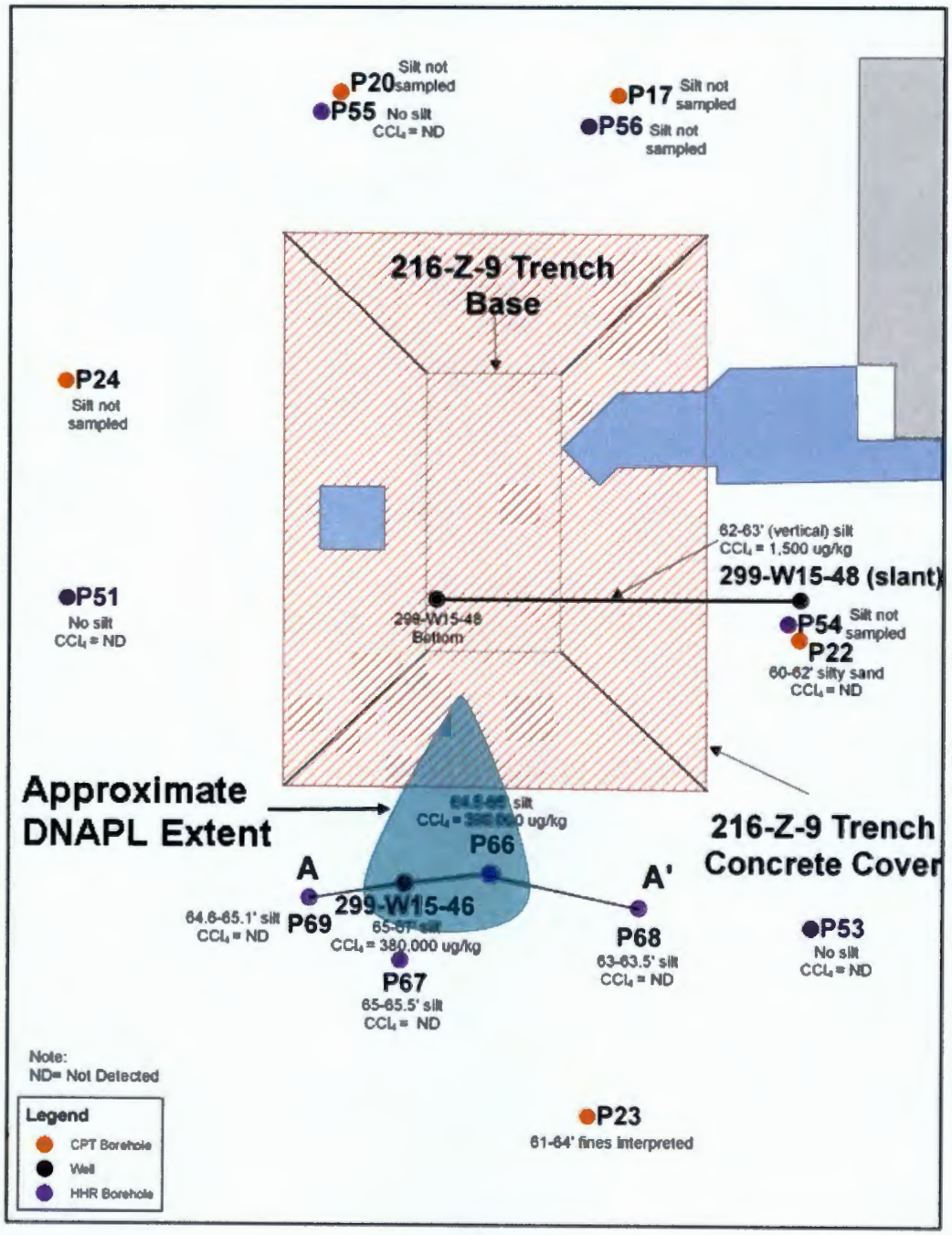


Table 2-1. Comparison of Analogous Waste Sites with the Representative or Unique Waste Sites for the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units.

Representative or Unique Waste Site	Analogous Waste Site	Correspondence
216-Z-1A Tile Field	216-Z-1 & -2 Cribs	Probable
	216-Z-3 Crib	Good
	216-Z-5 Crib	Probable
	216-Z-12 Crib	Good
	216-Z-18 Crib	Very good
216-Z-8 French Drain	None	
216-Z-9 Trench	None	
216-Z-10 Injection/Reverse Well	None	
241-Z-361 Settling Tank	241-Z-8 Settling Tank	Probable
216-A-8 Crib	216-A-7 Crib	Possible
	216-A-24 Crib	Very good
	216-A-31 Crib	Possible
	UPR-200-E-56	Possible

3.0 DEVELOPMENT OF REMEDIAL-ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

The RAOs for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are developed in this chapter. Inputs to developing the RAOs include the future land use, the results of the baseline risk assessment, and chemical-specific potential ARARs. The resulting RAOs are work statements that specify the media, COCs, potential exposure routes, and preliminary remediation goals (PRG) to protect human health and the environment and to ensure that the waste-site remedies comply with potential ARARs.

The RAOs are used throughout the FS process, first to aid in identifying technologies, and later as a basis for evaluating their effectiveness. The objectives for protection of human health and the environment are achieved by reducing or eliminating exposure routes, as well as by reducing contaminant concentrations and mass. The 200-PW-1, 200-PW-3, and 200-PW-6 OUs baseline risk assessment evaluated exposure routes under an industrial land-use scenario (to construction workers) and, for comparison, under a future failure of institutional controls scenario (to future well drillers and residential farmers). Protection of groundwater also was considered in the analysis of exposure routes.

A screening-level ecological risk assessment was conducted as part of the exposure assessment, and no ecological risks were identified at any of the 17 waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs.

Development of the RAOs and PRGs takes into account current and future land uses, current and future groundwater use, and the specific COCs. The potential ARARs impact and guide the RAO and PRG development. These elements are discussed in the following sections.

3.1 LAND USE

To identify appropriate cleanup objectives, the future land use of a site must be considered. Current and future land uses of the 200 Areas and the Central Plateau are discussed below.

3.1.1 Current Land Use

Current land-use activities associated with the 200 Areas and Central Plateau are industrial in nature. The facilities located in the Central Plateau were built to process irradiated nuclear fuel from plutonium-production reactors located in the 100 Areas. Most of the facilities directly associated with fuel reprocessing are now inactive and awaiting final disposition. Several waste-management facilities operate in the 200 Areas, including permanent waste-disposal facilities (e.g., the Environmental Restoration Disposal Facility [ERDF]), low-level radioactive waste burial grounds, and a mixed-waste trench permitted under RCRA. Construction of a facility for vitrification of wastes held in waste tanks (grouped in tank farms) in the 200 Areas began in 2002, and the 200 Areas are the planned disposal location for the vitrified low-activity tank wastes. Past-practice disposal sites in the 200 Areas are being evaluated for remediation that is likely to include institutional controls (e.g., deed restrictions or covenants) as part of the

identified preferred alternative. Federal agencies other than DOE (e.g., the U.S. Department of the Navy) use the Hanford Site 200 Areas nuclear waste TSD facilities. A commercial low-level radioactive-waste disposal facility, operated by U.S. Ecology, Inc., currently operates on a portion of a tract in the 200 Areas that is leased to the State of Washington.

The DOE-selected land use for the 200 Areas, documented through 64 FR 61615, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)," is industrial for areas located within the industrial (exclusive) use boundary and conservation (mining) for sites located outside of the industrial (exclusive) use boundary (Figure 3-1). A slightly different boundary was created to define the 200 Areas industrial land-use area by HAB, 2002.

According to DOE/EIS-0222-F, industrial (exclusive) land use would preserve DOE control of the continuing remediation activities and would use the existing compatible infrastructure required to support activities such as dangerous waste, radioactive waste, and mixed-waste TSD facilities. The DOE and its contractors, and the U.S. Department of Defense and its contractors, could continue their Federal waste-disposal missions; and the Northwest Interstate Compact for Low-Level Radioactive Waste Management could continue using the US Ecology, Inc., site for commercial radioactive waste. Research supporting dangerous waste, radioactive waste, and mixed-waste management facilities also would be encouraged within this land-use designation. New uses of radioactive materials (e.g., food irradiation) could be developed, and the products could be packaged for commercial distribution under this land-use designation.

The conservation (mining) land use would enable the extraction of valuable near-surface geologic resources to support implementation of remedial actions (i.e., surface barriers) at some locations on the Hanford Site after obtaining NEPA, RCRA, or CERCLA approval to protect NEPA-sensitive resources (e.g., biologic, geologic, historic, cultural). The Hanford Site has no proven reserve of any metallic ore bodies; therefore, heap/leach or open-pit mining methods would not be applicable. In addition, DOE/EIS-0222-F indicates that a notice-of-deed restriction would be placed in those areas where vadose-zone contamination remained in place, according to a CERCLA ROD or RCRA closure permit, foreclosing the mining option for any waste sites in this area. DOE/EIS-0222-F anticipates mining only for materials needed to build surface barriers as part of remedial actions and that mining would be precluded from contaminated areas. The conservation (mining) land use would afford protection of natural resources; however, other compatible uses (e.g., recreation or nonintrusive environmental-research activities) also would be allowed, provided that these activities are consistent with the purpose of the conservation land-use designation. Conservation would require active management practices to enhance or maintain the existing resources and to minimize or eliminate undesirable or non-native species.

64 FR 61615 identifies conservation (mining) as an area reserved for the management and protection of archeological, cultural, ecological, and natural resources. Limited and managed mining (e.g., quarrying for sand, gravel, basalt, and topsoil for governmental purposes only) could occur as a special use (i.e., a permit would be required) within appropriate areas. Limited public access would be consistent with resource conservation. The ROD also indicates that mining would be restricted from contaminated areas.

3.1.2 Anticipated Future Land Use

The reasonably anticipated future land use for the industrial (exclusive) use zone is continued industrial (exclusive) activities (HAB, 2002). Eventually, portions of this area may be used for non-DOE-related industrial uses. The DOE worked for several years with cooperating agencies and stakeholders, including the National Park Service, Tribal Nations, the states of Washington and Oregon, local county and city governments, economic and business development interests, environmental groups, and agricultural interests, to define land-use goals for the Hanford Site and develop future land-use plans. The results were reported in *The Future for Hanford: Uses and Cleanup, The Final Report of the Hanford Future Site Uses Working Group* (Drummond, 1992) and culminated in DOE/EIS-0222-F and the associated ROD (64 FR 61615) issued in 1999.

DOE/EIS-0222-F was written to address the growing need for a comprehensive, long-term approach to planning and development on the Hanford Site because of DOE's separate missions of environmental restoration, waste management, and science and technology. DOE/EIS-0222-F analyzes the potential environmental impacts of alternative land-use plans for the Hanford Site and considers the land-use implication of ongoing and proposed activities. In DOE/EIS-0222-F, the land-use designation for sites inside the industrial (exclusive) area is as follows:

- Industrial (exclusive): areas suitable and desirable for TSD of hazardous, dangerous, radioactive, and nonradioactive wastes, and related activities.

Under the preferred land-use alternative selected in 64 FR 61615, the area inside the industrial (exclusive) boundaries of the Central Plateau was designated for industrial (exclusive) use. The current vision for all of the 200 Areas is continued use for management of hazardous, dangerous, radioactive, and nonradioactive wastes. DOE/EIS-0222-F and the associated ROD (64 FR 61615) incorporate this vision in the identification of a preferred alternative, describe the means by which new projects will be sited, and focus on using existing infrastructure and developed areas of the Hanford Site for new projects. To support the current vision, the 200 Areas projects will maintain current facilities for continuing missions, remediate soil waste sites and groundwater as necessary to support industrial land uses, lease facilities for waste disposal (i.e., U.S. Ecology, Inc.), and demolish facilities that have no further beneficial use. Based on DOE/EIS-0222-F and the associated ROD (64 FR 61615), and consistent with other Hanford Site waste-management decisions, this FS assumes an industrial land use for all 17 of the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites that are located within the industrial (exclusive) land-use boundary. The 200-PW-1, 200-PW-3, and 200-PW-6 OUs baseline risk assessment evaluated exposure routes under an industrial land-use scenario (to construction workers) and, for comparison, under a future failure of institutional controls scenario (to future well drillers and residential farmers).

Operations at the Hanford Site are expected to terminate in approximately the year 2050, and active institutional controls are assumed for approximately another 100 years following the termination of operations (i.e., 2150). Effective passive institutional controls will be designed to endure, to provide protection for at least 500 years, which is the time period stated for ERDF (EPA/ROD/R10-95/100, *Declaration of the Interim Record of Decision for the Environmental*

Restoration Disposal Facility). Institutional controls are expected to be maintained until the contamination is no longer hazardous to human health or the environment.

Under the preferred land-use alternative selected in the ROD (64 FR 61615), the area outside of the industrial (exclusive) area of the Central Plateau was designated for other activities. This would include restrictions against intrusive human activities but would allow recreational use of the surface areas (e.g., hiking, biking, hunting, bird watching, where a receptor spends only a small fraction of time in actual proximity to any contaminated sites in this area). Restricted use (e.g., recreation or waste management) means that surface use of any waste sites in this area could occur, but subsurface activities such as excavation, well drilling, and farming would be restricted to preclude contact with or disturbance of contaminated soils. These activities could occur *around* the waste sites, but not *on* the waste sites in this area. Based on the risk framework workshops (HAB, 2002), groundwater use outside the industrial (exclusive) use area also would be restricted until remediation efforts result in meeting groundwater cleanup standards. At that point, unrestricted groundwater use would be assumed.

To date, the conservation (mining) land use has not been represented by a specific risk-assessment model. However, through the risk framework workshops (HAB, 2002), RL agreed to evaluate other scenarios as a means to provide decision makers and stakeholders with additional information for comparison purposes. As discussed in Section 3.2, the human-health risk assessment incorporates the current industrial land use in the exposure assessment and, for comparison, an unrestricted land-use scenario post-2150, should institutional controls fail in the future.

3.1.3 Regional Land Use

Communities in the region of the Hanford Site consist of the incorporated cities of Richland, West Richland, Kennewick, and Pasco, and numerous other smaller communities within Benton and Franklin Counties. The socioeconomics of the region are presented in Section 2.4.6. There are no residences on the Hanford Site. The inhabited residences nearest to the 200 Areas are farmhouses on land approximately 16 km (10 mi) north across the Columbia River. The City of Richland corporate boundary is approximately 27 km (17 mi) to the south (PNNL-6415) (Hanford NEPA).

3.1.4 Groundwater Use

DOE/EIS-0222-F indicates that contamination in the groundwater would restrict use. Groundwater beneath the Central Plateau currently is contaminated and is not withdrawn for beneficial uses. This FS evaluates potential future impacts to groundwater from current vadose-zone contaminants at the representative and unique waste sites, but does not evaluate groundwater remediation underlying these waste sites. This issue will be addressed by the groundwater OUs (i.e., the 200-ZP-1 Groundwater OU in the 200 West Area, and the 200-PO-1 OU in the 200 East Area) and through other site-wide assessments.

3.2 SUMMARY OF HUMAN-HEALTH RISK ASSESSMENT

A human-health risk assessment was conducted for five of the six representative and unique waste sites located in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The waste sites evaluated in this assessment are the 216-A-8 Crib, 216-Z-1A Tile Field, 216-Z-8 French Drain, 216-Z-9 Trench, and 216-Z-10 Injection/Reverse Well. These sites, plus the 241-Z-361 Settling Tank, were identified in the RI Report (DOE/RL-2006-51) as representative or unique, of the 17 waste sites in these three OUs. A discussion of the representative and analogous waste sites is presented in Section 2.6 of this FS. The 241-Z-361 Settling Tank was not included in this assessment, because there have been no documented environmental releases at the tank (RI Report, DOE/RL-2006-51). However, the potential for future releases warrants remedial action of the remaining tank contents. This risk assessment will be used to evaluate the need for remedial action in soil in these OUs and evaluate the protectiveness of certain remedies, based on current and potential future uses of the land. Except for the 216-A-8 Crib, which is located in the 200 East Area, the other four waste sites evaluated in this assessment are located in the 200 West Area.

Previous investigations identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in subsurface soil in the 200 West and East Areas of the Hanford Site from past disposal practices and unplanned releases associated with the processing of uranium and plutonium to make nuclear weapons materials. This risk assessment evaluated whether potential health risks are present if people encounter these impacted soils in their environment. The complete risk assessment is included as Appendix A. In Appendix A, risks to soil at the five waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs and to groundwater in the 200-ZP-1 Groundwater OU are addressed. However, this summary focuses on the results of the soil portion of the risk assessment. A discussion of the risk assessment from the 200-ZP-1 Groundwater OU is presented in the FS for that OU (DOE/RL-2007-28, *Feasibility Study for the 200-ZP-1 Groundwater Operable Unit*).

The risk assessment evaluates risks to adult workers from potential exposures under current and expected future industrial land-use conditions, assuming that the existing institutional controls remain in place. For comparison, the risk assessment also evaluates a hypothetical future unrestricted land-use condition if the existing institutional controls were to fail. Under current conditions, existing institutional controls prevent access to contaminants in soils. The unrestricted land-use scenario assumes that land-use controls will remain in place for 150 years; after that time there is assumed to be a failure of institutional controls such that potential exposures to a future residential farming population (adults and children) and a future working population (well drillers) hypothetically are possible. Inclusion of an unrestricted land-use scenario fulfills NCP requirements in 40 CFR 300.430(a), "Remedial Investigation/Feasibility Study and Selection of Remedy," "General," for a risk evaluation under a "no-action" scenario, fulfills EPA requirements to address current and future conditions, as noted in EPA/520/1-88/020, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, assesses food-chain exposures consistent with both EPA (EPA/520/1-88/020) and DOE/RL-91-45, *Hanford Site Baseline Risk Assessment Methodology*, and provides information to risk managers regarding the protectiveness of various remedies during the FS process. However, cleanup concentration goals and remedial decisions will be based on future industrial

land-use exposures, consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future (see Section 3.1.2).

3.2.1 Selection of Contaminants of Potential Concern

The first step in a human-health risk assessment was to evaluate the data to select COPCs for human health. The risk assessment primarily used the available soil data from the RI Report (DOE/RL-2006-51) for the representative and unique soil waste sites, supplemented by some additional historical data reports. In addition to soil data, three air samples collected from within the 216-Z-9 Trench were selected for inclusion in the risk assessment as the most representative data of what vapor concentrations might be possible in vapor intruding into basements.

Maximum detected concentrations in soil from each of the waste sites were compared to *EPA Region 6 Human Health Medium-Specific Screening Levels* (EPA, 2006) and EPA generic residential screening levels for radionuclides to select COPCs in soil from EPA/540/R-00/006, *Soil Screening Guidance for Radionuclides: Technical Background Document*, OSWER 9355.4-16. Because EPA Region 10 does not calculate their own screening levels, Region 10 mandates the use of Region 6 screening levels at EPA projects in Region 10. EPA Region 10 guidance for selecting COPCs was followed in that non-cancer human-health screening levels were divided by 10 to account for cumulative toxic effects, but the screening levels for carcinogens were not divided by 10 (EPA/910/R-98/001, 1998, *Interim Final Guidance: Developing Risk-Based Cleanup Levels at Resource Conservation and Recovery Act Sites in Region 10*). Human-health screening levels for carcinogens were not adjusted downward, because the screening levels are based on a 1×10^{-6} cancer-risk level, and action generally is not required at a site unless a cancer-risk level of 1×10^{-4} is exceeded. If the maximum concentration exceeded its screening level, then further evaluation was conducted as to whether the contaminant exceeded a natural background level, and whether its frequency of detection and frequency and magnitude of exceedance over screening levels warranted inclusion as a COPC (EPA/520/1-88/020). Further details on screening methodology and screening results are included in Sections A2.2 and A2.3 of Appendix A. Ten contaminants (eight at the 216-Z-9 Trench and two at the 216-A-8 Crib) with maximum concentrations above a screening level were eliminated in the further evaluation process because their health risks would be insignificant. These contaminants are discussed in depth in Appendix A, Sections A2.3 and A6.1.1. The selected COPCs are as follows (2 pages).

Contaminant	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib
Americium-241	√	√	√	
Cadmium			√	
Carbon-14				√
Carbon Tetrachloride (CCl_4)			√	
Cesium-137				√
Europium-152			√	
Manganese			√	

Contaminant	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib
Neptunium-237			√	√
Nickel-63			√	
Plutonium –238		√	√	
Plutonium-239/240	√	√	√	√
Protactinium-231			√	
Radium-226			√	
Radium-228			√	√
Strontium-90			√	
Technetium-99			√	√
Thallium				√
Thorium-228			√	√
Thorium-230			√	

No contaminants were detected in soil at the 216-Z-10 Injection/Reverse Well in samples collected within 4.6 m (15 ft) of the well; therefore, no COPCs were selected at this waste site, and it was not evaluated further in the risk assessment. Details regarding the sources and volumes disposed of at the 216-Z-10 Injection/Reverse Well, the analytical data, and the passive-neutron logging data, can be found in Appendix A, Section A.2, Table A2-5, and Section A6.1.1.2. All of this information was used in the evaluation to conclude that any concentrations of radionuclides in the immediate vicinity of the well that potentially were above health-based screening levels are not likely to be significant at the 216-Z-10 Injection/Reverse Well.

Concentrations of CCl_4 and chloroform in air, collected from within the covered 216-Z-9 Trench, are at concentrations below a health concern for workers; however, if these concentrations were in a residential home basement in the future, the indoor air pathway would be a health concern. Thus, CCl_4 and chloroform are COPCs for indoor air for a future residential farmer at waste sites 216-Z-1A Tile Field and 216-Z-9 Trench. No volatile organic compounds (VOC) were selected as COPCs in soil at the 216-Z-1A Tile Field (see above list), because they either were not detected or were detected below risk-based screening levels (detections were very infrequent; see Table A2-7 in Appendix A). Twenty-three soil samples were analyzed for VOCs at the 216-Z-1A Tile Field in samples collected down to a depth of 26 m (85 ft). An SVE system is in operation at the 216-Z-1A Tile Field and VOCs are being collected; therefore, VOCs still present in soil at the 216-Z-1A Tile Field appear to be located deeper than 26 m (85 ft), which is consistent with the conceptual contaminant distribution model for this site discussed in Section 2.5 Because VOCs still are being collected from the subsurface at the 216-Z-1A Tile Field, VOCs are considered COPCs in soil vapor beneath the 216-Z-1A Tile Field, as well as at the 216-Z-9 Trench, even though VOCs are not COPCs in soil at the 216-Z-1A Tile Field.

3.2.2 Exposure Assessment

Figures 3-2 and 3-3 present human-health conceptual site models depicting the populations and exposure pathways evaluated in the risk assessment under a current industrial land scenario and a future failure of institutional controls scenario, respectively. Note that the detailed information regarding contaminant sources, releases to the environment, and contaminant fate-and-transport information required to fully characterize the site was developed and presented as part of the RI Report for the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites (DOE/RL-2006-51). See also Table A2-5 in Appendix A, which provides a summary of sources and characterization information for each of the four representative and unique waste sites evaluated in this exposure assessment. This section provides a general discussion of contaminated media and focuses on human exposure to the media; it is not intended to reproduce the RI contaminant distribution models discussed in Section 2.5 of this report.

The risk assessment evaluates risks to adult workers from potential exposures under current and expected future industrial land-use conditions, assuming that the existing institutional controls remain in place. For comparison, the risk assessment also evaluates a hypothetical future unrestricted land-use condition if the existing institutional controls were to fail. The unrestricted land-use scenario assumes that after 2150 potential exposures to a future residential farming population (adults and children) and a future working population (future well drillers) hypothetically are possible.

For risk-assessment purposes, human exposures to soil can occur to "surface" and/or "subsurface" soil, depending on the particular population exposed. For workers, the EPA has three general categories, outdoor workers not involved in active soil disturbance (e.g., groundskeepers), indoor workers, and construction workers who would have intensive soil contact through active digging (*Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*, OSWER 9355.4-24 [EPA, 2002]). In this risk assessment, regular workers include both outdoor and indoor workers. Outdoor workers primarily would be exposed only to surface soil over the long-exposure durations (25 to 70 years) assumed in the risk-assessment equations. Construction workers involved in active soil disturbance (e.g., putting in an underground utility line or constructing a building) could be exposed to soils at depth for much shorter durations; the EPA default exposure duration for construction workers is one year. Surface soil is defined by EPA as the top 2 cm (0.78 in) in EPA/540/R-95/128, *Soil Screening Guidance: Technical Background Document*, although depths of 0 to 0.61 m (0 to 2 ft) and 0 to 0.91 m (0 to 3 ft) frequently are used as the "surface-soil" horizon as a protective measure (Oregon's *Final Guidance for Conduct of Deterministic Human Health Risk Assessments* [ODEQ, 2000]; and Alaska's *Draft Risk Assessment Procedures Manual* [ADEC, 2005]). The depth horizon for direct contact with subsurface soil in risk assessment is limited to depths up to 4.6 m (15 ft) bgs, because there would be very few instances of construction projects with deeper soil-disturbance requirements (EPA, 2002; WAC 173-340, "Model Toxics Control Act -- Cleanup").

Under the existing land-use controls, outdoor or indoor worker exposures (i.e., regular workers as opposed to construction workers) would occur only via the vapor-intrusion pathway, which is insignificant for workers based on the 216-Z-9 Trench air samples (see Figure 3-4). At all four of the quantitatively evaluated waste sites, impacts to soil do not begin until more that 1 m

(3 ft) bgs and, in some cases, contamination also is below 4.6 m (15 ft) – the depth interval limit for construction workers. Specific depth intervals of soil contamination presented and documented in the RI Report (DOE/RL-2006-51) and additional historical documents (RHO-RE-EV-46P) are as follows:

- 216-Z-1A Tile Field: 1.8 to 30.5 m (6 to 100 ft)
- 216-Z-8 French Drain: 5 to 11 m (16 to 35 ft)
- 216-Z-9 Trench: 6.4 to 36.6 m (21 to 120 ft)
- 216-A-8 Crib: 3.2 to 20 m (10.5 to 70 ft).

Based on the above, the direct-soil-contact pathways (i.e., ingestion, inhalation, dermal contact, and external radiation) only are complete for a construction worker. Because of the depth of the impacted soil, the overlying clean soil (and the cover on the 216-Z-9 Trench) provides sufficient shielding to effectively eliminate the external radiation pathway for the regular worker. The minimum of 1.8 m of clean soil cover at all of the waste sites provides sufficient shielding for even the very highest energy photon emitters at this site (DOE/RL-91-45; "Radiological and "Radiological and Chemical Fact Sheet to Support Health Risk Analyses for Contaminated Areas" [ANL, 2007]). Construction-worker exposures are evaluated at each waste site except the 216-Z-9 Trench, where the depth to impacted soil and the concrete slab covering the trench preclude disturbance.

In the event that knowledge of the Hanford Site is lost and institutional controls fail, a future unrestricted land-use scenario was evaluated where people could come into contact with groundwater and subsurface soil brought to the surface as drill cuttings from drilling a groundwater well. This scenario is assumed to occur 150 years in the future (2150). At that time, a future well driller and a future residential farming population could come into direct contact with impacted soil brought to the surface. Under the assumption that the impacted soil is spread in a garden, future residential farmers also could be exposed via ingestion of home-grown produce.

Native Americans currently live near the Hanford Site and potentially also could be exposed to contaminants in groundwater and subsurface soil in the 200 West Area and the 200 East Area under a future failure of institutional controls scenario, similar to a residential farming population. Native Americans have treaty fishing rights on portions of the Columbia River and have reserved the right to fish, hunt, gather roots and berries, and pasture horses and cattle on open unclaimed land (PNNL-15892, *Hanford Site Environmental Report for Calendar Year 2005*). With some exceptions, Native American exposures are similar in type to the residential farmer (e.g., both groups could be exposed via direct contact with contaminated soils and via the food chain), but exposures may be different in kind (e.g., more time spent outdoors, greater consumption of native plants and animals) than the typical default exposures that the EPA has developed for a residential population (*Risk Assessment Guidance for Superfund, Vol. I, Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors, (Interim Final)*, OSWER Directive 9285.6-03 [EPA, 1991]; EPA/600/P-95/002Fa; EPA/600/P-95-002Fa, *Exposure Factors Handbook*, Volumes I–III; and *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper, 2004]). For this assessment, the residential farming population has been selected to represent the future highly exposed population under the institutional controls failure scenario; however, implications on the results

of the risk assessment of not quantitatively evaluating a Native American population are further discussed in Section 3.2.5.

For the quantification of reasonable maximum exposure (RME), contaminant concentrations (referred to as exposure-point concentrations [EPC]) used for COPCs in soil were either the 95 percent upper confidence limit of the mean or maximum concentrations (if the data set was small). For radionuclide concentrations at the 216-Z-1A Tile Field and 216-Z-9 Trench, much of the available data is relatively old (1979 at 216-Z-1A Tile Field and 1963-1973 at 216-Z-9 Trench). The age of the data is not a concern for Pu-239 and Pu-240 because of their long half-lives; however, the parent compound of Am-241 is Pu-241, which has a short half-life (14.5 years) and no analytical data because of the difficulties of analyzing for this isotope of plutonium. Therefore, Am-241 concentrations in the older data sets likely do not represent the maximum in-growth concentrations of this radionuclide at these two sites (uncertainties surrounding maximum americium concentrations at the 216-Z-8 French Drain are discussed in Section A6.1.1; Am-241 is not a COPC at the 216-A-8 Crib). Therefore, maximum concentrations of Am-241 were estimated using the disposal-date information from the waste sites, the date of the available Am-241 data, and the RESidual RADioactivity dose model (RESRAD) (ANL, 2005, *RESRAD*, Version 6.3, available only online, at: http://web.ead.anl.gov/resrad/register2/), which can estimate radiological concentrations in the future, taking into consideration radionuclide decay and in-growth. The maximum predicted values for the 216-Z-1A Tile Field and the maximum predicted values from 1963-1973, combined with the 2006 data at the 216-Z-9 Trench, were used to estimate soil concentrations and subsequent health risks in the sections that follow. Details of the estimation process are provided in Appendix A, Section A3.2.1.1. The soil EPCs used in the risk calculations are shown on Table 3-1.

Soil EPCs are highest for construction workers directly exposed to impacted soil (the highest concentrations generally were the shallowest). Because future drillers are exposed to soils brought to the surface as drill cuttings (a 26.7 cm [10.5-in.] well was assumed in the calculations), impacted soil would be mixed with unimpacted soil, lowering the 95 percent upper confidence limit concentrations in the cuttings. Residential farmers are exposed to even lower concentrations, because the drill cuttings are assumed to be spread 15 cm deep in a 100 m^2 residential garden, where they would be diluted further.

The formulas and exposure factors that were used together with the EPCs to quantify doses for the complete and significant pathways shown on Figure 3-4 and Figure 3-5 are presented in Appendix A, Tables A3-11 through A3-18; the tables also indicate the sources of the factors. In general, EPA/600/P-95/002Fa default exposure factors were used for residential and industrial exposures. Default exposure factors are discussed in Appendix A, Attachment A-4. Where site-specific factors rather than accepted defaults were used, the rationale for their selection is provided in Appendix A, Section A3.3.

For radionuclide exposures in soil, EPCs and site-specific information were entered into RESRAD, Version 6.3 to determine risks. RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive materials that includes estimation of radionuclide decay and in-growth of daughter products. The RESRAD computer model was selected to evaluate risks for radionuclides in soil, because it is widely accepted as a tool for dose

and risk assessment at sites containing residual radioactive materials. Extensive documentation, including a user's manual, validation and verification documents, and guidance on input data sources support the validity of RESRAD risk and dose estimates. The calculations are based on widely accepted conservative models and assumptions that tend to overestimate the doses and risks to individuals.

3.2.3 Toxicity Assessment

The third step in risk assessment is an evaluation of the toxicity of the COPCs by an assessment of the relationship between the dose of a contaminant and the occurrence of toxic effects. Chemical toxicity criteria, which are based on this relationship, consider both cancer effects and effects other than cancer (noncancer effects). The toxicity criteria are required to quantify the potential health risks caused by the COPCs. Only cancer effects are of concern for the radionuclides (except for uranium, which was not a COPC in soil); however, a number of the nonradionuclide COPCs are considered toxic for their potential to induce cancer and because of their non-cancer toxic effects. The toxicity criteria used in the risk calculations are presented in Appendix A, Tables A4-1 through A4-3. Toxicity criteria for nonradionulcides are from EPA, preferentially EPA's *Integrated Risk Information System* (IRIS) (EPA, 2007), an online database of toxicity criteria, but were obtained from other EPA sources if a value was not available in IRIS. Toxicity criteria for the radionuclides are from EPA/402/R-99/001, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report No. 13. This report incorporates state-of-the-art models and methods that take into account age and gender dependence of radionuclide intake, metabolism, dosimetry, radiogenic cancer risk, and competing risks. Additional toxicological information for the COPCs can be found in Appendix A, Attachment A-5.

3.2.4 Risk-Assessment Results

Risks (for cancer) and hazards (for noncancer effects) are calculated for an RME scenario for each pathway, a calculation that overestimates risks for the majority of the population to ensure that public health is protected. Cancer risk estimates represent the potential for cancer effects by estimating the probability of developing cancer over a lifetime from site exposures (e.g., a risk of 1×10^{-6} indicates a one-in-one-million chance of developing cancer from exposures at the site). Noncancer hazards assume that there is a level of chemical intake that is not associated with an adverse health effect even in sensitive individuals. The EPA's target cancer risk goal is 1×10^{-6} to 1×10^{-4}, with action usually required if risks exceed 1×10^{-4}; target health goals for non-cancer contaminants are a hazard index of less than or equal to 1. Table 3-2 summarizes the cancer risks from exposure to COPCs in soil for all three populations evaluated: construction workers, future drillers, and future residential farmers. No non-cancer hazard indexes exceeded one for any population at any waste site. Non-cancer results are shown on Tables A5-3 and A5-7 in Appendix A.

Under current industrial land use and institutional controls, there are no significant exposures to chemicals and radionuclides in soil. Volatile or radiological emissions from the subsurface are insignificant for workers. Institutional controls prevent the use of impacted groundwater, and impacted soil is covered by at least 1.8 m (6 ft) of un-impacted soil. However, if construction

workers disturbed soil down to 4.6 m (15-ft) depths at 216-Z-1A Tile Field, 216-Z-8 French Drain, or 216-A-8 Crib, they could come into contact with COPCs. Under that unlikely scenario (existing institutional control programs at the Hanford Site are designed to prevent unprotected digging in impacted soil), health risks would exceed 1×10^{-4} at the 216-Z-1A Tile Field (risks of 4×10^{-2}) and 216-A-8 Crib (risks of 5×10^{-2}), indicating that remedial action would be necessary. Risks from digging in soil at the 216-Z-8 French Drain were less than 1×10^{-6}. Risks from subsurface soil exposures at the 216-Z-1A Tile Field were driven by Pu-239, followed by Pu-240, then Am-241. Risks from subsurface soil exposures at the 216-A-8 Crib are driven by Cs-137. Section 3.2.2 noted that construction worker exposures would not be quantified at the 216-Z-9 Trench because of the depth to impacted soil and the concrete cover over the site. However, based on the americium and plutonium isotope concentrations in the soils immediately beneath the bottom of the 216-Z-9 Trench, if construction workers ever were to be exposed to that soil, risks likely would exceed the construction worker risks seen at the 216-Z-1A Tile Field and would be above 1×10^{-4}.

Under the future failure of institutional controls scenario 150 years from now, cancer risks for well drillers exposed to drill cuttings during a one-week drilling event were below 1×10^{-4} and ranged from 3×10^{-5} at the 216-Z-9 Trench to 3×10^{-9} at the 216-Z-8 French Drain. Similar to construction workers, the well driller risks at the Z Plant sites are driven by Pu-239, followed by Pu-240, then Am-241, and risks at the 216-A-8 Crib are almost entirely from Cs-137. Future residential farmers' risks from direct soil exposures were higher than for drillers and are comparable to those for construction workers. Although the concentrations to which future residents would be exposed are lower than the concentrations for construction workers and future well drillers because of the dilution that would occur by spreading and tilling the drill cuttings, the future resident's exposures occur over a longer period of time, include children's exposures, and would include exposures from consuming produce grown in impacted soils, in addition to direct-contact pathways (e.g., incidental ingestion). Risks from direct soil exposures and ingestion of produce exceeded 1×10^{-4} at all sites but the 216-Z-8 French Drain. Combined risks from exposures to soil and produce were 1×10^{-2} at the 216-Z-1A Tile Field, 1×10^{-5} at the 216-Z-8 French Drain, 1×10^{-1} at the 216-Z-9 Trench, and 2×10^{-2} at the 216-A-8 Crib. The risk drivers are the same as those for construction workers and drillers, although at the 216-Z-9 Trench, risks from Np-237 and Ra-226 also exceeded 1×10^{-4}. Note that the concentrations of nonradionuclide COPCs were not reduced as were the radionuclides to account for future decay, and CCl_4 in 216-Z-9 Trench soil exceeds 1×10^{-4} for the produce ingestion pathway. However, in 150 years, CCl_4 concentrations in soil are expected to be lower than present values, but this reduction was not quantified.

Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and in-growth of daughter products. Because two of the three risk-driver radionuclides at the three Z Plant sites are plutonium isotopes with extremely long half-lives in soil (24,000+ years for Pu-239 and 6,500+years for Pu-240), the future risk calculations for these sites are not significantly different than current risks, nor are there daughter products that become significant (from a health-risk perspective) in the 1,000-year time frame. The other risk driver radionuclide, Am-241, has a shorter half-life (432 years) than the plutonium isotopes, and a

significantly toxic daughter product (Np-237) with a long half-life. Nevertheless, risks from Am-241 (including daughter products) do decrease significantly over the 1,000-year period[11]; however, cumulative risks do not change significantly within 1,000 years. Therefore, cumulative risks at future time horizons were not included on Table 3-2 for the Z Plant sites. Figure 3-4 illustrates the decline in risk over 1,000 years for the future residential farmer at the 216-Z-9 Trench, which shows cumulative risks decreasing very little over 1,000 years. This risk reduction pattern is similar for all evaluated populations at all the Z Plant sites. Current and future risk results, including daughter-product risks, are included on the tables in Attachment A-7 of Appendix A.

For the 216-A-8 Crib, where Cs-137 is the risk-driving radionuclide, risks from future time horizons decline significantly, because Cs-137 has a half-life of approximately 30 years, and risks at the 216-A-8 Crib decrease significantly within the 1,000 years evaluated in this assessment. Therefore, Table 3-2 includes cumulative risks at future time horizons for the 216-A-8 Crib. Figure 3-5 shows the decrease in cancer risks for the future residential farmer for the 216-A-8 Crib. The risk-reduction pattern shown on the figure is similar for the well driller and construction worker.

The air samples collected in 2006 from within the 216-Z-9 Trench were compared to residential screening levels (EPA, 2006) in air (IRIS), calculated to be protective of a 1×10^{-6} cancer risk level. Carbon tetrachloride and chloroform both exceeded the human-health medium-specific screening levels by many orders of magnitude and were selected as COPCs in indoor air for a future residential population (see Section A2.4 in Appendix A). If the concentrations of CCl_4 and chloroform identified in the trench air are assumed to be the same concentrations that one would find in the basement of a residential home, then these concentrations would correspond to a cancer risk of 7×10^{-1} and 5×10^{-2} for CCl_4 and chloroform, respectively, significantly greater than the maximum acceptable cancer-risk level of 1×10^{-4}. However, there is a great deal of uncertainty as to future indoor-air risks, because the concentrations of VOCs are declining over time, caused by their removal via the active SVE system and because of their natural decrease in environmental media, caused by volatization and breakdown in the environment. Therefore, while this pathway is shown as potentially complete and significant for future residents on Figure 3-5, these risks only are considered to be semiquantitative, because of the simplification of the evaluation process.

In summary, the conclusions of the subsurface soil risk assessment are as follows.

- Risks from exposure to soils at 216-Z-8 French Drain are below levels that are a health concern for all three populations evaluated.
- Risks to future well drillers are below 1×10^{-4} at all four waste sites evaluated.

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[11] Part of the reason for Am-241's decline likely is not caused by decay but by leaching from the site. The relatively high leaching is caused by the low default K_d value that RESRAD assigns to the compound, which potentially overestimates its leach rate from a future garden.

- Risks from soil exposures at the 216-Z-1A Tile Field and 216-A-8 Crib are similar and exceed 1×10^{-4} for construction workers and future residential farmers. Risks from soil exposures at the 216-Z-9 Trench were the highest for the four waste sites evaluated, with risks exceeding 10^{-1} (i.e., there is a nearly 100 percent chance of developing cancer) for future residential farmers.

- Plutonium-239, followed by Pu-240 and Am-241, were the risk drivers in soil for the Z Plant sites; Cs-137 was the risk driver in soil at the 216-A-8 Crib.

- Carbon tetrachloride and chloroform in soil gas beneath the 216-Z-1A Tile Field and the 216-Z-9 Trench may be a concern in indoor air if a residential home ever were to be constructed above those waste sites. Concentrations of VOCs in soil gas are not a concern for workers.

- Future residential farmer risks from soil exposures were highest for ingestion of produce, followed by ingestion of soil or, for some radionuclides, external radiation.

3.2.5 Uncertainties

Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, such that simplifying assumptions must be made to quantify health risks. Some key areas of uncertainty evaluated in the risk assessment are listed below. A more detailed discussion regarding uncertainties in the risk-assessment process is presented in Section A.6 of Appendix A.

- Produce ingestion uncertainties. Risks are significantly above target health goals due to ingesting homegrown produce grown in impacted soils (Table 3-2). Risks and hazards also are significantly above target health goals if produce is watered with impacted groundwater (see Tables A5-10 and A5-11 in Appendix A). Calculated risks and hazards from ingestion of homegrown produce are dependent on the concentration in the plant tissue and the produce ingestion rate. Plant tissue concentrations were estimated using health-protective modeling that likely overestimates the amount of COPC that could be in the plant. The modeling equations used were from the RESRAD Version 6.3 computer model (soil-to-plants) and those developed by the Oak Ridge National Laboratory for calculation of PRGs (water-to-plants and water-to-cattle). The transfer factors for water-to-plants and water-to-cattle were obtained from HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment*, which preferentially used Hanford Site-specific data, where available. Modeling details and transfer factors are described in detail in Section A3.2.3 of Appendix A. Modeling necessarily simplifies complex environmental processes and, therefore, concentrations in plants cannot be absolutely determined without field data. While transfer factors are generally chosen to be conservative (i.e., concentrations of contaminants in the food chain will be overestimated), it is possible that modeling also might underestimate actual plant concentrations in a future garden.

- In addition to uncertainties surrounding actual concentrations of COPCs in plants, there also is uncertainty surrounding how much home-grown produce a person would eat. The

risk calculations used average home-grown fruit and vegetable ingestion rates for households who farm in the Western United States, from EPA/600/P-95/002Fa (see Section A3.3.2.1 in Appendix A). These values were selected to best represent a rural farming population that would be expected to receive a significant portion of their produce from their own garden; however, actual ingestion rates could vary. A more detailed discussion regarding produce ingestion rates can be found in Section A6.2.4 of Appendix A.

- A Native American population was not quantitatively evaluated. Because cancer risks and non-cancer hazards are already well above target health goals for the future residential farmer, risks and hazards were not quantitatively evaluated for a Native American scenario. A future residential farming population was selected to represent the RME "bounding" scenario because this population has widely accepted exposure factors that have been used over many years at many CERCLA sites. However, based on ongoing work evaluating the differences between a tribal scenario and a future residential farmer, Native Americans likely have higher exposure to many environmental media, although, with few exceptions, Native American exposure pathways are the same as those of the future residential farmer (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain). Table 3-3 compares the exposure factors and possible risks for a future residential farmer and Native Americans using exposure factors established for the Confederated Tribes of the Umatilla Indian Reservation by Harris and Harper, 2004, for the exposure pathways that are the same (i.e., direct soil- and water-contact pathways). Because the risk-assessment equations are linear for non-cancer hazards and for cancer risks up to 1×10^{-2}, an increase in exposure could result in an increase in risk of the same amount. Thus, as shown in the example risk estimations on Table 3-3, combined exposures to soil and groundwater for Native Americans could result in an estimated increase of about an order of magnitude (10 times) of the exposure of the future residential farmer.

  Another area where tribal-subsistence scenarios and residential scenarios can differ, in addition to increased exposures for pathways that are the same (e.g., soil ingestion), is in the amount of food gathered or grown locally. Under the assumptions in this risk assessment, groundwater is used to irrigate a garden area sufficient to produce a significant portion of a residential farmer's diet, but not sufficient in size to supply all a family's dietary needs. Therefore, in this case, the homegrown-produce ingestion rates (produce ingestion was a risk-driving pathway) would be similar between the two populations. However, irrigating a garden with groundwater is not limited by area. Produce-ingestion risks, assuming that the only source of contaminants into plants was irrigation water, also were significant ($> 1 \times 10^{-4}$ for carcinogens, and hazard indexes well above one because of CCl_4 exposures, at the 90th and 50th percentile groundwater concentrations). Therefore, if more food is produced from a larger garden irrigated with groundwater, risks and hazards would increase. This would be true for both a future residential farming population and a Native American population. However, risks and hazards already exceed target health goals by a significant amount, so an increase in the amount of homegrown produce ingested would not change the conclusions of the risk assessment.

Similar to produce irrigated with groundwater, if a Native American produced more of his/her own protein than a future residential farmer did, he/she might ingest more of his/her own beef. Beef ingestion had the lowest risks and hazards for the future residential farmer exposure pathways, with risks of 3×10^{-5} or less and no non-cancer hazards above one (see Section A5 of Appendix A for risks from groundwater-to-cattle food-chain pathways). Ingestion rates of dairy products from home-raised dairy cattle also are potentially different for Native Americans than the ingestion rates established by the EPA for families who farm.

Several exposure pathways applicable to a Native American population are not evaluated for the residential farmer: ingestion of wild plants and wild game, and exposures to water and water vapor in a sweat lodge. Under the assumptions in this assessment, wild plants and game would not be affected significantly by contaminants, because contaminants are confined to a residential garden and watered from groundwater. While contaminants in soil might be spread by wind-blown dust and, if an irrigation ditch system is used, there could be minimal exposure to groundwater, in general a developed farm would not be conducive to wild plant and animal growth and habitat. Therefore, these exposure pathways are not applicable to the Hanford Site Central Plateau waste sites. However, a sweat lodge using groundwater would be possible and, using the sweat lodge exposure parameters developed by Harris and Harper (2004), a sweat lodge could be a significant exposure pathway to contaminants in groundwater, with risks and hazards potentially exceeding the drinking water pathway. The estimates of sweat lodge risks as approximately an order of magnitude larger than those for drinking water shown in the example on Table 3-3, are based on a comparison of risks from vapor inhalation in a sweat lodge to risks from drinking water for the Native American sweat lodge scenario evaluated for Midnite Mine, a uranium mine in northeastern Washington State (*Midnite Mine Superfund Site Spokane Indian Reservation Washington, Record of Decision* [EPA, 2006]). As noted above for ingestion of produce, risks and hazards already exceed target health goals by a significant amount, so an increase in the amount of exposure and risk caused by addition of the sweat lodge exposure pathway would not change the conclusions of the risk assessment.

- Construction worker: At all three of the waste sites, characterization of the top 4.6 m (15 ft) was limited, with few soil samples representing that depth horizon because the shallower soil has not been impacted. Therefore, use of exposure concentrations from the deepest soil depth that construction workers likely would encounter potentially has resulted in risks that are biased high, because the majority of a construction worker's exposure would be to the shallower, uncontaminated soil.

- Future residential farmer soil concentrations: Concentrations are dependent on the size of garden over which drill cuttings would be spread. The risk calculations assumed a 100 m^2 (1,076 ft^2) garden, based on an area that likely could supply 16 percent to 49 percent (depending on whether high-end or average consumption rates are used) of the vegetables and fruit for a family of four. Larger size gardens or other types of spreading areas could result in a decrease in concentrations.

3.2.6 Risk-Based Concentrations

Although risks were calculated under both a current and a future industrial land-use scenario, as well as for a future unrestricted land-use scenario, cleanup goals and decisions generally will be based on industrial land-use exposures as being consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future, and groundwater will not be used as a drinking water source as long as institutional controls are functioning and concentrations remain above cleanup levels. For the purposes of evaluating remedial options and long-term protectiveness in this FS, risk-based concentrations (RBC) have been calculated based on a current construction worker who has 30 days of exposure to subsurface soils over one year, during a project that requires active soil disturbance.

The RBCs do not need to be calculated for every COPC at a waste site. In general, RBCs are calculated in two cases:

- The contaminant exceeds target health goals
- The contaminant does not exceed a target health goal but contributes a significant percentage to total site risks (i.e., is a concern not necessarily alone, but contributes substantially to the site's cumulative risks).

Under the current industrial land-use scenario, soil risks presented in Table 3-3 for current construction workers indicate four radionuclides: Am-241, Pu-239, Pu-240, and Cs-137 exceed 1×10^{-4} target cancer risk levels; thus, current construction worker RBCs are calculated only for those four radionuclides. In addition, because the RESRAD doses and risks depend on the site size (particularly for sites much smaller than the sizes assumed here, see Section A7.2 in Appendix A), site-specific RBCs are calculated for radionuclides in soil that are specific to the site. Therefore, site-specific RBCs were calculated for the construction worker risk drivers using site-specific information from the 216-Z-1A Tile Field (Am-241, Pu-239, Pu-240) and the 216-A-8 Crib (Cs-137). The RBCs were calculated using the RESRAD model and the same site-specific inputs and exposure assumptions for construction workers (see Attachment A-3, Tables A-2 and A-5 of Appendix A) that were used during the calculation of radionuclide risks for construction workers. Table 3-4 shows RBC values based on both a risk level of 1×10^{-4} and a target dose of 100 mrem/yr. DOE O 435.1, *Radioactive Waste Management*, establishes target dose limits of 100 mrem/yr, chronic, and 500 mrem, acute, for the inadvertent intruder (well driller). To account for uncertainty in the evaluation of the dose associated with that receptor, the chronic dose of 100 mrem/yr was used to develop RBCs for this analysis.

In contrast, EPA's *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*, OSWER Directive 9200.4-18 (EPA, 1997), states that, at CERCLA sites, PRGs should be based on the CERCLA target-risk range of 1×10^{-6} to 1×10^{-4} and not on dose. "Memorandum re: Distribution of OSWER Radiation Risk Assessment Q&A's, Final Guidance" (EPA, 1999) further states that "*...cleanup levels at CERCLA sites should be established as they would for any chemical that poses an unacceptable risk and the risks should be characterized in standard Agency risk language consistent with CERCLA guidance.*"

The EPA has recommended using target risks, rather than target doses for RBC calculations, because radionuclide cleanup criteria based on a 100 mrem/yr dose usually are less protective of human health than criteria based on a 10^{-4} lifetime risk (i.e., 10^{-4} lifetime RBCs are lower than 100 mrem/yr dose-based concentrations). However, the opposite is true when comparing a 10^{-4} annual risk to a 100 mrem/yr acute (one-year) dose for these specific radionuclides. Cleanup levels based on the 100 mrem annual dose are lower than RBCs based on a 10^{-4} annual risk. Therefore, the 100 mrem/yr target dose was selected for the RBC calculations as more health protective. Section A7.1.1 in Appendix A provides additional information on the reasons for the differences in RBCs according to whether dose or risk target health goals are used for the four radionuclides that are the key risk drivers.

The RBCs for each of the individual risk drivers were calculated to be protective of the maximum acceptable cancer-risk level of 1×10^{-4}, or the specific dose level for all three applicable pathways (i.e., combined exposures to inhalation, ingestion, and external radiation). However, combined exposures to each of the risk drivers at the RBCs could result in an exceedance of the target health goals. The RBC adjustments downwards to account for cumulative exposures are applied on a location-specific basis, because risk drivers may not all be present at the same location and the high concentrations of the risk drivers may not be collocated. Therefore, risk managers consider potential cumulative exposures to the COPCs when applying the RBCs in the evaluation of the protectiveness of various remedial alternatives.

An additional consideration in the application of these RBCs is that construction activities would be assumed to occur within the framework of existing institutional controls at the Hanford Site. Therefore, all occupational health requirements would need to be met, and any contaminated subsurface material brought to the surface during construction would require appropriate handling such that the material did not pose any health hazards to human populations other than construction workers.

3.3 SCREENING-LEVEL ECOLOGICAL RISK ASSESSMENT

A SLERA was performed for all 17 sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs following EPA/540/R-97/006, *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (Interim Final)* (ERAGS). Waste sites were considered with regard to exposure potential for plants and animals. The 17 waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are listed in Table 1-1 and described further in Appendix B.

The SLERA steps focus the assessment and determine whether the potential for risk warrants further investigation. The most critical aspect of an ecological screen is problem formulation. This is the systematic planning incorporated into the beginning of the risk-assessment process that identifies the major factors to be considered and is linked to the regulatory and policy contexts of the assessment. As established in the ecological DQOs and sampling and analysis plans for the Central Plateau, ERAGS is the regulatory context for assessing ecological risks at the Hanford Site. The DQOs are WMP-20570, *Central Plateau Terrestrial Ecological Risk Assessment Data Quality Objectives Summary Report – Phase I*; WMP-25493, *Central Plateau Terrestrial Ecological Risk Assessment Data Quality Objectives Summary Report – Phase II*; and

WMP-29253, *Central Plateau Terrestrial Ecological Risk Assessment Data Quality Objectives Summary Report – Phase III*. The sampling and analysis plans are DOE/RL-2004-42, *Central Plateau Terrestrial Ecological Sampling and Analysis Plan - Phase I*; DOE/RL-2005-30, *Central Plateau Terrestrial Ecological Sampling and Analysis Plan - Phase II*; and DOE/RL-2006-27, *Central Plateau Terrestrial Ecological Sampling and Analysis Plan – Phase III*).

Problem formulation involved reviewing relevant site records (e.g., WIDS) as a first step to assess existing data on site conditions pertinent to ecological exposure. This information was considered before the site visit was undertaken (ERAGS Step 1). As noted in ERAGS, a possible outcome of the site visit is a determination that present or future ecological impacts are negligible because complete exposure pathways do not exist. This is an important determination, and the guidance emphasizes that all sites should be evaluated by qualified personnel to determine whether this conclusion is appropriate. In accordance with this guidance, the principal authors of the Central Plateau ecological DQOs and sampling and analysis plans evaluated whether complete exposure pathways exist for the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites.

Evaluating potential exposure pathways is one of the primary tasks of the screening-level characterization of a site. For an exposure pathway to be complete, a contaminant must be able to travel from the source to ecological receptors and to be taken up by the receptors via one or more exposure routes. If an exposure pathway is not complete for a specific contaminant, the exposure pathway does not need to be evaluated further.

Exposure potential was one of the key considerations in the framework of the Central Plateau Ecological Risk Assessment study design and was considered in selecting areas for sampling and analysis. This process started with a master list of sites including all Central Plateau waste sites listed in the Tri-Party Agreement, Appendix C, as amended September 1, 2003. A query of the WIDS database was used for waste-site selection. Given the focus of the Central Plateau Ecological Risk Assessment to support remediation decisions, considerable effort went into evaluating the soil depth where cleanup is required. The *Washington Administrative Code* defines the soil cleanup depth (the standard point of compliance) as extending from the ground surface to 4.6 m (15 ft) bgs (WAC 173-340-7490[4][b], "Terrestrial Ecological Evaluation Procedures," "Point of Compliance," "Standard Point of Compliance").

Information is provided in Table 3-5 for the deeper rooted plant species and deeper burrowing mammal and ant species occurring on the Hanford Site (PNL-2774, *Characterization of the Hanford 300 Area Burial Grounds: Task IV – Biological Transport*; RHO-SA-211, *Intrusion of Radioactive Waste Burial Sites by the Great Basin Pocket Mouse (*Perognathus parvus*)*. None of the maximum depths reported for plant or animal species were greater than 3 m (10 ft), well above the 4.6 m (15-ft) interval defined for applicability of shallow-zone screening thresholds (WAC 173-340-7490[4][b]), which indicates that the pathway from deep soil to ecological receptors is incomplete. The Hanford Site-specific data indicate that the shallow-zone soil (<4.6 m [15 ft) bgs) is the primary contaminated medium of concern for ecological receptors. Waste sites were considered inaccessible to ecological receptors if the contamination was deeper than 4.6 m (15 ft) bgs or if the potential contaminant pathways to ecological receptors have been broken by man-made structural features.

Based on these considerations, the following sites are removed from further evaluation:

- 216-A-31 Crib (contamination deeper than 15 ft)
- 216-Z-3 Crib (contamination deeper than 15 ft)
- 216-Z-5 Crib (contamination deeper than 15 ft)
- 216-Z-8 French Drain (contamination deeper than 15 ft)
- 216-Z-9 Trench (contamination deeper than 15 ft, concrete pad at the surface)
- 216-Z-10 Injection/Reverse Well (contamination deeper than 15 ft)
- 216-Z-12 Crib (contamination deeper than 15 ft)
- 216-Z-18 Crib (contamination deeper than 15 ft)
- 241-Z-8 Settling Tank (waste contained in steel-lined concrete tank)
- 241-Z-361 Settling Tank (contamination deeper than 15 ft, waste contained in steel-lined concrete tank)
- UPR-200-E-56 (contamination deeper than 15 ft).

In considering the subsurface extent of plant roots or animal burrows, it is important to realize that burrow and root density are not continuous from the soil surface to the maximum reported depths; biotic activity decreases with depth. In recognition of this, the *Washington Administrative Code* allows for a conditional point of compliance to be set at the terminus of the biologically active zone (1.8 m [6 ft] (WAC-173-340-7490[4][a], "Terrestrial Ecological Evaluation Procedures," "Point of Compliance," "Conditional Point of Compliance") for sites having institutional controls in place, such as those sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The depths to which insects, animals (burrows), and plants (roots) are likely to occur define the biologically active zone. The working hypothesis is that biological activity is limited largely to the top 1.8 m (6 ft), and a conceptual model of below ground biotic activity is presented in Figure 3-6.

Empirical data on arid-adapted species offer support for the conceptual model, showing that the burrow fraction and percentage of root biomass is heavily weighted to shallow soils (Figure 3-7). "Biotic Transport of Radionuclides From A Low-Level Radioactive Waste Site" (Kennedy et al., 1985), and "Vertical Distribution of Soil Removed by Four Species of Burrowing Rodents in Disturbed and Undisturbed Soils" (Reynolds and Laundré, 1988) offer data for pocket mice, kangaroo rats, pocket gophers, and ground squirrels to illustrate how burrow density is a function of depth. Except for the kangaroo rat, these arid-adapted mammals are all Hanford Site species (PNNL-SA-32196, *Hanford Site Ecological Monitoring & Compliance*). Similar to mammalian burrow density, the below-ground mass of deeply rooting desert shrubs also is weighted toward greater density near the surface and, similar to mammalian burrow density, root mass declines with depth (Figure 3-7). In this figure, the different colors represent data on different species of plants and animals. The y-axis represents depth, and the x-axis is the fraction of burrow density or plant-root density above a given depth in the subsurface. For example, approximately 80 percent of the plant-root density is located above a depth of 30 cm (12 in.). Thus, while certain plants and animals have maximum rooting or burrowing depths many feet into the subsurface, it is clear that most of the biotic activity for these species is in the top few feet of the soil column. The animal and plant data used to generate Figure 3-7 have been published previously in WMP-20570, Appendix F.

Soil macroinvertebrates also burrow extensively in deserts. For example, some species of spiders (e.g., trap-door spiders) are known to burrow albeit shallowly (usually less than 15 cm [6 in.]), as do many species of arid-system beetles such as the ubiquitous *Eleodes spp.* and other darkling beetles. At the Hanford Site, harvester ants likely are the deepest burrowing animals occurring on the Central Plateau (PNL-2774). For this reason, harvester ants are actively managed for removal where they occur on waste sites. For example, alpha contamination was found on the soil surface at one of the sites (216-Z-9 Trench) that apparently had been brought to the surface by ants. The contamination was detected at the edge of the existing concrete pad through site surveillance. This contamination pathway was promptly mitigated by pesticide application and the installation of a biobarrier to circumvent this potential exposure pathway.

Plants rely on extensive below-ground biomass to capture nutrients and water. The extent of the rooting systems for species in the 200 Areas was evaluated in PNL-5247, *Rooting Depth and Distributions of Deep-Rooted Plants in the 200 Area Control Zone of the Hanford Site*. This study concentrated on plant species suspected of having deep-root systems and those species reported in previous studies to contain radionuclides in aboveground parts. These maximum rooting depths listed in Table 3-5 are consistent with the majority of plant species in a literature review of rooting depth by vegetation types ("Maximum Rooting Depth of Vegetation Types at the Global Scale" [Canadell et al., 1996]). This review indicates that 194 of 253 species had maximum rooting depths of 2 m (6.6 ft) or less. Deeper rooting plant species also are actively managed on waste sites. Although root depth determines whether buried waste is accessible by plants, biologically mediated contaminant transport is a function of the biomass available for transport. Consequently, the relative density of roots is more important than the absolute depth attained. As shown in Figure 3-7, only a minor percentage of roots ever reach depths greater than 1.5 m (5 ft) bgs. This is especially true for arid-adapted plants of the Central Plateau. In dry environments such as this where groundwater is inaccessible, plants must rely on meteoric water infiltration to survive, and plant roots tend to extend laterally (rather than vertically) to capture this infiltrating water.

It is important to recognize that biointrusion into subsurface sites requires above-ground conditions favoring burrowing animals and deep-rooted plants. These conditions are lacking for the majority of sites within the 200-PW-1, 200-PW-3, and 200-PW-6 OUs because of the institutional controls in place to discourage biotic access to buried waste. These controls include (1) at least an annual visual site inspection to look for evidence of subsidence or animal intrusion, (2) a surface radiological survey performed in any areas where radiation is detected, covered with soil, or posted for further action, (3) herbicide application performed several times a year to control any vegetation, and (4) pesticides applied as needed to control ants and termites.

Because of the active management practices and lack of biological activity at 1.8 m (6 ft) bgs, exposure potential to ecological receptors is not of concern for the remaining sites, because waste is buried deeper than 1.8 m (6 ft), and there are no aboveground receptors that could access the waste. These waste sites include the following:

- 216-A-7 Crib
- 216-A-8 Crib
- 216-A-24 Crib
- 216-Z-1 Crib

- 216-Z-2 Crib
- 216-Z-1A Tile Field.

In summary, a combination of factors contribute to ruling out the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites from further consideration of potential ecological risk, including: waste buried deeper than plants and animals can access, physical barriers preventing exposure, lack of habitat to support receptors capable of waste biointrusion and an active management program to preclude the establishment of deeply rooted/burrowing. Appendix B provides a summary table identifying the key characteristics of each of the 17 waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs with respect to the likelihood of exposure potential to ecological receptors. Appendix B also provides brief summaries of each of the sites based on data reported in WIDS.

3.4 EVALUATION OF GROUNDWATER PROTECTION

This section summarizes the methodology and results of the evaluation of COPCs that may migrate through the vadose zone into groundwater. The details and additional discussion of the methodology are provided in Appendix E.

3.4.1 Rationale for Evaluation

The NCP (40 CFR 300) requires that a baseline risk assessment be conducted to "characterize the current and potential threats to human health and the environment" (40 CFR 300.430(d)(4), "Remedial Investigation"). The environment is defined in the NCP as "the navigable waters, the waters of the contiguous zone, and the ocean waters of which the natural resources are under the exclusive management authority of the United States under the *Magnusen-Stevens Fishery Conservation and Management Act of 1996*; and any other surface water, ground water, drinking water supply, land surface or subsurface strata, or ambient air within the United States or under jurisdiction of the United States" (40 CFR 300.5, "Definitions"). The baseline risk assessments performed for CERCLA sites generally conform to EPA/540/1-89/002, 1989, *Risk Assessment Guidance for Superfund (RAGS), Volume I -- Human Health Evaluation Manual, (Part A) Interim Final,* OSWER 9285.7-01A, and EPA/630/R-95/022F, *Final Guidelines for Ecological Risk Assessment, Risk Assessment Forum.* These documents focus on human health and ecological risk and do not specifically address protection of groundwater from potential future impacts from vadose-zone sources. Currently, no CERCLA guidance document is available that specifically addresses risk-assessment criteria and methods to assess the protection of groundwater from potential future impacts from vadose-zone sources. Additionally, EPA and Ecology have the expectation that remedial actions will be protective of groundwater and that DOE will take the steps necessary to prevent further degradation of groundwater (DOE/RL-2002-59, *Hanford Site Groundwater Strategy: Protection, Monitoring, and Remediation*).

3.4.2 Migration To Groundwater Methodology

The summary of human-health risks for the COPCs identified for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs in the RI Report is presented in Section 3.2. To evaluate potential future human-health concerns in groundwater from the 200-PW-1, 200-PW-3, and 200-PW-6 OUs COPCs, *all* of the contaminants detected in soil during investigations of the six representative and unique waste sites for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs were evaluated.

The following methods were used to evaluate whether the current COPC concentrations at the six waste sites could continue to migrate to groundwater in concentrations that exceed MCLs. The details and additional discussion of the methodology are provided in Appendix E.

1. An initial screening of COPCs for potential migration to groundwater was performed by comparing the maximum concentration of a chemical or radionuclide detected in soil to an EPA soil-screening level. The EPA soil-screening levels are generic risk-based migration-to-groundwater screening levels developed to assess the potential for contaminants to reach groundwater at concentrations above a human-health target-level MCL or a drinking-water human-health screening level. If the maximum soil contaminant concentration did not exceed the soil-screening level, then the contaminant was not carried forward as a COC for the protection of groundwater.

2. If the maximum concentration exceeded the soil-screening level, then further evaluation was conducted as to whether the contaminant exceeded a natural background level and whether its frequency of detection and frequency and magnitude of exceedance over screening levels warranted inclusion as a COC for the migration to groundwater pathway (EPA/540/1-89/002), using the following additional evaluation steps.

    a. **Comparison of maximum detected contaminant concentrations to site background levels.** The maximum concentrations of inorganics and radionuclides were compared to Hanford Site-specific background values (DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, and DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*). Inorganics and radionuclides were eliminated from selection as a COC if their maximum concentrations did not exceed these site-specific background values. In addition, if the maximum concentration exceeded background, but was within two times the background level, and exceedances above background were detected in less than 5 percent of the soil samples analyzed for the contaminant, then the constituent was eliminated as a COC because it likely was present at background levels.

    b. **Evaluation of the frequency of detection.** The EPA generally allows constituents detected in less than 5 percent of the data to be eliminated from risk assessment, even if a health-based screening level is exceeded (EPA/540/1-89/002). Therefore, contaminants that were detected in less than 5 percent of samples in which the contaminant was analyzed for were eliminated as COCs.

c. **Evaluation of evidence for eliminating COPCs that do not significantly contribute to overall site risks.** EPA guidance (EPA/540/1-89/002) allows further reduction in the number of constituents carried through the risk assessment, as long as the rationale is clearly documented and the constituents contributing 99 percent of the risk have been identified. Therefore, in addition to frequency of detection, the frequency of exceedance of concentrations above the screening level and the magnitude of exceedance over the screening value also were evaluated.

d. The screening process outlined above yielded the COPCs for protection of groundwater shown in Table 3-6. No COPCs for the protection of groundwater were identified for the 241-Z-361 Settling Tank and the 216-Z-10 Injection/Reverse Well. Because of the conservative and simplifying assumptions used to calculate the generic screening levels for the migration to groundwater pathway (see Appendix E), an exceedance of a screening level does not necessarily mean that a threat to groundwater is present, but rather that more evaluation is needed. Therefore, the contaminants identified in Table 3-6 as COPCs for protection of groundwater were evaluated further as described below.

3. The COPCs shown in Table 3-6 further were evaluated using fate and transport models. To evaluate the migration to groundwater pathway for the radionuclides listed in Table 3-7, RESRAD Version 6.3 (ANL, 2005) was used. To evaluate potential impacts to groundwater from the nonradionuclide COPCs listed in Table 3-6, the fate and transport model RESRAD-CHEM was used (ANL/EA/CP-79679, "RESRAD-CHEM: A Computer Code for Chemical Risk Assessment," and ANL/EA/CP-86614, "Applying RESRAD-CHEM for Chemical Risk Assessment"). A detailed discussion of the rationale for selecting these models, model parameters, and modeling methodology is provided in Appendix E.

3.4.3 Contaminants of Concern for Potential Migration to Groundwater

Based on the methodology described above, the following COCs were identified as having the potential to migrate to groundwater Table 3-7):

- 216-Z-9 Trench: CCl_4, hexachloroethane, and PCE.
- 216-A-8 Crib: Tc-99 (only detected at significant concentration in one soil sample [79.6 pCi/g at 5.8 to 6.5 m {19 to 21.5 ft} bgs])
- 216-Z-1A Tile Field: CCl_4 (although not identified in RI soil samples, the current SVE system continues to remove kilogram quantities of carbon tetrachloride from the vadose zone annually, suggesting that migration to groundwater is possible)
- 216-Z-8 French Drain: none identified

- 241-Z-361 Settling Tank: none identified
- 216-Z-10 Injection/Reverse Well: none identified.

The COCs for the protection of groundwater are addressed as part of the evaluation of remedial alternatives for the representative and unique waste sites (see Chapters 5.0 and 6.0).

Nitrate was evaluated for the potential to impact groundwater, based on data collected from Boreholes C3426 and C3427, drilled for the RI at the 216-Z-9 Trench. The potential to impact groundwater initially was based on detected nitrate concentrations in soil above background and on the fact that no EPA soil-screening level is available for nitrate.

However, the nitrate concentrations in soil at the 216-Z-9 Trench are unlikely to represent a threat to groundwater, for the following reasons.

- Nitrate was not identified as a COC in groundwater for the 200-ZP-1 Groundwater OU. Nitrate within the 200-ZP-1 Groundwater OU is part of a larger site-wide nitrate groundwater contamination issue at the Hanford Site. Concentrations of nitrate within the 200-ZP-1 Groundwater OU have been detected above the maximum contaminant level. Nitrate in groundwater beneath the 200-ZP-1 Groundwater OU is expected to be captured by the preferred remedial alternative (pump-and-treat system) for that OU.

- Drinking nitrate in groundwater was not a significant health hazard at the 90th percentile groundwater concentration that was calculated in the baseline risk assessment. The 90th percentile nitrate concentrations in groundwater resulted in a hazard index of only 3 for young children drinking the water (see Table A5-9 in Appendix A); therefore, nitrate was not selected as a COC in groundwater. In comparison, the 90th percentile concentration for carbon tetrachloride resulted in a hazard index of over 300.

- Nitrate does not bioaccumulate and is not a hazard via food-chain pathways (see Table A3-5 in Appendix A).

- Nitrate concentrations in groundwater are unlikely to be higher in the future than they are for current conditions; therefore, future groundwater concentrations will not pose an unacceptable risk, because current groundwater concentrations were not identified as an unacceptable risk. Nitrate was released to the soil column at various waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs during past relatively large wastewater releases (e.g., at the 216-Z-1A Tile Field, 216-Z-9 Trench). Liquid discharges to these waste sites ended 38 and 45 years ago, respectively. The current soil-moisture conditions beneath the 216-Z-9 Trench are relatively low (generally less than 10 percent moisture) and no future wastewater discharge will occur at these past-practice waste sites. Therefore, any future transport to groundwater from current nitrate concentrations in soil is expected to be significantly less than in the past, when significant quantities of discharged wastewater provided the driving mechanism for migration of contaminants through the vadose zone into groundwater.

Therefore, nitrate was not carried forward as a COC for the protection of groundwater

3.5 CONTAMINANTS OF CONCERN

The COPCs identified in the RI Report (DOE/RL-2006-51) underwent additional assessment as part of the baseline risk assessment (described in Section 3.2). The risk assessment process compared contaminant concentrations, appropriate radiological risk and dose limits, and risk-based cleanup standards through computed modeling and/or screening. Only those constituents that exceeded one or more of these criteria and were not removed by further evaluation were retained as COCs.

The SLERA that was conducted for all 17 waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs ruled out further consideration of these sites with regard to ecological risk potential (see Section 3.3 and Appendix B).

The 200-ZP-1 Groundwater OU underlies the 200-PW-1 and 200-PW-6 OUs. The 200-PO-1 Groundwater OU underlies the 200-PW-3 OU. To evaluate future potential threats to the underlying groundwater, an evaluation was conducted of the COPCs that may migrate through the vadose zone and impact groundwater in concentrations that exceed MCLs. The methodology and results of this evaluation are discussed in Section 3.4 and Appendix E.

The risk-assessment and groundwater-protection evaluation identified COCs for the representative and unique waste sites, as shown in the following table (2 pages).

Contaminants of Concern for Representative and Unique Waste Sites.

Waste Site	Risk Receptor				
	Industrial Site Construction Worker	**Ecological Risk**	**Future Well Driller**	**Future Residential Farmer**	**Groundwater Protection**
216-Z-1A Tile Field	Am-241, Pu-239/240	None identified	None identified	Am-241, Pu-239/240	CCl_4 [a]
216-Z-8 French Drain	None identified	None identified	None identified	None identified	None identified
216-Z-9 Trench	Am-241, Pu-239/240 [b]	None identified	None identified	Am-241, Pu-239/240	CCl_4 Hexachloroethane Tetrachloroethylene
216-Z-10 Injection/Reverse Well	None identified	None identified	None identified	None identified	None identified
241-Z-361 Settling Tank [c]	None identified	None identified	None identified	None identified	None identified

Contaminants of Concern for Representative and Unique Waste Sites.

Waste Site	Risk Receptor				
	Industrial Site Construction Worker	Ecological Risk	Future Well Driller	Future Residential Farmer	Groundwater Protection
216-A-8 Crib	Cs-137	None identified	None identified	Cs-137	Tc-99 [d]

"None identified" – The CERCLA risk assessment process did not identify any condition that would result in unacceptable levels of risk to human health or the environment.

[a] Although not identified in remedial investigation soil samples, soil-vapor recovery activities continue to remove kilogram quantities of carbon tetrachloride from the vadose zone annually, suggesting that migration to groundwater is possible.

[b] Not identified as contaminants of concern for site construction worker, but best management practice warrants a more substantial form of physical separation from the contaminated soil.

[c] Contaminants of concern were not identified for this site, because there has been no identified release to the environment.

[d] Technetium-99 was identified at significant concentrations in only one soil sample (79.6 pCi/g at 5.8 to 6.5 m [19 to 21.5 ft] bgs). Pending confirmatory soil sampling, the preferred alternative will mitigate the potential future impacts that this contaminant may have on groundwater beneath the waste site.

Section 2.5 provides additional detail on the nature and extent of the COCs in these waste sites.

It is necessary to determine which COCs are principal threat contaminants and which are low-level threat contaminants. This determination is important in determining how the remedial alternatives presented in Chapter 5.0 are formulated. In general, principal threat wastes are those source materials considered to be highly toxic or highly mobile or which generally cannot be contained in a reliable manner or would present a significant risk to human health and the environment, should exposure occur (40 CFR 300.430[a]). "EPA expects to use treatment to address the principal threats posed by a site, wherever practicable." (40 CFR 300.430[a][1][iii][A], "Introduction," "Expectations"). Conversely, low-level threat wastes are those source materials that generally can be reliably contained and that would represent only a low risk in the event of exposure.

Using data from the baseline risk assessment, the analysis in Appendix E of the fate and transport of the COPCs, and the nature and extent of contamination at the waste sites, the COCs were classified as either principal-threat or low-level-threat contaminants. The principal-threat contaminants for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs include CCl_4, Pu-239/240, Cs-137 and Am-241 because of the risks posed by these contaminants (as a function of toxicity, contaminant mass, and mobility) and the mass of contaminants present at the various waste sites. Remedial alternatives developed in Chapter 5.0 address the potential treatment and containment of these COCs. The remaining COCs will be addressed as low-level threat contaminants. The low-level threat COCs will be cooperatively contained or treated during the remediation of principal-threat contaminants.

Although no COCs were identified for the 241-Z-361 Settling Tank, because there has been no identified release to the environment, the potential for future releases warrants remedial action of the remaining tank contents. The significant risk posed by exposure to the remaining tank

contents is the basis for considering the Pu-239/240 and Am-241 in the sludge remaining in this tank as principal-threat contaminants.

Based on these COCs, RAOs will be developed to provide a basis for evaluating the capability of specific remedial alternatives to achieve compliance with ARARs and/or an intended level of risk protection for human health or the environment.

3.6 POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The ARARs identification process is based on CERCLA guidance (EPA/540/G-89/006, *CERCLA Compliance with Other Laws Manual: Interim Final*, and RI/FS guidance in EPA/540/G-89/004. Section 121 of CERCLA, as amended, requires, in part, that any ARAR standard, requirement, criterion, or limitation promulgated under any Federal environmental law, or any more stringent state requirement promulgated pursuant to a state environmental statute, be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain on site after completion of remedial action.

"Applicable" means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than Federal requirements may be applicable.

"Relevant and appropriate" requirements means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than Federal requirements may be relevant and appropriate. In evaluating the relevance and appropriateness of a requirement, the eight comparison factors in 40 CFR 300.400(g)(2), "Identification of Applicable or Relevant and Appropriate Requirements," are considered:

i. The purpose of the requirement and the purpose of the CERCLA action

ii. The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site

iii. The substances regulated by the requirement and the substances found at the CERCLA site

iv. The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site

v. Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the CERCLA site

vi. The type of place regulated and the type of place affected by the release or CERCLA action

vii. The type and size of structure or facility regulated and the type and size of structure or facility affected by the release or contemplated by the CERCLA action

viii. Any consideration of use or potential use of affected resources in the requirement and the use or potential use of the affected resource at the CERCLA site.

In addition, potential ARARs were evaluated to determine if they fall into one of three categories: chemical-specific, location-specific, or action-specific. These categories are defined as follows.

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of public- and worker-safety levels and site-cleanup levels.

- Location-specific requirements are restrictions placed on the concentration of dangerous substances or the conduct of activities solely because they occur in special geographic areas.

- Action-specific requirements are usually technology- or activity-based requirements or limitations triggered by the remedial actions performed at the site.

In summary, a requirement is applicable if the specific terms or jurisdictional prerequisites of the law or regulations directly address the circumstances at a site. If not applicable, a requirement may nevertheless be relevant and appropriate if (1) circumstances at the site are, based on best professional judgment, sufficiently similar to the problems or situations regulated by the requirement and (2) the requirement's use is well suited to the site. Only the substantive requirements (e.g., use of control/containment equipment, compliance with numerical standards) associated with ARARs apply to CERCLA on-site activities. The ARARs associated with administrative requirements, such as permitting, are not applicable to CERCLA on-site activities (CERCLA, Section 121[e][1]). In general, this CERCLA permitting exemption will be extended to all remedial and corrective action activities conducted at the 200-PW-1, 200-PW-3, and 200-PW-6 OUs.

"To be considered" information is nonpromulgated advisories or guidance issued by Federal or state governments that is not legally binding and does not have the status of potential ARARs. In some circumstances, to-be-considered information will be considered along with ARARs in determining the remedial action necessary for protection of human health and the environment. To-be-considered information complements the ARARs in determining protectiveness at a site or implementation of certain actions. For example, because soil-cleanup standards do not exist for all contaminants, the health advisories, which would be to-be-considered information, may be helpful in defining appropriate remedial-action goals.

Potential Federal and state ARARs are presented in Appendix C. The chemical-specific ARARs likely to be most relevant and appropriate to remediation of the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are Federal regulations that implement the drinking water standards (40 CFR 141, "National Primary Drinking Water Regulations") used in this FS report for protection-of-groundwater evaluation.

Action-specific ARARs that could be pertinent to remediation are state solid and dangerous waste regulations (for management of characterization and remediation of wastes and performance standards for waste left in place). For radionuclides, DOE O 435.1 is to-be-considered information.

Waste Streams

Regarding waste-management activities during remediation, a variety of waste streams may be generated under the preferred remedial-action alternatives. It is anticipated that most of the waste will be designated as low-level waste. However, quantities of dangerous or mixed waste, polychlorinated biphenyl-contaminated waste, and asbestos and asbestos-containing material also could be generated. The great majority of the waste will be in a solid form.

- The identification, storage, treatment, and disposal of hazardous waste and the hazardous component of mixed waste generated during the remedial action would be subject to the substantive provisions of RCRA. In the State of Washington, RCRA is implemented through WAC 173-303, "Dangerous Waste Regulations," which is an EPA-authorized state RCRA program. The substantive portions of the dangerous-waste standards for generation and storage would apply to the management of any dangerous or mixed waste generated during this remedial action. Treatment standards for dangerous or mixed waste that is subject to RCRA land-disposal restrictions are specified in WAC 173-303-140, "Land Disposal Restrictions," which incorporates 40 CFR 268, "Land Disposal Restrictions," by reference.

- The *Toxic Substances Control Act of 1976* and regulations at 40 CFR 761, "Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions," govern the management and disposal of polychlorinated biphenyl wastes. The *Toxic Substances Control Act of 1976* regulations contain specific provisions for polychlorinated biphenyl waste, including polychlorinated biphenyl waste that contains a radioactive component. Polychlorinated biphenyls also are considered underlying hazardous constituents under RCRA and thus could be subject to WAC 173-303 and 40 CFR 268 requirements for wastes that also designate as hazardous or mixed wastes.

- Removal and disposal of asbestos and asbestos-containing material are regulated under the *Clean Air Act of 1990*, and 40 CFR 61, Subpart M, "National Emission Standards for Asbestos." These regulations provide for special precautions to prevent environmental releases or exposure to personnel of airborne emissions of asbestos fibers during remedial actions. Packaging requirements are identified in 40 CFR 61.52, "Emission Standard." Asbestos and asbestos-containing material would be removed, packaged as appropriate, and disposed of in ERDF.

Waste designated as low-level waste that meets ERDF waste-acceptance criteria is assumed to be disposed of at ERDF, which is engineered to meet the appropriate performance standards of 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste." In addition, waste designated as dangerous or mixed waste would be treated as appropriate to meet land-disposal restrictions and ERDF acceptance criteria, and would be disposed of at ERDF. ERDF is engineered to meet minimum technical requirements for landfills under WAC 173-303-665, "Landfills." Applicable packaging and pretransportation requirements for dangerous or mixed waste generated at the 200-PW-1, 200-PW-3, and 200-PW-6 OUs would be identified and implemented before any waste was moved. Alternate disposal locations may be considered when the remedial action occurs, if a suitable and cost-effective location is identified. Any potential alternate disposal location will be evaluated for appropriate performance standards to ensure that it is adequately protective of human health and the environment.

Waste designated as transuranic will be stored at the Central Waste Complex (CWC), with eventual disposal at a geologic repository such as the Waste Isolation Pilot Plant (WIPP).

Waste designated as polychlorinated biphenyl remediation waste likely would be disposed of at ERDF, depending on whether it is low-level waste and meets the waste-acceptance criteria. Polychlorinated biphenyl waste that does not meet ERDF waste-acceptance criteria would be retained at a polychlorinated biphenyl storage area that meets the requirements for *Toxic Substances Control Act of 1976* storage and would be transported for future treatment and disposal at an appropriate disposal facility.

CERCLA Section 104(d)(4) states that where two or more noncontiguous facilities are reasonably related on the basis of geography, or on the basis of the threat or potential threat to the public health or welfare or the environment, the facilities can be treated as one for purposes of CERCLA response actions. Consistent with this, the 200-PW-1, 200-PW-3, and 200-PW-6 OUs and ERDF would be considered to be onsite for purposes of Section 104 of CERCLA, and waste may be transferred between the facilities without a permit being required.

All alternative actions will be performed in compliance with the waste-management ARARs. Waste streams will be evaluated, designated, and managed in compliance with the ARAR requirements. Before disposal, waste will be managed in a protective manner to prevent releases to the environment or unnecessary exposure to personnel.

Airborne Emissions

The proposed remedial-action alternatives have the potential to generate airborne emissions of both radioactive and criteria/toxic pollutants.

RCW 70.94, "Washington Clean Air Act," requires regulation of radioactive air pollutants. The state implementing regulation WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides," sets standards that are as stringent as or more so than the Federal standards under the *Clean Air Act of 1990*, and under the Federal implementing regulation, 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities." The state standards protect the public by conservatively establishing exposure standards applicable to the maximally exposed public individual, be that individual real or hypothetical. To that end, the standards address any member

of the public at the point of maximum annual air concentration in an unrestricted area where any member of the public may be. Radionuclide airborne emissions from the facility are not to exceed amounts that would cause an exposure to any said member of the public of greater than 10 mrem/yr effective dose equivalent. The state implementing regulation WAC 246-247, "Radiation Protection – Air Emissions," which adopts the WAC 173-480 standards and 40 CFR 61, Subpart H, requires verification of compliance with the 10 mrem/yr standard and would be applicable to the remedial action.

WAC 246-247 further addresses emission sources that emit radioactive airborne emissions by requiring monitoring of such sources. Such monitoring requires physical measurement of the effluent or ambient air. The substantive provisions of WAC 246-247 that require monitoring of radioactive airborne emissions would be applicable to the remedial action.

The above state implementing regulations further address control of radioactive airborne emissions where economically and technologically feasible (WAC 246-247-040[3] and -040[4], "General Standards," and associated definitions. To address the substantive aspect of these requirements, best or reasonably achieved control technology will be addressed by ensuring that applicable emission-control technologies (those successfully operated in similar applications) will be used when economically and technologically feasible (i.e., based on cost/benefit). If it is determined that there are substantive aspects of the requirement for control of radioactive airborne emissions, then controls will be administered as appropriate using reasonable and effective methods.

The Federal implementing regulations also contain requirements for managing asbestos material associated with demolition and waste disposal (40 CFR 61, Subpart M).

3.7 REMEDIAL-ACTION OBJECTIVES

The RAOs are descriptions of what the remedial action is expected to accomplish (i.e., medium-specific or site-specific goals for protecting human health and the environment). They are defined as specifically as possible and usually address the following variables:

- Media of interest (e.g., contaminated soil, groundwater)
- Types of contaminants (e.g., radionuclides, inorganic and organic chemicals)
- Potential receptors (e.g., humans, animals, plants)
- Possible exposure pathways (e.g., external radiation, ingestion)
- Levels of residual contaminants that may remain following remediation (i.e., contaminant levels below cleanup standards or below a range of levels for different exposure routes).

The RAOs provide a basis for evaluating the capability of a specific remediation alternative to achieve compliance with potential ARARs and/or an intended level of risk protection for human health or the environment. The RAOs specific to the 200 Areas for soils, solid wastes, and groundwater were developed in the Implementation Plan (DOE/RL-98-28). Specific RAOs for

this FS were defined based on the RME model scenarios developed in the risk assessment, the risk-assessment results, fate and transport of contaminants, and projected land uses for the 200 Areas. The RAOs for this FS are further discussed in the following subsections.

3.7.1 Remedial-Action Objective 1

RAO 1 - Prevent unacceptable risk to human health from direct contact with COCs in the soil within 4.6 m (15 ft) of the ground surface. Unacceptable risks are (1) an excess lifetime cancer risk greater than 1 in 10,000 (1×10^{-4}) or (2) a dose exceeding 100 mrem/yr, consistent with an industrial land-use scenario. With respect to this RAO, the COCs include Am-241 and Pu-239/240 at the 200-PW-1 OU and 200-PW-6 OU waste sites and Cs-137 at the 200-PW-3 OU waste sites.

RAO 1 will be achieved by preventing industrial-site construction workers from direct contact with soils containing radionuclide COC concentrations above RBCs that would exceed an excess lifetime cancer risk greater than 1×10^{-4} or a dose exceeding 100 mrem/yr. The RBCs for these COCs are listed in Table 3-4. In addition, RAO 1 can be achieved by maintaining at least 4.6 m (15 ft) of separation between the ground surface and soils exceeding the RBCs for these COCs.

3.7.2 Remedial-Action Objective 2

RAO 2 - Prevent migration of COCs to groundwater in concentrations that exceed MCLs. With respect to this RAO, the COCs include carbon tetrachloride, hexachloroethane, and PCE at the 200-PW-1 OU waste sites and Tc-99 at the 200-PW-3 OU waste sites.

RAO 2 is achieved by preventing or reducing migration of these COCs through the soil column to groundwater such that concentrations reaching groundwater do not exceed MCLs under 40 CFR 141 or the groundwater cleanup levels that are established for these COCs in the 200-ZP-1 and 200-PO-1 Groundwater OUs.

3.8 PRELIMINARY REMEDIATION GOALS

The PRGs (i.e., cleanup levels) are numeric representations of the RAOs. Using the anticipated future land use, the conceptual exposure model, and the RAOs as a basis, the PRGs are identified for applicable contaminants and exposure pathways. The PRGs are used to define unacceptable risk posed by specific contaminants, provide target cleanup goals for use during remedial design, and provide guidance during remediation. They are based on acceptable levels of human health and ecological risk, ARARs, to-be-considered guidance, and remediation timeframes. The remediation goals will be used to assess the effectiveness of the identified preferred alternative in meeting the RAOs. Final RAOs are developed from the PRGs and are specified in a ROD that selects the remedial alternative for the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites.

Typically, PRGs are identified for individual hazardous substances identified as COCs. If multiple contaminants are present at a site, the suitability of using individual PRGs as final cleanup values protective of human health and the environment is evaluated based on

site-specific information and the potential for contaminant interaction. Meeting these PRGs, the potential ARARs (and by extension, achieving RAOs) can be accomplished by reducing concentrations (or activities) of contaminants to remediation-goal levels or by eliminating potential exposure pathways/routes.

Contaminant-specific PRGs for soils are presented numerically as concentrations (milligrams per kilogram or micrograms per kilogram) or radioactivity (picocuries per gram). The PRGs for soil COCs are developed based on risks to the industrial-site construction worker from the 200-PW-1, 200-PW-3, and 200-PW-6 OU waste sites that were identified from the risk assessment, and on the groundwater-protection evaluation as discussed in the following subsections. Interim remedial measures at several 200-PW-1 OU waste sites have reduced some of the identified potential risks, and continued remedial actions are expected to prevent future risk.

3.8.1 Construction-Worker Preliminary Remediation Goals

3.8.1.1 Radioactive Contaminants

The waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are within the boundaries of the industrial-exclusive land-use area described in DOE/EIS-0222-F. The future land use within the Core Zone is designated as industrial (exclusive), as described in Section 3.1. Therefore, the PRGs were calculated based on RBCs for an industrial-site construction worker for the soil COCs (Am-241, Pu-239/240, and Cs-137). The PRGs were calculated for these COCs that could be present in soil above a depth of 4.6 m (15 ft) and could be protective of the maximum acceptable cancer risk level of 1×10^{-4}, or the target dose level of 100 mrem/yr for all three applicable pathways for the construction worker (i.e., combined exposures to inhalation, ingestion, and external radiation). Discussion of the calculation details for the PRGs (RBCs) is provided Section 3.2.6 and Appendix A. The PRGs for radioactive COCs in soil for construction workers are shown in Table 3-4.

3.8.1.2 Nonradionuclide Contaminants

No risks above 1×10^{-4} were identified for construction workers from nonradioactive contaminants. Therefore, no PRGs were developed for nonradioactive contaminants for the construction-worker pathway.

3.8.2 Protection of Groundwater Preliminary Remediation Goals

The following subsections describe the PRGs for protection of groundwater for radioactive and nonradioactive contamination for human receptors.

3.8.2.1 Radionuclide Contaminants

Protection of groundwater for the 200-PW-1, 200-PW-3, and 200-PW-6 OU representative and unique waste sites was evaluated for the COPCs (and associated parent radionuclides and daughter products) as discussed in Section 3.4 and Appendix E. The evaluation included fate-and-transport modeling using RESRAD (ANL, 2005), as summarized in Appendix E. The

only radionuclide identified as a COCs for the protection of groundwater was Tc-99 at the 216-A-8 Crib.

Because Tc-99 was only identified at significant concentrations in one soil sample (79.6 pCi/g at 5.8 to 6.5 m [19 to 21.5 ft] bgs) at the 218-A-8 Crib, and the modeling of the potential transport to groundwater was based on conservative assumptions, confirmatory soil sampling is needed to confirm the concentrations and mass of Tc-99 that are present at this crib. As part of the remedial design of the selected remedy for this crib, the evaluation of a PRG for Tc-99 will be completed. The evaluation will include whether the remaining mass of Tc-99 poses a potential threat to groundwater, consideration of the final selected remedy, and performance criteria for the selected remedy.

3.8.2.2 Nonradionuclide Contamination

The protection of groundwater evaluation identified CCl_4 as a COC along with hexachloroethane and PCE, because they also are VOCs. The evaluation included fate and transport modeling using RESRAD-CHEM to calculate the concentration of CCl_4 that could be left in-place in the source area that would not impact groundwater (i.e., be protective of groundwater) above the MCL of 5 µg/L. Calculation details are provided in Appendix E. A concentration of 1 mg/kg was calculated as the concentration of CCl_4 in the source area that would be protective of groundwater.

However, the remediation goal for organic COCs will be developed during remedial design and remedy implementation to demonstrate that the migration to groundwater pathway has been mitigated. The final performance criteria will be selected during the remedial-design phase, and the assessment of the performance criteria and achievement of the RAOs will be conducted as part of the required CERCLA 5-year reviews.

As part of the remedy for soil contaminated with organics, SVE is proposed for the 200-PW-1 OU waste sites. The SVE system has been used as an expedited response action at three of the 200-PW-1 OU waste sites. Between April 1991 (when the pilot test was conducted) and September 2006, 78,884 kg (173,900 lb) of carbon tetrachloride have been removed from the vadose zone with the SVE system. Carbon tetrachloride concentrations in the extracted soil vapor have decreased significantly at the three sites during operation of the SVE system. Initial carbon tetrachloride concentrations in extracted soil vapor were approximately 30,000 ppmv at the 216-Z-9 Trench well field and 1,500 ppmv at the 216-Z-1A Tile Field/216-Z-18 Crib well field. In contrast, concentrations in extracted soil vapor were approximately 21 ppmv at the 216-Z-9 Trench well field in September 2006 and 10 ppmv at the 216-Z-1A Tile Field/216-Z-18 Crib well field in July 2006. The mass of carbon tetrachloride extracted each year by the SVE system also continues to decline. From 1991 through 1997, approximately 74,851 kg (165,000 lb) were removed. In comparison, from fiscal year 1998 through fiscal year 2006 only 4,033 kg (8,900 lb) were removed (SGW-33746).

The SVE system proposed as part of the final remedy for organics at the 200-PW-1 OU waste sites will be operated until performance metrics demonstrate that the migration to groundwater pathway has been mitigated and the system should be shut down. The implementation, performance monitoring, and end point of the selected vadose-zone remedy for the

200-PW-1 OU waste sites must be linked to what is technically practicable for remediating the carbon tetrachloride in groundwater as part of the 200-ZP-1 Groundwater OU remedy. The selected remedies for CCl_4 in the vadose zone and underlying groundwater will need to be implemented together and to have compatible remediation goals so that transfer of CCl_4 between the two media is minimized.

Performance metrics for the SVE system will be developed as part of the remedial design and remedy implementation and are likely to include measurements or calculations of soil-vapor concentration, vapor-moisture content, vapor-oxygen concentration, vapor-carbon dioxide concentration, yearly mass extracted, yearly soil-vapor rebound concentrations, and other appropriate measurements or calculations. These calculations and measurements will be compared to fate-and-transport modeling conditions that demonstrate that any residual contamination that may exist once the system is shut down does not pose a threat to the groundwater. These metrics are expected to be analyzed to evaluate total mass removed over time, vadose-zone volume treated, potential human-health risks from remaining mass (e.g., migration to groundwater), and calculations of cost per unit mass removed. Once the system is shut down, long-term monitoring will be continued to ensure that conditions remain as expected and that future migration of CCl_4 to groundwater is not occurring.

3.8.3 Preliminary Remediation Goals for Protection of Ecological Resources

The SLERA that was conducted for all 17 waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs ruled out further consideration of these sites with regard to ecological-risk potential (see Section 3.3 and Appendix B). Therefore, no PRGs were developed for protection of ecological resources.

Figure 3-1. Location of the Industrial (Exclusive) Land-Use Area.

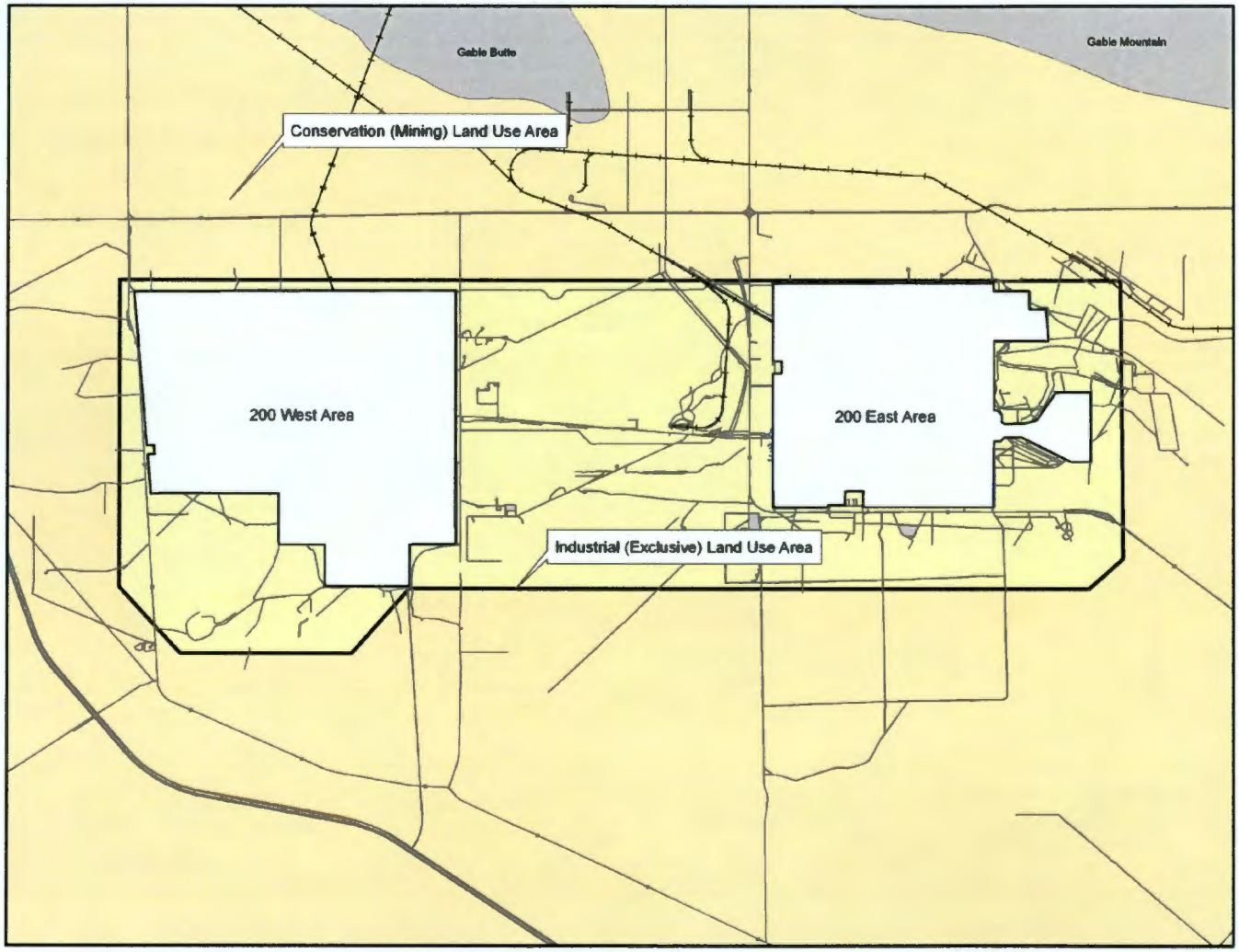


Figure 3-2. Present Human-Health Conceptual Site Model Depicting the Populations and Exposure Pathways Evaluated in the Risk Assessment Under a Current Industrial Land-Use Scenario.

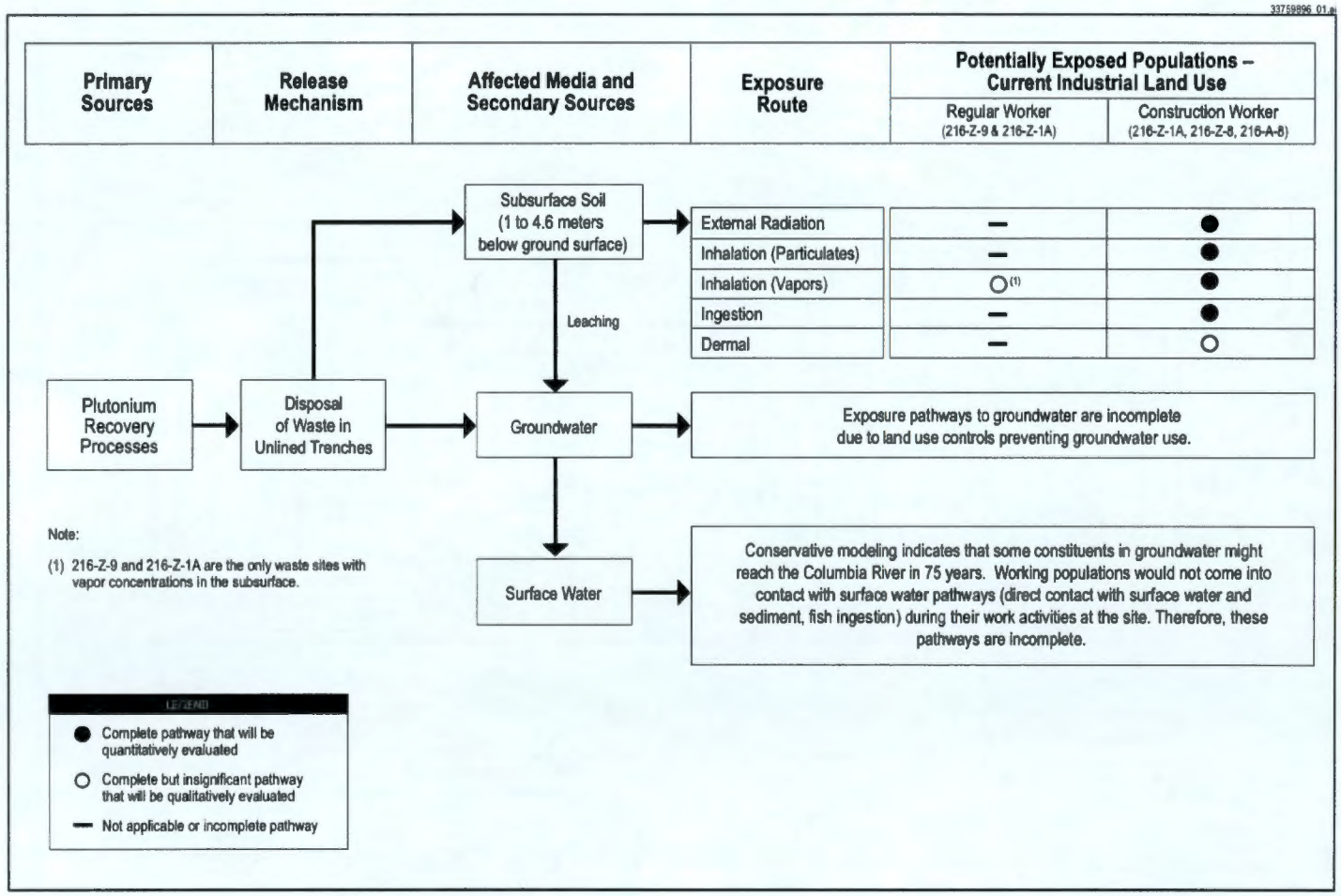


Figure 3-3. Present Human-Health Conceptual Site Model Depicting the Populations and Exposure Pathways Evaluated in the Risk Assessment Under a Future Unrestricted Land-Use Scenario.

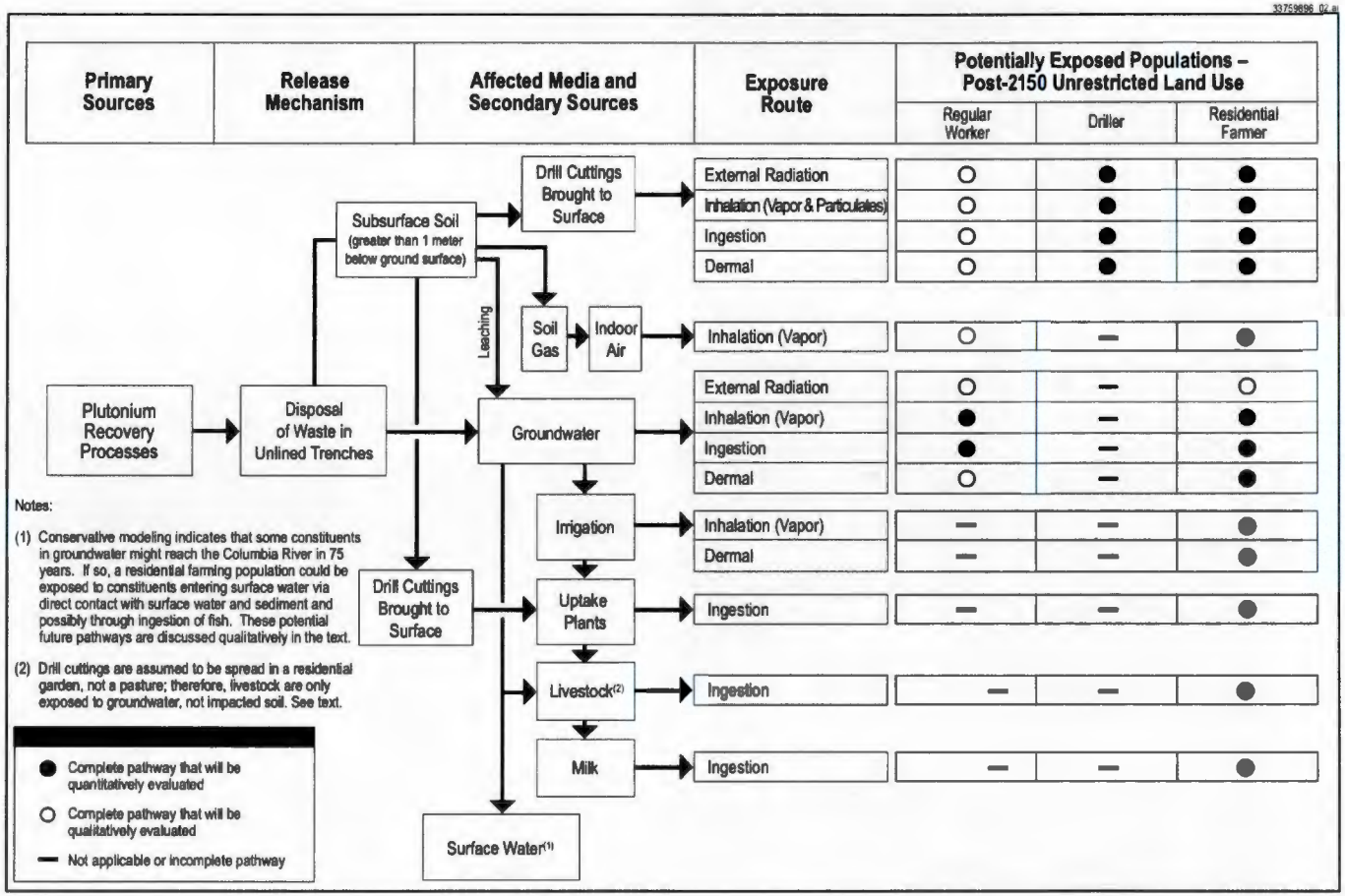


Figure 3-4. Decrease in Cancer Risks Over Time, Residential Farmer at the 216-Z-9 Trench.

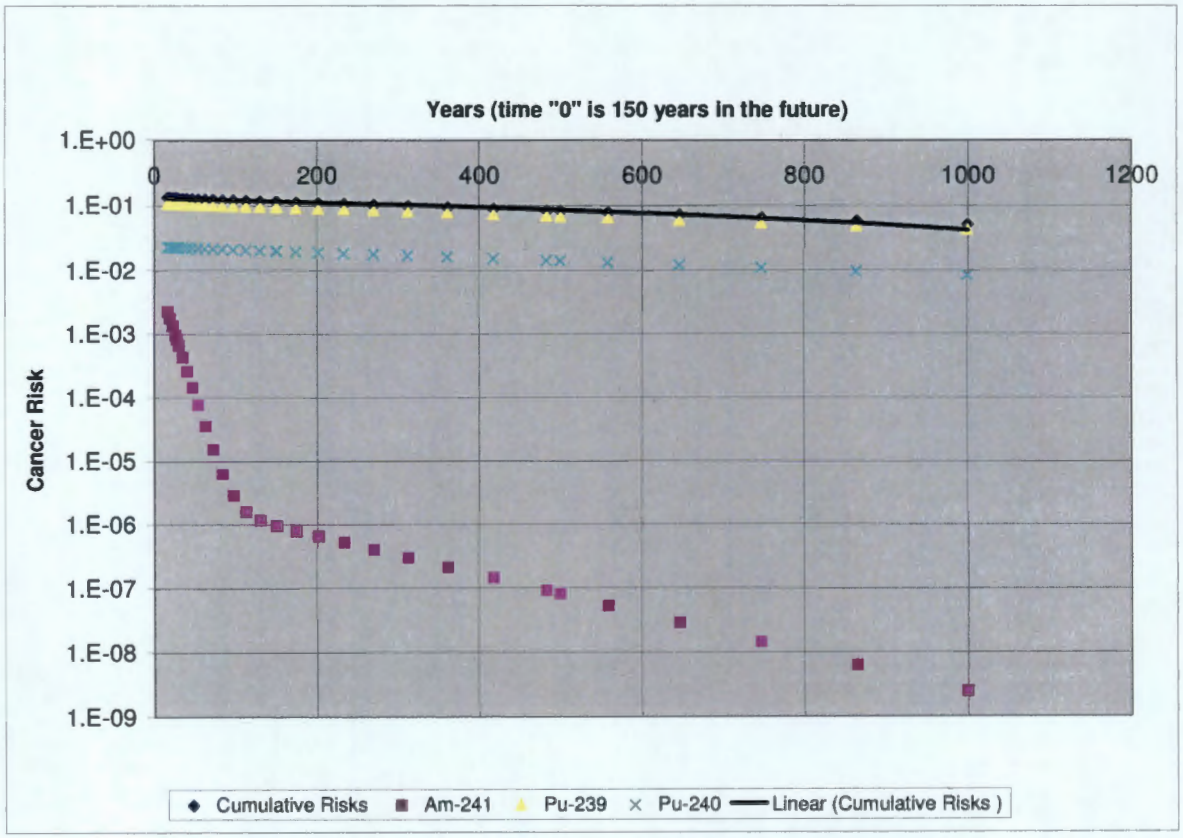


Figure 3-5. Decrease in Cancer Risk Over Time, Residential Farmer 216-A-8.

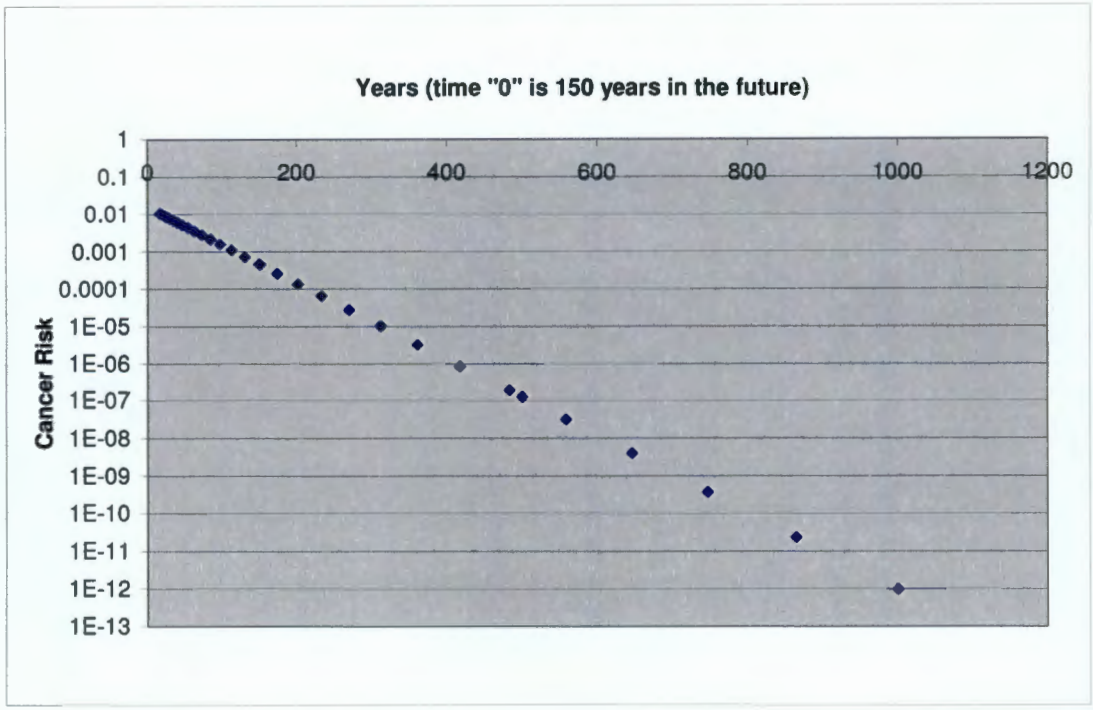


Figure 3-6. Conceptual Model of Biotic Activity in Soil.

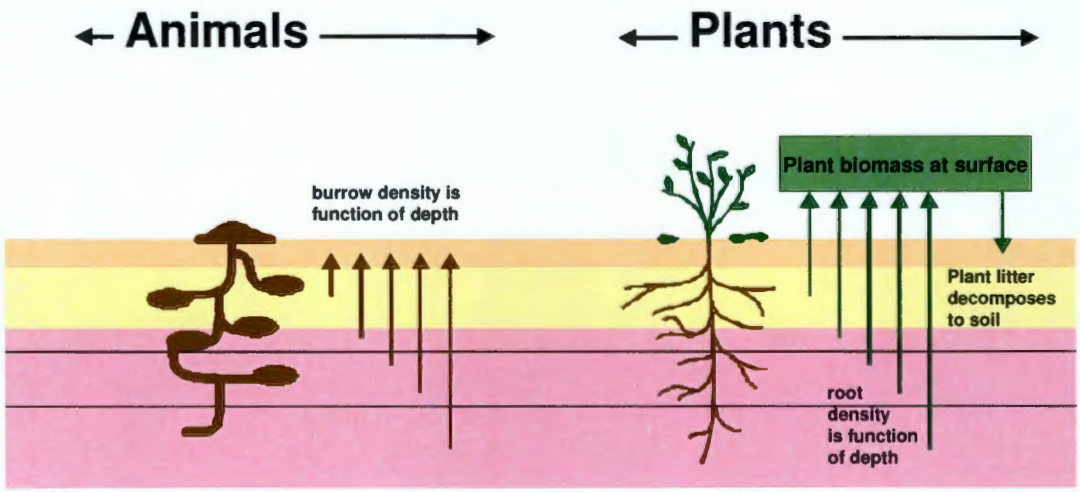
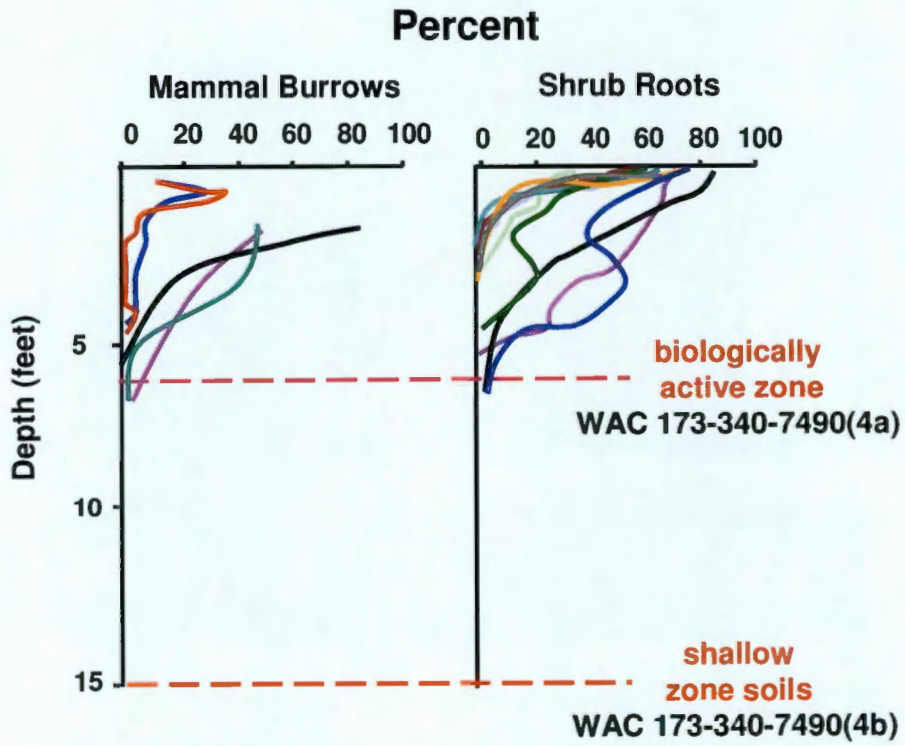


Figure 3-7. Fraction of Burrow and Root Density versus Depth Below the Ground Surface.



NOTE: Colored lines represent data on mammal burrow density for pocket gophers, pocket mice, kangaroo rats, and Townsend's ground squirrel. Plant-root density is represented by white bursage, annual bursage, basin big sagebrush, four-winged saltbush, shadescale saltbush, blackbrush, Nevada jointfir, rubber rabbitbrush, range ratany, creosote bush, Anderson's wolfberry, and rabbit thorn.

Table 3-1. Summary of Exposure-Point Concentrations for Soil. (2 Pages)

Contaminant of Potential Concern	Construction Worker Exposure-Point Concentrations Current Concentrations	Future Well Driller Exposure-Point Concentrations 150 Years in the Future	Future Residential Farmer Exposure-Point Concentrations 150 years in the future	Units
216-Z-1A Tile Field				
Americium-241	2028358	29037	10609	pCi/g
Plutonium-239	12637125	183471	67035	pCi/g
Plutonium-240	2872074	41236	15066	pCi/g
216-Z-8 French Drain				
Americium-241	457	17.64	6.2	pCi/g
Plutonium-238	77.5	0.0012	0.58	pCi/g
Plutonium-239	3764.44	259.89	91.28	pCi/g
Plutonium-240	855.56	58.41	20.52	pCi/g
216-Z-9 Trench				
Americium-241	--	80156	28152	pCi/g
Cadmium	--	8.12	2.85	mg/kg
Carbon tetrachloride (CCl_4)	--	36.07	12.67	mg/kg
Europium-152	--	0.012	0.003888	pCi/g
Manganese	--	267.78	94.05	mg/kg
Neptunium-237	--	41.6	14.61	pCi/g
Nickel-63	--	289.39	101.64	pCi/g
Plutonium-238	--	319.72	112.29	pCi/g
Plutonium-239	--	2634617	925331	pCi/g
Plutonium-240	--	570882	200505	pCi/g
Protactinium-231	--	4.54	1.59	pCi/g
Radium-226	--	6.17	2.17	pCi/g
Radium-228	--	6.98 E-08	2.45 E-08	pCi/g
Strontium-90	--	0.13	0.05	pCi/g
Technetium-99	--	1.33 E-06	4.68 E-07	pCi/g
Thorium-228	--	1.0 E-07	3.52 E-08	pCi/g
Thorium-230	--	6.95	2.44	pCi/g
216-A-8 Crib				
Carbon-14	--	--	2.02 E-36	pCi/g
Cesium-137	877000	1557.87	625.32	pCi/g
Neptunium-237	3.53	0.67	0.27	pCi/g
Plutonium-239	45.39	4.62	1.85	pCi/g
Plutonium-240	10.31	1.04	0.42	pCi/g
Radium-228	1.1	1.12 E-06	4.51 E-07	pCi/g
Technetium-99	--	--	1.40 E-12	pCi/g

Table 3-1. Summary of Exposure-Point Concentrations for Soil. (2 Pages)

Contaminant of Potential Concern	Construction Worker Exposure-Point Concentrations Current Concentrations	Future Well Driller Exposure-Point Concentrations 150 Years in the Future	Future Residential Farmer Exposure-Point Concentrations 150 years in the future	Units
Thallium	--	--	0.19	mg/kg
Thorium-228	0.699	1.68 E-06	6.76 E-07	pCi/g

-- Not a contaminant of potential concern for workers at this site. Note: construction workers were not evaluated at the 216-Z-9 Trench because of the depth of impacted soil materials and the existing concrete cover.

Table 3-2. Summary of Risks From Soil. (2 Pages)

Radionuclide or Contaminant	Current Construction Worker (Soil)	Future Well Driller (Soil)	Future Residential Farmer	
			Soil	Produce (a)
216-Z-1A Tile Field				
Am-241	4 E-03	3 E-06	1 E-04	3 E-04
Np-237 (b)	--	--	6 E-06	6 E-07
Pu-239	3 E-02	5 E-07	1 E-03	7 E-03
Pu-240	6 E-03	1 E-07	2 E-04	2 E-03
Total (c)	4 E-02	3 E-06	2 E-03	9 E-03
216-Z-8 French Drain				
Am-241	1 E-07	2 E-09	2 E-08	2 E-07
Pu-238	1 E-08	4 E-12	7 E-09	5 E-08
Pu-239	7 E-07	7 E-10	2 E-06	9 E-06
Pu-240	1 E-07	2 E-10	3 E-07	2 E-06
Total (c)	9 E-07	2 E-09	3 E-06	1 E-05
216-Z-9 Trench				
Ac-227 (b)	Construction Worker not evaluated at 216-Z-9 (d)	--	1 E-05	6 E-07
Am-241		7 E-06	4 E-03	8 E-04
Eu-152		1 E-10	1 E-07	3 E-11
Ni-63		4 E-12	7 E-09	2 E-06
Np-237		7 E-08	2 E-04	1 E-05
Pa-231 (b)		--	2 E-06	1 E-06
Pb-210 (b)		--	6 E-07	3 E-05
Pu-238		8 E-10	2 E-06	1 E-05
Pu-239		7 E-06	2 E-02	9 E-02
Pu-240		2 E-06	3 E-03	2 E-02
Ra-226		8 E-08	2 E-04	2 E-05
Ra-228		5 E-16	3 E-13	2 E-13

Table 3-2. Summary of Risks From Soil. (2 Pages)

Radionuclide or Contaminant	Current Construction Worker (Soil)	Future Well Driller (Soil)	Future Residential Farmer	
			Soil	Produce (a)
Sr-90	Construction Worker not evaluated at 216-Z-9 (d)	5 E-12	5 E-09	3 E-07
Tc-99		6 E-21	1 E-18	1 E-14
Th-228		1 E-15	9 E-13	3 E-15
Th-230		3 E-11	5 E-08	2 E-07
U-235 (b)		--	8 E-07	1 E-08
Radionuclide Total (c)		2 E-05	3 E-02	1 E-01
Cadmium		1 E-12	1 E-09	--
Carbon tetrachloride (CCl_4)		2 E-06	5 E-05	1 E-03
Chemical Total (c)		2 E-06	5 E-05	1 E-03
216-A-8 Crib				
C-14	--	--	6 E-16	6 E-16
Cs-137	5 E-02	7 E-06	2 E-02	4 E-04
Np-237	7 E-08	1 E-09	3 E-06	3 E-07
Pu-239	1 E-07	1 E-11	3 E-08	2 E-07
Pu-240	2 E-08	3 E-12	6 E-09	4 E-08
Ra-228	1 E-07	8 E-15	6 E-12	3 E-12
Tc-99	--	--	4 E-24	3 E-20
Th-228	1 E-07	2 E-14	2 E-11	5 E-14
Total (c)	5 E-02	7 E-06	2 E-02	4 E-04
Total - 500 years	7 E-07	4 E-11	2 E-06	2 E-07
Total – 1,000 years	2 E-07	3 E-13	1 E-06	9 E-08

(a) Produce grown in impacted soil is the only food chain evaluated for soil.
(b) This radionuclide was not on the original contaminants of potential concern list, but is included here because it is a daughter product with risk greater than 1×10^{-7}.
(c) Totals are based on unrounded risk values.
(d) Construction worker risks were not quantified at the 216-Z-9 Trench because of the depth to impacted soil and the concrete cover over the site. However, based on the americium and plutonium isotope concentrations in the soils immediately beneath the bottom of the 216-Z-9 Trench, if construction workers ever were to be exposed to that soil, risks likely would exceed the construction worker risks seen at the 216-Z-1A Tile Field and would be above 1×10^{-4}.
-- : indicates incomplete pathway or not applicable (e.g., not a contaminant of potential concern for this receptor).

Table 3-3. Comparison of Residential Farmer Exposure Factors with Tribal Subsistence Exposure Factors.

Exposure Pathway	Residential Farmer (Soil at the 216-Z-9 Trench; 90th Percentile Groundwater)		Tribal Exposures (Intake Rates from Harris & Harper, 2004)	
	Intake Rate	Risk	Intake Rate	Risk[b]
Drinking Groundwater	2 L/day, 30 years	2 E-02	4 L/day, 70 years	8 E-02
Soil Exposure				
incidental ingestion	200 mg/day (child – 6 yrs); 100 mg/day (adult – 24 yrs)	2 E-02	400 mg/day (child & adult – 70 years)	2 E-01
inhalation	20 m^3/day, 30 years	2 E-04	30 m^3/day, 70 years	7 E-04
external radiation	30 yrs	1 E-02	70 yrs	2 E-02
Produce Ingestion	16% - 49% home grown[a], 30 years	1 E-01	Not stated, up to 100%, 70 years	3 E-01
Sweat Lodge *(inhalation of vapor)*	not evaluated for residential farmer		estimated	4 E-01
Total Cancer Risks:		2 E-01		9 E-01

[a] Produce (fruits and vegetables) ingestion rates used in the risk-assessment calculation are 16% of total per capita consumption rates for high-end consumers (95th percentile) and are 49% of total per capita average consumption rates from EPA/600/R-05/062F, *Analysis of Total Food Intake and Composition of Individual's Diet Based on USDA's 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII).*

[b] These values should be considered screening-level values and may not capture every difference between a residential-farming and a Tribal-risk scenario.

Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways.*

Table 3-4. Summary of Soil Risk-Based Concentrations for Current Construction-Worker Exposures.

Risk Driver	RBC, Based on a Target Annual Risk of 1×10^{-4} (pCi/g)	RBC, Based on Target Dose of 100 mrem/yr (pCi/g)
Americium-241	45,000	2,510
Plutonium-239	50,000	2,650
Plutonium-240	50,000	2,650
Cesium-137	1,600	1,220

pCi/g = picocurie per gram.
RBC = risk-based concentration.

Table 3-5. Maximum Plant-Rooting and Burrowing Depth for Hanford Site Receptors.

Species	Maximum Depth		Reference
	(cm)	(ft)	
Plants			
Antelope bitterbrush	300	9.8	PNL-5247
Big Sagebrush	200	6.6	PNL-5247
Spiny hopsage	195	6.4	PNL-5247
Russian thistle	172	5.6	PNL-5247
Mammals			
Great Basin pocket mouse	200	6.6	RHO-SA-211
Soil Biota			
Harvester ants	270	8.8	PNL-2774

PNL-2774, *Characterization of the Hanford 300 Area Burial Grounds: Task IV – Biological Transport.*

PNL-5247, *Rooting Depth and Distributions of Deep-Rooted Plants in the 200 Area Control Zone of the Hanford Site.*

RHO-SA-211, *Intrusion of Radioactive Waste Burial Sites by the Great Basin Pocket Mouse (*Perognathus parvus*).*

Table 3-6. Contaminants of Potential Concern for Migration to Groundwater.

Migration to Groundwater Contaminant of Potential Concern	Representative or Unique Waste Site			
	216-A-8 Crib	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench
Radionuclides				
Americium-241		√	√	√
Carbon-14	√			
Cesium-137	√			
Europium-152				√
Neptunium-237	√			√
Nickel-63				√
Plutonium-238			√	√
Plutonium-239/240	√	√	√	√
Protactinium-231				√
Radium-228	√			√
Strontium-90				√
Technetium-99	√			√
Thorium-230				√
Uranium-234				√
Metals				
Cadmium				√
Manganese				√
Chromium				√
Volatile Organic Compounds				
Carbon Tetrachloride (CCl_4)				√
Hexachloroethane				√
Methylene Chloride				√
Tetrachloroethylene				√
Inorganics				
Nitrate		√		√

(1) √ = Identified COPC for potential impact to groundwater

Table 3-7. Contaminants of Concern for Migration to Groundwater.

Migration to Groundwater Contaminants of Concern	Representative Waste Site	
	216-A-8 Crib	216-Z-9 Trench
Radionuclides		
Technetium-99	√	
Volatile Organic Compounds		
Carbon tetrachloride (CCl_4)		√
Hexachloroethane		√
Tetrachloroethylene		√

√ = identified contaminant of concern for potential impact to groundwater.

4.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

A primary objective of this FS Report is to identify remedial technologies and process options that meet the RAOs for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs, and then combine them into a range of remedial alternatives for further evaluation. This chapter of the FS report discusses the technology selection process.

The potential remedial technologies are selected for evaluation based on their ability to mitigate the identified risks or achieve compliance with the potential ARARs that are ARAR to the remedial action. Those selected for evaluation are assessed with respect to their implementability, effectiveness, and relative cost in accordance with EPA guidance (*The Feasibility Study: Development and Screening of Remedial Action Alternatives*, OSWER 9355.3-01FS3, Fact Sheet [EPA, 1989]; EPA/540/G-89/004); and the NCP (40 CFR 300.430[e], "Remedial Investigation/Feasibility Study and Selection of Remedy," "Feasibility Study").

CERCLA requires development and evaluation of a range of responses, including a no-action alternative, to ensure that an appropriate remedy is identified and selected. The selected final remedy must comply with ARARs and must protect human health and the environment. The technology-screening process consists of a series of steps that include the following:

- Identify GRAs that may meet RAOs, either individually or in combination with other GRAs
- Identify, screen, and evaluate remedial-technology types for each GRA
- Select one or more representative process options for each technology type.

Following the technology screening, the representative process options are assembled into remedial alternatives (in Chapter 5.0) that are evaluated further in the detailed and comparative analyses of alternatives (in Chapters 6.0 and 7.0, respectively).

4.1 GENERAL-RESPONSE ACTIONS

The GRAs describe those actions that will satisfy the RAOs. The RAOs for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs are identified in Chapter 3.0. Briefly, they are to (1) prevent unacceptable risk (greater than 1×10^{-4} excess lifetime cancer risk or a dose exceeding 100 mrem/yr for the industrial land-use scenario) to human health from direct contact with COCs in the soil within 4.6 m (15 ft) of the ground surface, and (2) prevent migration of COCs to groundwater in concentrations that exceed MCLs. Five GRAs, listed below, were selected to implement the RAOs:

- No action – baseline GRA required by CERCLA
- Institutional controls – to mitigate risk by controlling access to, and use of, the contaminated sites

- Containment – to mitigate risks by physically inhibiting direct contact with contaminants, and by controlling migration of contaminants
- Removal of contaminated media, treatment as necessary, and disposal – to mitigate risks by excavating contaminated media, treating it as necessary, and disposing of it
- In situ treatment of contaminated media – to mitigate risks by treating contaminated media in place to reduce contaminant toxicity, mobility, or volume.

4.2 TECHNOLOGIES

The GRAs and potential implementing technologies were first addressed in the Implementation Plan (DOE/RL-98-28). The document provided an initial framework to guide the RIs in the 200 Areas and documented a preliminary screening of remedial technologies appropriate to the contaminants, media, and conditions found in the arid environment in the 200 Areas (Appendix D, Sections D5.0 to D5.6, and Table D-1 of the Implementation Plan).

This section discusses subsequent evaluation of remedial technologies, which focused more specifically on the contaminants and conditions encountered at the 200-PW-1, 200-PW-3, and 200-PW-6 OU representative waste sites, and the associated risks. In accordance with CERCLA guidance, technologies were evaluated based on their effectiveness, implementability, and relative cost.

Where currently available site-characterization data are not sufficient to determine whether a specific technology has application, or do not support meaningful assessment of a promising technology, that technology may be carried forward as a "supplementary technology." This approach is intended to allow pre-ROD scrutiny of the technology and its potential application by the public and regulators. The expectation is that this approach will facilitate post-ROD evaluation and, where appropriate, implementation of the technology without significant revision to the ROD.

4.2.1 Screening of Remedial Technologies Based on Risk-Assessment Results

The potential remedial technologies retained in the Implementation Plan were reviewed based on the contaminant distribution models presented in the RI Report (DOE/RL-2006-51). A search was conducted to identify new and emerging remedial technologies. The list of technologies retained through that activity was subjected to a final screening, based on the results of the baseline risk assessment (Section 3.2 and Appendix A). The technologies were screened based on their effectiveness, implementability, and relative cost. Technology screening results are summarized in Table 4-1. Retained remedial technologies and associated process options are listed in Table 4-2 and discussed in the following sections.

An earlier study (DOE/RL-2003-52, *Tank 241-Z-361 Engineering Evaluation/Cost Analysis*) assessed sludge removal and stabilization technologies for the 241-Z-361 Settling Tank. The

technologies recommended in that document were reviewed to assess the need for changes in implementability and relative cost and are discussed in Section 4.2.2.5.6.

4.2.2 Summary of Remedial Technologies and Process Options

The following sections describe the remedial technologies, grouped by the GRA they implement. Although the no-action response, institutional controls, and monitored natural attenuation (MNA) are not technologies, they are discussed here because they constitute potential response actions.

4.2.2.1 No Action

The NCP (40 CFR 300) requires that a no-action alternative be evaluated as a baseline for comparison with other alternatives. This alternative proposes that the site be left as it is, with no need for additional remedial activities, monitoring, or access restrictions. The no-action alternative does not preclude nonremedial activities, and the EPA (1989) specifically allows environmental monitoring as part of a no-action response. At the Hanford Site, this would be implemented as a component of the site-wide environmental monitoring program. That program has administrative controls that would trigger appropriate responses if monitoring were to indicate conditions contrary to the RAOs.

4.2.2.2 Institutional Controls

Institutional controls are restrictions imposed on land use to prevent or reduce exposure to hazardous wastes or hazardous constituents. They are intended to act as a barrier, to separate the public from levels of contamination that exceed acceptable health risks. Restrictions may include land-use restrictions, natural-resource use restrictions, well-restriction areas, deed restrictions, deed notices, declaration of environmental restrictions, access controls, monitoring requirements, site-posting requirements, information distribution, notification in closure letter, restrictive covenants, and Federal/state/county/local registries. These activities are implemented at the Hanford Site through DOE/RL-2001-41, *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions*.

The use of an institutional control to meet a performance standard must include a mechanism to ensure its maintenance for protectiveness over time, or until exposure to hazardous substances would no longer result in unacceptable risks. Only certain types of institutional controls have such mechanisms (e.g., easements, zoning, use restrictions). Institutional controls that do not have these mechanisms require alternatives for maintaining protectiveness.

Operations at the Hanford Site are expected to terminate in approximately 2050, and active institutional controls are assumed for approximately another 100 years following the termination of operations. Effective passive institutional controls will be designed to provide protection for at least 500 years, which is the time period stated in EPA/ROD/R10-95/100.

4.2.2.3 Containment

This section discusses technologies intended to mitigate risk by blocking potential exposure pathways. These include technologies that inhibit direct contact with contaminants or that control migration of the contaminants. The discussion includes arid-climate engineered surface barriers, intrusion barriers, vertical subsurface barriers, and dry-air (soil-desiccation) barriers.

4.2.2.3.1 Arid-Climate Engineered Surface Barrier

Engineered surface barriers are constructed over waste sites to control the amount of precipitation that infiltrates into contaminated media, thereby reducing the potential for migration of contaminants to groundwater. They also may serve as impediments to intrusion by potential human and ecological receptors. To be considered as viable remedies, engineered surface barriers must be maintained. Therefore, in addition to environmental monitoring, barriers may require administratively controlled long-term operations and maintenance programs that include surveillance and monitoring, to ensure their physical integrity and functionality. Surface barriers address all contaminants and all representative waste sites by controlling infiltration of water (typically precipitation) from the ground surface into the contaminated media. Several types of barriers were considered that incorporate an evapotranspiration (ET) process into their design, including a Hanford-like barrier design and monofill and capillary-break ET barriers (EPA/542/F-03/015, *Evapotranspiration Landfill Cover Systems Fact Sheet*).

An ET barrier concept was chosen as the primary surface-barrier technology for the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The functional components of an ET barrier are soil(s) and vegetation. Barrier soils retain infiltrating water primarily by absorption until plant transpiration and evaporation from the near surface can return it to the atmosphere. Engineered fill typically is emplaced before barrier construction is begun to provide a stable foundation. The uppermost portion of the barrier typically includes materials (e.g., pea gravel) to impede erosion.

The ET barriers are effective in semiarid and arid environments, where precipitation is limited and ET potential is high. Water-balance studies at the Hanford Site have shown that vegetation and soil type are the primary factors that control the downward movement of precipitation, and for finer grained soils with a healthy plant cover of shrubs and grasses, net recharge is close to zero (PNNL-14702, *Vadose Zone Hydrogeology Data Package for the 2004 Composite Analysis*).

The Hanford-type barrier was screened out early in this evaluation. Relative to the other technologies, the complexities in design and construction place it last with respect to implementability and cost.

The monofill and capillary-break ET barriers are a type of modified RCRA barrier. For the purposes of the FS, the monofill and capillary-break barriers will be considered, and design and construction complexities can be addressed during the remedial-design process.

Monofill Evapotranspiration Barriers

Monofill ET barriers use a single layer of a uniform soil type, covered with native vegetation, to control infiltration. The only design parameter that can be varied to achieve functional requirements is the thickness of the soil layer(s) and the presence or absence of a bio-barrier. As a result, when designed to meet the same performance criteria, monofill ET barriers tend to be thicker than capillary-break ET barriers. All ET barriers typically include an upper layer intended to limit erosion.

A monofill barrier consisting of a pea-gravel/silt-loam surface layer overlaying the silt-loam layer has been designed for use at the Hanford Site (Figure 4-1). The thickness of the barrier has been designed to eliminate downward flux from precipitation from some plausible extreme events or conditions. The barrier sits atop an engineered fill base that has a minimum thickness of 51 cm (20 in), and has side slopes with a 3:1 slope constructed from soil-filled basalt (8 to 20 cm [3 to 8 in.] of basalt) that is 30 cm (12 in) thick. The surface is planted with native sagebrush and rabbitbrush as well as native bunchgrasses.

Relative advantages of the monofill ET barrier include simplicity in design and construction, demonstrated effectiveness in arid and semiarid climates, and relatively low cost. Additionally, because this type of barrier does not rely on structural features to control infiltration, it is not as likely to be compromised by differential settlement, subsidence, or seismic events. This is an especially important consideration for barriers intended to last for hundreds of years. In addition, because monofill ET barriers tend to be thicker, they provide additional separation between residual contaminated media and potential human and ecological receptors.

Barrier design establishes specific side-slope requirements to ensure slope stability and barrier integrity. Generally, monofill ET barriers, because of their relatively greater thickness, will have a larger footprint than thinner, multilayer barriers, so they may be more likely to encroach on adjacent sites, facilities, or infrastructure.

Capillary Evapotranspiration Barriers

For this FS report, a capillary ET barrier consists of a fine-grained soil layer placed atop a relatively coarse-grained soil layer, depicted in Figure 4-2. The distinct textural interface between the two soil layers creates a capillary break, which functionally increases the water-holding capacity of the fine-grained soil, and produces relatively low moisture conditions in the coarse-grained soil. Alternatively, the barrier can incorporate a synthetic membrane as the structural feature that inhibits vertical flow of infiltrating water. Again, the barrier will be constructed atop a layer of engineered fill material, and the upper potion of the top soil layer will incorporate pea gravel to control erosion.

By increasing the water-holding capacity of the fine-grained soil, it is possible to achieve the same functional requirements with a thinner, fine-grained soil layer (relative to the thickness of the soil layer in a comparable monofill ET barrier). More of the infiltrated water is held within the near-surface evaporative regime and within the root zone of the more shallow-rooted plants. In addition, the low-moisture conditions in the coarse-grained soil may limit biointrusion and maximize root retention in the fine-grained layer.

The structural interface between the fine-and coarse-grained soil layers is a critical functional component of capillary ET barriers. This interface can be compromised locally by differential settling, subsidence, and seismic events. This vulnerability must be taken into consideration during design and construction. Another potential issue with capillary and monofill barriers is water flow between the two contrasting soil layers and the resultant potential for moisture discharges near or at the toe slope of the barrier. Some form of water routing (e.g., subsurface french drains) may need to be incorporated into the final barrier design.

Capillary ET barriers are thinner than comparable monofill ET barriers and will have a smaller footprint, so they are less likely to encroach on adjacent sites, facilities, and infrastructure.

4.2.2.3.2 Intrusion Barrier

An intrusion barrier inhibits direct contact with residual contaminated media and helps to mitigate radiation exposures to an inadvertent intruder to meet the RAOs. Protection can be achieved by establishing and maintaining sufficient depth of cover or by incorporating structural components that provide an equivalent level of protection. Two types of intrusion barriers are considered here. The simplest is controlled-density fill (CDF). The second, referred to here as an intrusion-prevention feature (IPF), is more robust. Intrusion barriers are considered for sites where shallow contaminants pose a direct-contact risk to potential human and ecological receptors, and existing cover materials or the planned infiltration barrier may not be sufficient to mitigate the targeted risk.

Controlled-Density Fill

Typically, CDF is a blend of cement, fly ash, sand, and water, usually employed as a low-strength, flowable backfilling material. Because it is flowable, self-leveling, and self-compacting, it can be deployed in situations where physical-access restrictions may preclude other backfilling options. Formulation can be varied to modify several parameters, including compressive strength and excavatability (difficulty encountered when excavating or drilling into the material). Like cement, it also can be dyed, an application that is employed as a visual warning in CDF that is used to backfill underground utility trenches. CDF can be formulated to make intrusion difficult, but not impossible. Application of CDF would rely equally on its anomalous appearance (with respect to typical soils in the area) to alert an inadvertent intruder. A reasonable person who excavated or drilled into the subsurface and encountered CDF would realize that they had encountered abnormal subsurface conditions.

Intrusion-Prevention Feature

The actual design of the IPF, if used, will be determined in the remedial-design phase. For the purposes of the FS report, the IPF carried forward for evaluation is a coarse, fractured-basalt layer, overlain by gravel and sand layers intended to prevent overlying fine-grained material from settling into the void spaces of the basalt layer. When the coarse basalt is encountered during drilling, it causes sudden, noticeable, undesirable changes in drilling conditions that would alert a reasonable person to the presence of abnormal conditions. The basalt is difficult to excavate or burrow through and, because the void spaces do not retain moisture, it will discourage plant-root penetration.

Both CDF and the IPF are carried forward as containment technologies targeting direct-contact risks to human and environmental receptors.

4.2.2.3.3 Vertical Subsurface Barriers (Slurry Walls and Grout Curtains)

Slurry walls and grout curtains were retained in the Implementation Plan (DOE/RL-98-28). Both have potential application in the vadose zone to limit the horizontal movement of moisture into contaminated materials or to limit the horizontal migration of contaminants. A slurry wall is a nonstructural underground wall, constructed by placing a cement-bentonite mixture into a trench excavated to the desired depth. Formulation of the slurry can be varied to effect permeability, durability, and compatibility with site soils and contaminants. Grout curtains are formed by injecting grout, under pressure, directly into the soil matrix (permeation grouting) or in conjunction with drilling (jet grouting) at regularly spaced intervals to form a continuous low permeability wall. If the grout is injected vertically, like the slurry wall, it forms a continuous low-permeability barrier to the horizontal movement of moisture and contaminants.

Neither technology will be effective as a stand-alone technology to mitigate identified risks. However, they are retained as supplementary technologies for situations where it is necessary or desirable to limit the lateral extent of an engineered surface barrier.

4.2.2.3.4 Dry-Air Barrier (Soil Desiccation)

Drying vadose-zone soils by injecting dry air and extracting soil moisture at SVE wells reduces the hydraulic drive for downward transport of contaminants. When implemented in conjunction with surface controls to prevent further precipitation infiltration, soil desiccation has the potential to significantly reduce the migration of vadose-zone contaminants to groundwater. However, it is not intended as a very long-lived (hundreds of years) barrier.

It also may be used to supplement other technologies. By removing moisture from the soil-pore space, it may improve access to residual contaminants and enhance volatilization of VOCs. It also would support capture of VOC vapors generated by other remedial technologies, by creating preferential flow paths for the vapors. Additionally, injection of heated air, a process option, may further enhance volatilization and accelerate abiotic degradation. These supplemental applications are unproven and would require treatability testing.

The construction and operation of air-injection wells and air-supply blowers generally is proven and is relatively easy to implement. Capital and operating costs are well defined. Soil desiccation is retained for further consideration at sites where a threat to groundwater is identified.

4.2.2.4 Excavation

Excavation employs earthmoving equipment to remove contaminated media from the site, thereby reducing site-specific long-term risks. In combination with appropriate treatment and disposition options, it can be used to reduce residual risk to acceptable levels, achieve PRGs and compliance with ARARs, eliminate the need for long-term maintenance at the site, and most likely reduce the level of long-term environmental monitoring required. Excavation is most practical at sites with shallow contamination; depth of the excavation typically is up to 7.6 m

(25 ft). Deeper excavations require larger footprints because of the need to maintain safe side slopes, which makes them less practical and more likely to encroach on adjacent sites, facilities, and infrastructure.

Earthmoving equipment is used to remove clean overburden, which can be staged for later use in backfilling, and to remove contaminated media and stage it for appropriate waste-management activities. Removal technologies do not require that the extent of contamination be precisely known before excavation. Rather, characterization can occur as the excavation proceeds, and the extent of contamination can be determined using an observational approach. Contaminated media typically are removed in lifts (layers of uniform thickness) to allow screening for contamination. Field screening supports waste designation and helps determine when remedial goals are achieved.

Potential limitations associated with excavation include the following.

- Handling of contaminated media could pose significant short-term exposure risks to workers, the public, and the environment.
- Side-slope angles to maintain slope stability result in significant lateral expansion of the excavation as depth increases and may encroach on other waste sites, facilities, or infrastructure. (Note: Shoring can be used in some instances to limit the lateral extent of excavation, but this adds to costs.)
- Disturbance of natural and cultural resources may occur.

Contaminated soil removal with disposal at ERDF has been the preferred alternative for waste sites in the 100 Areas and 300 Area and has been demonstrated to be effective at the Hanford Site. Given the same type of contamination, the suitability of this alternative is enhanced for the 200 Areas, because haul distances to ERDF would be substantially reduced.

Some waste sites in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs have transuranic constituents in the soils. Soils excavated from these sites may contain alpha-emitting transuranic isotopes with half-lives exceeding 20 years in concentrations that exceed 100 nCi/g, which would require disposal off site at WIPP. Such soils must be managed and disposed of in accordance with applicable administrative and substantive requirements. Remedies that may generate transuranic waste must be planned and implemented in coordination with the Hanford Transuranic Waste Certification Program.

4.2.2.4.1 Conventional Excavation

Conventional excavation, employing standard earthmoving equipment such as backhoes and front-end loaders, is a viable technology for all subject waste sites, although access issues and worker-safety concerns may preclude its use for portions of some sites.

4.2.2.4.2 Remote Excavation

Where access issues or worker-safety concerns preclude conventional excavation methods, robotic or extended-reach equipment may be employed to remove subsurface waste. Remote excavation was successfully implemented at the 216-Z-9 Trench in the early 1970s, when a

0.3 m (1 ft) layer of highly contaminated soil was removed from the trench floor to mitigate criticality concerns. Remote excavation has been successfully implemented for the F and H fuel-storage basins at the Hanford Site. Although more expensive than conventional excavation, remote excavation can be cost effective when targeting long-lived contaminants that otherwise would require remedies with very long-term monitoring and maintenance requirements.

4.2.2.4.3 Soil-Vacuum Excavation

High-vacuum systems can be employed as a soil-excavation technology. Alternately, a wand with a supersonic air stream is delivered through a nozzle under high pressure to break up soil and move soil particles. A secondary air vacuum withdraws loose soil from the excavation to a collection vessel. Soil-vacuum excavation processes facilitate removal of contaminated media with minimal damage to adjacent pipelines or utilities and may be invaluable in instances where excavation encroaches on underground structures. Soil-vacuum or air-jet excavation techniques are less effective where large gravel and cobbles or debris are encountered. The implementability, effectiveness and cost of the technology are well known. Soil-vacuum excavation has been successfully demonstrated through use of the soil-vacuum excavation equipment in the 300 Area and as part of the 200-PW-1, 200-PW-3, and 200-PW-6 OUs RI soil-vapor probe installations around the PFP Complex.

4.2.2.5 Ex Situ Treatment

Characterization data presented in the RI Report (DOE/RL-2006-51) suggest that no treatment will be necessary to meet disposal-facility waste-acceptance criteria. However, ex situ treatment technologies have been considered in this section for their ability to minimize the volume of material that may require disposal. These technologies (thermal desorption, vitrification, vapor extraction, soil washing, automated segregation based on radioactivity, and solidification/stabilization) are described in detail in the following subsections.

4.2.2.5.1 Thermal Desorption

Thermal desorption has been identified as a presumptive remedy by EPA (EPA/540-F-93-048, OSWER Directive 9355.0-48FS) for the removal of VOCs from soil. This technology uses heat to volatilize organic contaminants from soil, typically employing a rotary kiln to disaggregate soils to facilitate volatilization. A carrier gas or vacuum is used to collect and transport the volatilized organics to a gas-treatment system. Concentrated contaminants can be removed (e.g., by carbon adsorption) from the process stream or destroyed using a secondary combustion chamber or catalytic oxidizer. Residual liquids and spent activated carbon require further treatment. With low temperature thermal desorption, the decontaminated soil retains its physical properties and its ability to support biological growth.

Current characterization data show that all VOCs are collocated with radiological contaminants; therefore, thermal treatment (such as thermal desorption or incineration) that reduces or eliminates the VOCs will not reduce waste volume and most likely will not affect selection of the disposal facility. Current data also suggest that the waste soils will meet disposal-facility waste-acceptance criteria without treatment. Thus, the short-term risks and costs incurred in

implementing ex situ thermal desorption would provide little benefit. This technology is not retained for further evaluation.

4.2.2.5.2 Vitrification (Ex Situ)

Vitrification of excavated material can be conducted at a facility or on site using in-container vitrification. The in-container vitrification process mixes silica-rich contaminated soil with sand and insulation in a large steel box. Electrodes heat the mixture to over 1,300 °C to vitrify the waste material. The entire container with glass and electrodes then can be disposed of. Vitrification addresses all contaminants for all representative waste sites by melting excavated materials to form glass or other crystalline solids.

4.2.2.5.3 Vapor Extraction (Ex Situ)

Vapor extraction is a standard method for removing VOCs from excavated soil by inducing airflow through the soil. Based on current understanding, it would be used only if soils were excavated from the 19.8 m (65-ft) depth interval on the south side of the 216-Z-9 Trench. This technology would be implemented, if needed, to reduce CCl_4 concentrations to meet ERDF/WIPP waste-acceptance criteria.

4.2.2.5.4 Soil Washing

Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics or heavy metals. This is a media-transfer technology; wash water subsequently is treated. Complex waste mixtures (e.g., metals with organics) make formulating washing fluid difficult. No previous studies were identified that showed this process to be effective, or potentially effective, with Pu-239/240 or Am-241, or with the very high concentrations of Cs-137 anticipated. Other technologies are more effective with the identified organic contaminants. Soil washing is not retained for further consideration.

4.2.2.5.5 Automated Segregation Based on Radioactivity

Systems have been developed that convey excavated soil past radioactivity sensors. Soil can be segregated based on threshold radioactivity levels. Such technology uses proven soil-handling, screening, and conveying equipment with radiation-detection sensors integrated into the process. A segmented gate system has been demonstrated by Eberline Corporation. The effectiveness, implementability, and cost for this technology have been demonstrated and are well defined. Automated segregation is retained for further consideration where such a separation function on excavated contaminated soil is appropriate.

4.2.2.5.6 Solidification/Stabilization

As assessed here, solidification/stabilization addresses inorganic and radionuclide contaminants for the 241-Z-8 and 241-Z-361 Settling Tanks by mixing extracted sludge with a binding agent to form an encapsulated mass that inhibits contaminant mobility. Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced

between the stabilizing agent and contaminants, to reduce their mobility (stabilization). Multiple process options exist, including bituminization, emulsified asphalt, modified sulfur cement, polyethylene extrusion, pozzolan/Portland cement, sulfide-forming compounds, and soluble phosphates. The target contaminant group is inorganics, including radionuclides. Most solidification/stabilization processes have limited effectiveness with organic contaminants. Solidification/stabilization is retained for further consideration. DOE/RL-2003-52 identified a recommended remedial action for the ex situ stabilization of the sludge in the 241-Z-361 Settling Tank. Power Fluidics[12] technology would be used to remove the sludge from the tank and place it in standard waste boxes (SWB), where it would be stabilized with a polymer absorbent, WaterWorks SP-400 Superabsorbent Crystals.[13] This previously recommended stabilization technology is retained.

4.2.2.6 In Situ Treatment

4.2.2.6.1 Soil-Vapor Extraction

The SVE process is a conventional process for remediating soils contaminated with VOCs and has been identified by EPA as a presumptive remedy (EPA/540/F-93/048, *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils*, OSWER Directive 9355.0-48FS). SVE with carbon adsorption currently is implemented as an expedited response action at the 200-PW-1 OU. The technology has proven very effective, removing approximately 78,884 kg (173,909 lb) of CCl_4 from the vadose zone between 1992 and September 2006 (SGW-33746). However, the mass of CCl_4 removed annually continues to diminish.

The SVE process involves inducing airflow through the soil matrix with an applied vacuum that facilitates the mass transfer of adsorbed, dissolved, or free phases to the vapor phase. Vapors are drawn to the surface through vapor-extraction wells for treatment.

Carbon adsorption is the most commonly employed vapor-treatment process and is adaptable to a wide range of VOC concentrations and process flow rates. The treatment process using skid-mounted, off-site-regenerated carbon canisters generally is employed for low soil-vapor flow volumes, as encountered at the subject waste sites. The process can be used alone or with other methods. Spent carbon requires treatment or disposal by thermal desorption and destruction of the CCl_4. Radiological contamination may preclude disposal or regeneration off site.

4.2.2.6.2 Passive Soil-Vapor Extraction

Passive soil-vapor extraction (PSVE) removes underground VOCs by enhancing the natural air-pressure changes that occur in subsurface soils in response to naturally occurring changes in

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[12] Power Fluidics is a trademark of NuVision Engineering, Inc., Pittsburgh, Pennsylvania.

[13] WaterWorks Crystals is a registered trademark of WaterWorks America, Inc., North Royalton, Ohio.

atmospheric pressure. In wellhead PSVE, airflow results when the surface and subsurface soils are connected by a well. A valve at the wellhead allows air to flow out of the well but not back into the well. An adsorber can be added to the system to remove VOCs from the exhaust air stream, if warranted. The PSVE systems have been successfully tested at multiple DOE sites including the Hanford Site. The PSVE process with carbon adsorption currently is implemented as an interim response at selected wells in the 200-PW-1 OU. Approximately 10 kg (22 lb) of CCl_4 were removed from the vadose zone using PSVE in fiscal year 2006; between October 1999 and September 2006, approximately 80 kg (176.4 lb) of CCl_4 were removed (SGW-33746).

4.2.2.6.3 Soil Mixing

Soil mixing addresses shallow subsurface inorganic and radionuclide contaminants, using a large-diameter auger to mix cement or a binding agent with the soil, to physically encapsulate or chemically bind contaminants. One limiting factor that can influence the effectiveness of the stabilization and solidification processes is organic solvents. Depending on the type of binding agent, organic solvents can react in ways that are problematic to the effectiveness of the technology. As a result, it is not suitable when organic solvents are present or for subsurface objects. This technology would have very limited application within the 200-PW-1, 200-PW-3, and 200-PW-6 OUs, where underground structures are common. Most targeted contamination will be at depth, and organic contamination is anticipated. Soil mixing is not retained for further evaluation.

4.2.2.6.4 Electrical-Resistance Heating and Soil-Vapor Extraction

Thermally enhanced SVE is an active technology that uses heating to increase the volatilization rate of volatile and semivolatile organic contaminants and then captures and treats the vapors. Electrical-resistance heating (ERH) uses an electric current to heat soils, preferentially heating fine-grained soils. Wells are drilled into the contaminated media in a polygon pattern. Electrodes are placed in the wells and power is applied to initiate the flow of electrical current through the soil matrix. The electrical resistance of the soil generates heat. The elevated temperature accelerates volatilization of the contaminants and also may accelerate naturally occurring attenuation processes such as biotic and abiotic degradation.

4.2.2.6.5 In Situ Vitrification

In situ vitrification (ISV) technology, as assessed here, is the AMEC GeoMelt[14] vitrification process. This process originated as an in situ treatment method developed at PNNL for contaminated soils at DOE sites. Today, GeoMelt is available as two distinct treatment options: Subsurface Planar Vitrification[15] (SPV), which is a mature second-generation in-place (i.e., subsurface) treatment technology based on improvements to the original in situ technology;

[14] GeoMelt is a trademark of AMEC plc, London, England.

[15] Subsurface Planar Vitrification is a trademark of AMEC plc, London, England.

and an ex situ method, In-Container Vitrification[16], also known as bulk vitrification at the Hanford Site. The in situ SPV treatment technology is evaluated here. Figure 4-3 shows a conceptual schematic of this ISV treatment technology.

The GeoMelt process represents a group of vitrification technologies that can be configured in various ways to meet a wide range of treatment requirements. In all GeoMelt applications, a mixture of waste and glass formers, usually soil, is electrically melted to destroy, remove, or permanently immobilize contaminants. Melt temperatures generally are between 1200 and 2000 °C (2200 to 3600 °F), depending on the composition of the mixture being melted. Organic materials are destroyed and/or removed during the melting process. Nonvolatile hazardous metals and radionuclides are immobilized in a durable semicrystalline glass. This glass is very durable and has excellent long-term leach characteristics.

The SPV process is a mobile thermal-treatment process that involves the in-place electric melting of contaminated soils, sludges, or other earthen materials and debris for the purpose of permanently destroying, removing, and/or immobilizing hazardous and radioactive contaminants. A conductive starter path is injected between two sets of electrodes to enable subsurface electrical current flow. Starter-path installation is performed remotely with conventional drilling methods, thus reducing worker-exposure risk. As electricity flows through each starter path, the surrounding soil melts through resistive (joule) heating. Once the soil is molten, it too becomes electrically conductive. Continued application of power results in joule heating within the molten media between and around the electrodes. Because the process is initiated with two independent vertically oriented planar melts that merge together horizontally late in the treatment process, the potential for restricting the flow of gases generated below the melts is reduced significantly. By the time the melts have grown sufficiently to merge into a single melt, all volatile materials have been effectively and safely removed from the treatment zone and captured in the off-gas treatment system. To accommodate soil densification (caused by vitrification), clean overburden is placed over the melt zone before the melt is initiated, thereby avoiding subsidence issues while increasing thermal efficiency and radionuclide retention.

Organic contaminants are destroyed by pyrolysis, which occurs as the temperature increases before the to actual melting, and by catalytic dechlorination reactions, which occur as contaminated soils approach melt temperatures under reducing conditions. Heavy metals and radionuclides are homogeneously distributed throughout the melt because of the relatively low viscosity of the molten glass and the convective flow that occurs within the melt. The radionuclides and heavy metals are retained within the melt. When electrical power is shut off, the molten mass cools and solidifies into a vitreous rock-like monolith with excellent physical, chemical, and weathering properties. The resulting product typically is 10 times stronger than concrete, and 10 to 100 times more resistant to leaching than glasses used to immobilize high-level wastes.

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[16] In-Container Vitrification is a trademark of AMEC plc, London, England.

The vitrified material retains plutonium, other radionuclides, and hazardous metals in an extremely durable form. Plutonium oxide has a fairly high solubility limit in most glasses (in the range of 2 to 5 wt%) and, in the case of GeoMelt, would be distributed throughout the glass by convective mixing. The homogeneity of radionuclide species within GeoMelt glass from convection is well established. Pre- and post-melt radionuclide concentrations from the SPV project (LA-UR-03-6494, *IM Completion Report for the NTISV Hot Demonstration at SWMU 21-018(a)-99 (MDA V)*) are depicted on Figure 4-4. As shown, analytical data identified both a general reduction in radionuclide concentrations in post-melt glass (maximum measured concentrations are approximately one order of magnitude less in the post-melt glass than in the pre-melt absorption bed samples), and a more uniform distribution of radionuclides as a result of the convective mixing that occurs during the melting process.

Criticality Issues

Transuranic radionuclides that emit neutrons can reach criticality if they are sufficiently concentrated or if the moderation properties of the media are suitably altered. The GeoMelt process changes the physical and chemical nature of the contaminated media. These changes prevent conditions necessary for a criticality event to occur. Because plutonium is a strong reducing agent, it is converted to an oxide during the vitrification process. It will chemically reduce species such as iron oxide (Fe_2O_3, naturally present on Hanford Site soil) to form an oxide that is particularly stable at high temperatures. Any plutonium metal in the melt would oxidize rapidly. In fact, if any plutonium metal exists in the soil, it most likely would be fully oxidized in the high-heat environment ahead of the advancing melt. Figure 4-5 shows the standard free energy of the formation of the oxide for several metals including plutonium.

The lower the $\Delta G°$ value, the more likely it is that the oxide species will exist. As shown in Figure 4-5, plutonium has a value of around -200 kcal/g mole O_2 at the temperatures achieved in the GeoMelt process. The data illustrate that to reduce plutonium to its metallic state in a typical multicomponent glass melt, numerous other species first would have to be reduced by the plutonium (such as iron oxide and silicon dioxide) before plutonium oxide could be reduced.

Plutonium oxide has a fairly high solubility limit in most glasses, in the range of 2 to 5 wt%. Various programs under the DOE Office of Fissile Materials Disposition have achieved up to 10 wt% plutonium in certain glass formulations (PNNL-11346, *Plutonium Dioxide Dissolution in Glass*).

Because of heat-driven convective mixing that occurs during the GeoMelt process, plutonium oxide is mixed throughout the glass. Previous GeoMelt projects (LA-UR-03-6494) have shown that plutonium is not reduced to its metallic state, is not concentrated as a result of the process, and is uniformly dispersed as an oxide within the glass.

Plutonium oxide is stable and soluble within the melt, has a very low vapor pressure at melt temperatures, and is not volatile. Consequently, most of the plutonium is retained in the melt. Empirical data from GeoMelt operations as well as other vitrification operations have established that typically >99.99 percent of the plutonium is retained within the melt. Only trace concentrations of the plutonium inventory are released from the melt to the off-gas treatment system. Because of the very low inventories released to the off-gas treatment system, there are

no practical means to accumulate sufficient inventories of plutonium in the off-gas treatment system to give rise to criticality concerns. In most applications, the first step of the off-gas treatment system is particulate filtration, which is very effective at removing any particles from the gas stream. The particulate is, in most cases, recycled back into subsequent melts. In some melts, the high-efficiency particulate air filters contained no detectable activity, indicating near total retention of plutonium in the glass. This excellent retention is a result of the enhanced depth capabilities of GeoMelt SPV and the use of cover soil.

Environmental Protection and Waste Management

Off-gases generated by the process are contained under a steel hood that covers the treatment area and are drawn to an off-gas treatment system that meets EPA and State standards (i.e., ARARs). Off-gas treatment steps can vary depending on project requirements but generally consist of particulate filtration, quenching, wet scrubbing, a second stage of particulate filtration, and carbon adsorption and/or thermal oxidation.

Waste streams from the GeoMelt process include high-efficiency particulate air filters and liquid effluent from the off-gas treatment system, drilling wastes (contaminated soils, equipment, and decontamination wastes), GeoMelt decontamination wastes, and personal protective equipment. Spent high-efficiency particulate air filters are fed back into the melt (except for the last ones of each melt). Liquid effluent from the off-gas treatment system and decontamination activities likely can be disposed to on-site liquid-waste disposal facilities. Most, if not all, of the remaining wastes can be disposed of at ERDF. At sites with transuranic constituents, it is possible that some wastes may designate as transuranic wastes. This technology is retained for further evaluation for sites with long-lived radionuclides.

Developmental Maturity and Implementability

The SPV process is a mature, second-generation technology based on improvements to the conventional ISV process that was developed by PNNL for the DOE. As part of the development of the original ISV process, a full-scale radioactive melt was completed at the 216-Z-12 Crib (see Figure 1-2). Using the established U.S. Department of Defense Technology Readiness Levels (nine-point scale used to assess technology maturity), the SPV technology is rated at Level 9: the actual system has been proven through successful project operations. SPV has been successfully deployed at full scale in several hot and cold demonstrations for Los Alamos National Laboratory, Idaho National Engineering Laboratory, and the DOE Office of Cleanup Technologies. Figure 4-6 depicts AMEC's SPV equipment in use at Los Alamos National Laboratory in 2000.

Summary

GeoMelt SPV ISV technology appears to warrant consideration. Although not in wide use, the technology has evolved substantially. The most likely application of this technology is at sites where excavation of contaminated soils might generate large volumes of waste with high levels of transuranic isotopes. A primary benefit of using the GeoMelt SPV process at the subject waste sites is that, essentially, it can encapsulate the soils with the highest identified concentrations of Pu-239/240 and Am-241. Vitrification safely immobilizes alpha emitters such that any subsequent direct contact poses only moderate risks. (AMEC has experience in the

vitrification and subsequent removal of more than 4,600 metric tons of plutonium waste. During glass-removal operations, plutonium contamination immobilized in the glass was nonsmearable, and there was no detectable airborne plutonium.) A significant secondary benefit at the subject waste-disposal sites is that the glass monolith forms a substantial physical barrier that inhibits both human and biological intrusion into the residual contamination that exists at depth. This technology is retained for further evaluation at sites with long-lived radionuclides.

4.2.2.6.6 Monitored Natural Attenuation

Although technically not a treatment process, MNA is included in this group because it occurs in situ. Remedies relying on MNA processes are implemented following EPA/540/F-99/009, *Use of Monitored Natural Attenuation at Superfund RCRA Corrective Action and Underground Storage Tank Sites November 1997*, OSWER 9200.4-17P. Protocols providing guidance for implementation of MNA for chlorinated solvents are available from the EPA (EPA/540/G-89/004). Protocols for metals and radionuclides are being developed. MNA is retained for all representative waste sites and all contaminants that are amenable to MNA processes in reasonable timeframes.

The most significant reliance on MNA processes is expected to be at the 200-PW-3 OU waste sites contaminated with Cs-137. This radionuclide has a half-life of approximately 30 years, so natural radiological decay can achieve substantial reductions in contaminant mass in a relatively short period of time (e.g., MNA processes will eliminate more than 96 percent of the current Cs-137 mass by the year 2150).

At present, it does not appear that the other identified COCs can be addressed effectively in the vadose zone using MNA processes. The PNNL is conducting studies to assess the abiotic degradation of CCl_4 in Hanford Site soils; see Table 4-3.

Figure 4-1. Conceptual Schematic: Perimeter of a Monofill Evapotranspiration Barrier.

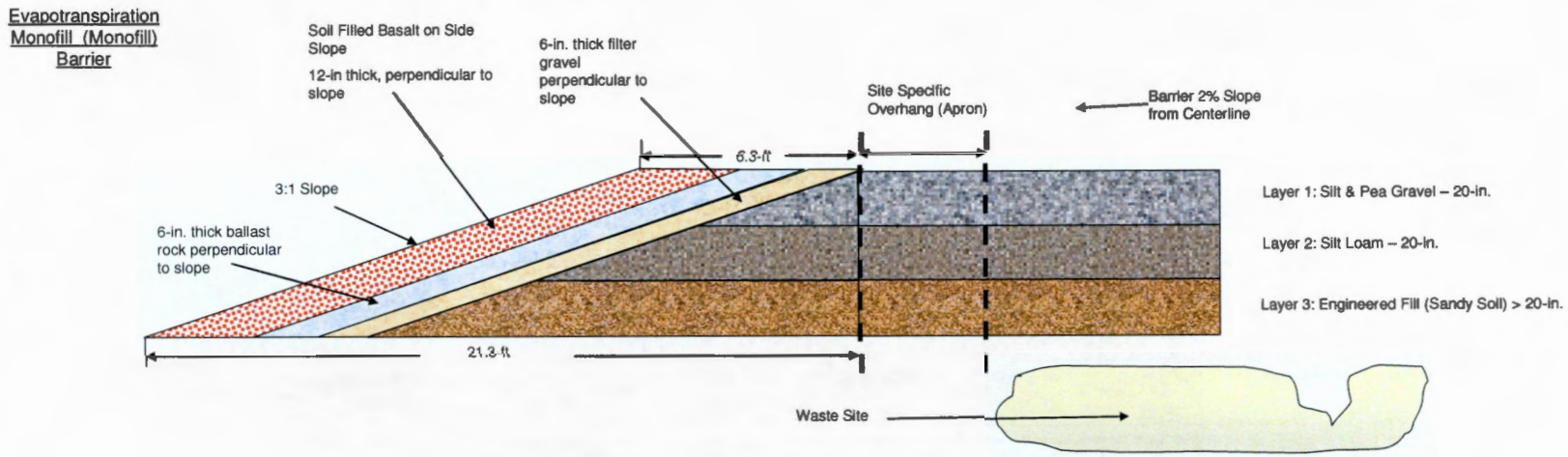


Figure 4-2. Conceptual Schematic: Perimeter of a Capillary Evapotranspiration Barrier.

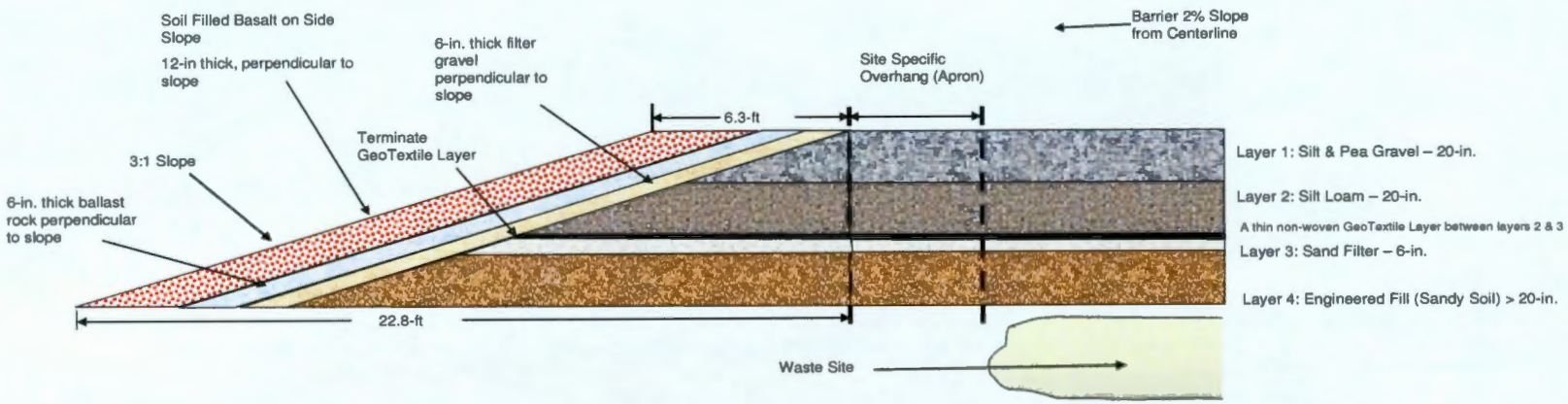


Figure 4-3. Conceptual Schematic: In Situ Vitrification.

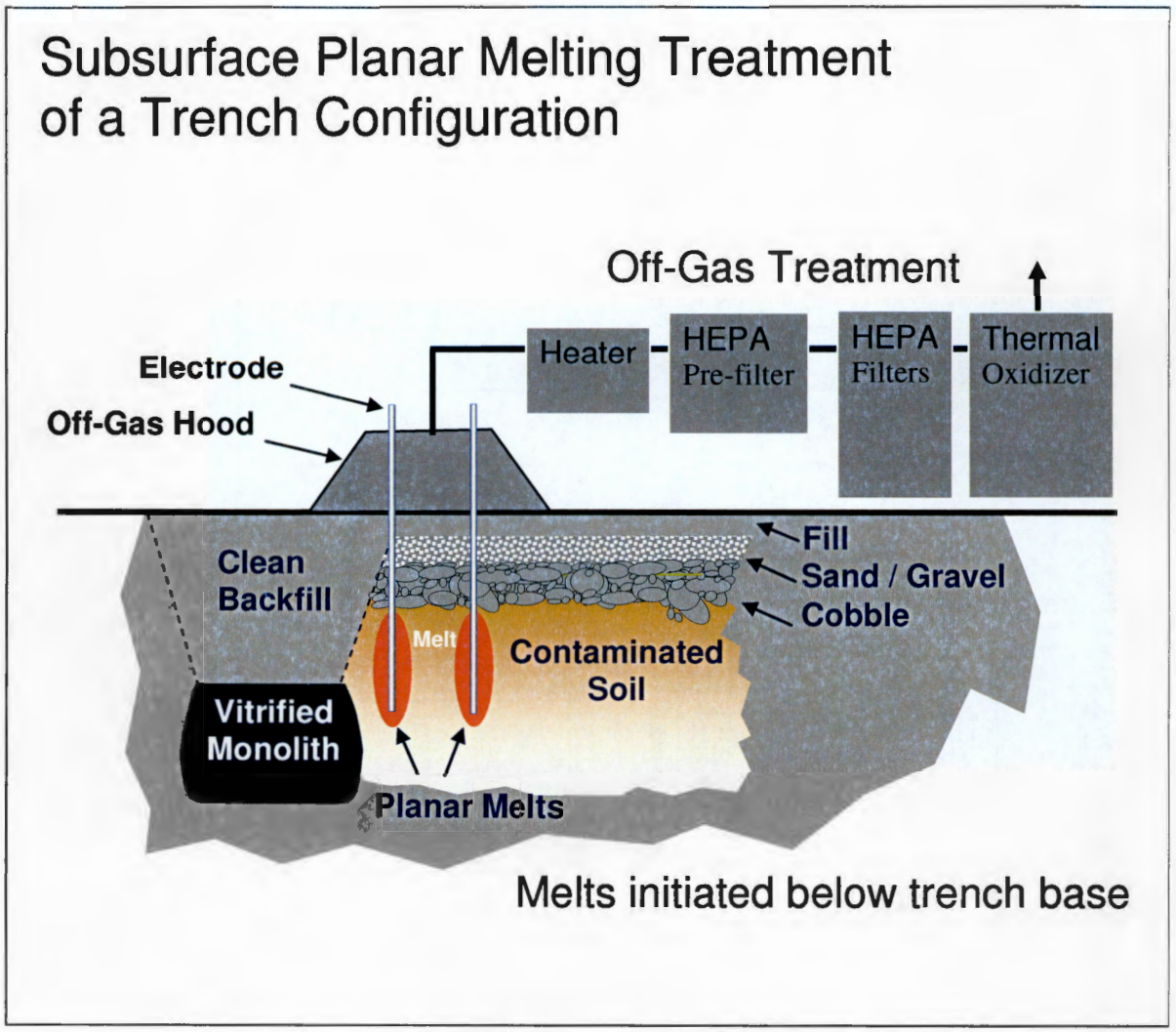
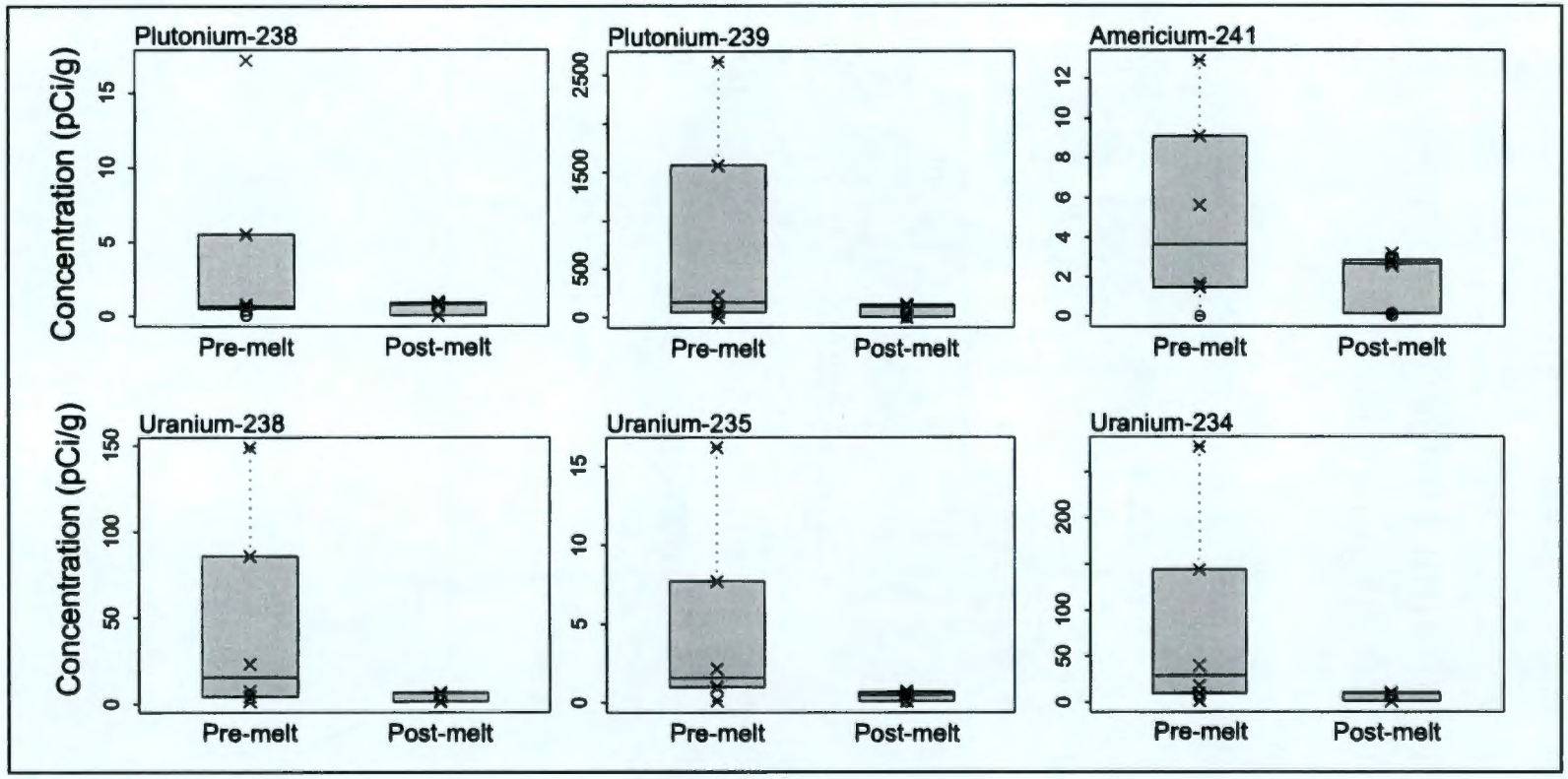


Figure 4-4. Comparison of Pre and Post-GeoMelt Subsurface Planar Vitrification Radionuclide Concentrations.



(From LA-UR-03-6494)

Figure 4-5. Standard Free Energy of Formation for Various Metal Oxides.

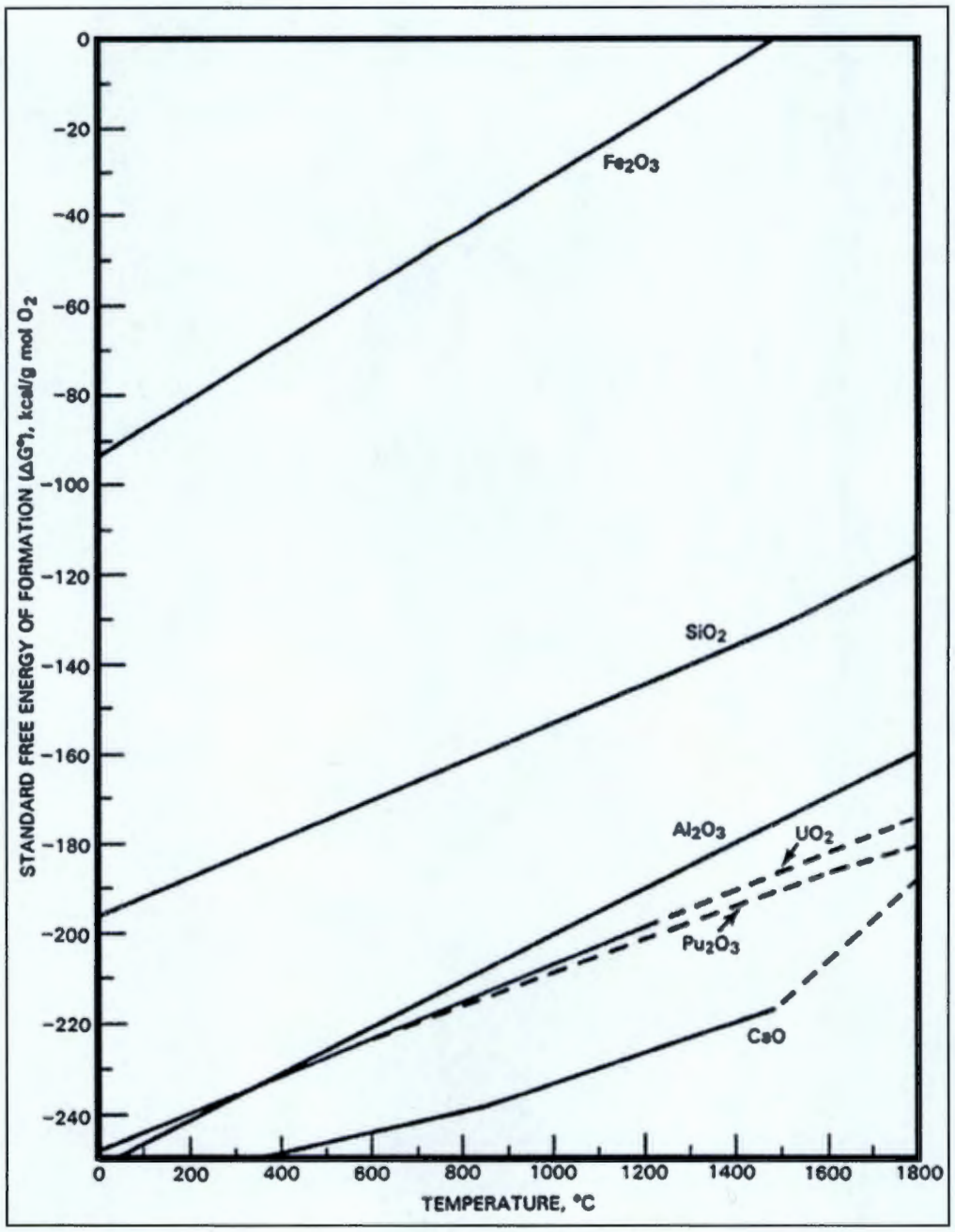


Figure 4-6. GeoMelt Subsurface Planar Vitrification Processing Equipment at Los Alamos National Laboratory in 2000.

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
No Action	No Action	No action, with supplemental environmental monitoring	None	Retained as baseline	Retained
Institutional Controls	Warning Notices	Signs	IMRO	Effectiveness: does not reduce contamination. Effective in supporting mitigation of potential for direct contact with residual contaminants if consistently well implemented for duration of elevated risk. Prevents disturbance of ongoing remedies. Implementability: easy to implement, requires ongoing surveillance and maintenance. Cost: low	Retained
	Entry Restrictions	Procedural requirements for access Warning signs Fencing	IMRO		
	Land-Use Management	Land use and real property controls (e.g., deed restrictions) Excavation permits	IMRO	Effectiveness: does not reduce contamination. Effective in mitigating potential for direct contact with residual contaminants if consistently well implemented for duration of elevated risk. Ensures compatible land use. Implementability: easy to implement, must identify and comply with all necessary legal requirements. Cost: low	Retained
	Groundwater Use Management	Groundwater controls	IMRO	Effectiveness: ensures no improper use of groundwater. Implementability: easily implemented, but requires ongoing action. Cost: low	Retained
	Waste-Site Information Management	Administrative	IMRO	Effectiveness: ensures access to information on the location and nature of contamination. Implementability: readily implemented, but requires ongoing action. Cost: low	Retained

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
Containment	Surface Barriers	Arid-climate engineered cap	IMRO	Effectiveness: effective, but requires surveillance and maintenance for duration of risk. Those with capillary breaks are susceptible to damage by subsidence and seismic activity. Monofill barrier is self-healing. All engineered surface caps are susceptible to weathering. Implementability: easily implemented, although design and construction complexity varies greatly between the two options (monofill and capillary break evapotranspiration barriers). Cost: moderate capital and maintenance costs for both evapotranspiration barriers; Monofill barrier lower cost because design, construction, and maintenance are less complex.	All retained
	Intrusion Barriers	Controlled-density fill	IMRO	Effectiveness: effective Implementability: easily implemented. Cost: low to moderate capital cost (depending on material).	Retained
		Intrusion-prevention feature	IMRO	Effectiveness: effective Implementability: easily implemented. Cost: moderate capital cost (depending on materials used).	Retained
	Vertical Barriers	Vertical barriers are not effective in addressing the risk scenarios identified to date. They are considered here as ancillary technologies to support the application of surface-barrier technology.			
		Grout curtains	IMRO	Effectiveness: effective Implementability: implementable, but can be difficult to verify continuity of barrier. Cost: cost varies with depth, orientation, thickness of grout curtain, and composition of grout. Low to moderate capital cost.	Retained as supplementary technology

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
Containment (cont)	Vertical Barriers (cont)	Slurry walls (cement-bentonite slurry)	IMRO	Effectiveness: effective for shallow application to contain lateral movement of contaminants and infiltrating water and as a barrier to intrusion. Application envisioned would be as supplement to engineered surface barriers, when lateral extension of surface barrier is constrained. Durability may be an issue if contaminants are very long lived. Implementability: easily implemented. Cost: low to moderate capital cost (dependent on depth and thickness of wall and need for specialized slurry formulations. No maintenance costs.	Retained as supplementary technology to support surface barriers
	Subsurface Barriers	Dry-air barrier (soil desiccation)	IMRO	Effectiveness: effective in controlling vertical movement of moisture and contaminants through the more permeable intervals of the soil column. Technology also will support localized control of vapor-transport pathways. Implementability: implementable. Complexities in geology, size and depth of target area, number of wells, and emission controls are factors affecting ease of implementation. Use of existing soil-vapor extraction system components and wells may simplify implementation. Dry-air barriers can be operated in a pulsed manner similar to soil-vapor extraction rebound to minimize long-term operation costs (tens to hundreds of years). Cost: capital cost is moderate, varying with the number of wells, the size and depth of the target area(s), the design capacity of the system, and whether any treatment is needed for the system air emissions or effluent. Costs can be reduced if coupled with existing soil-vapor extraction system components and infrastructure. Operation and Maintenance costs are moderate, varying with size of system and waste streams generated, frequency of operation, and full duration of implementation.	Retained

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
Removal	Excavation	Conventional excavation	IMRO	Effectiveness: effective Implementability: readily implemented, although as-low-as-reasonably-achievable considerations may add to the complexity. Cost: moderate capital costs, moderate operations and maintenance costs; as-low-as-reasonably-achievable issues may increase cost substantially.	Retained
		Remote excavation	IMRO	Effectiveness: effective for excavation when access restrictions or worker health and safety concerns preclude conventional excavation. Implementability: readily implemented. Difficulty increases with depth and with increased levels of risk. Specialized equipment and trained personnel expected to be readily available. Cost: moderate capital costs, moderate to high operations and maintenance.	Retained
		Soil-vacuum excavation	IMR	Effectiveness: effective for precise removal of soils. Implementability: readily implemented. Equipment and trained personnel expected to be readily available. Emission controls are required. Cost: moderate capital and operations and maintenance costs	Retained as supplementary technology
Disposal	Landfill Disposal	Onsite landfill (ERDF)	IMRO	Currently the only path forward for onsite disposal of hazardous waste, low-level waste, and mixed low-level waste generated by CERCLA activities. Effectiveness: effective Implementability: readily implemented. Cost: moderate	Retained

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
Disposal (cont)	Landfill Disposal (cont)	Offsite landfill	IMO/IMRO	Effectiveness: effective Implementability: offsite activity, so both substantive and administrative requirements apply. Offsite waste transportation imparts additional costs and risks. Cost: moderate to high, depending on distance to facility, treatment required to meet acceptance criteria.	Because of the implementability issues, offsite disposal is retained only for use as contingent action if disposal at ERDF is not possible.
		Offsite repository (Waste Isolation Pilot Plant)	IMRO (as transuranic waste)	Effectiveness: effective. Excavation may generate suspect transuranic wastes. Currently the Waste Isolation Pilot Plant is the only path forward for disposition of transuranic wastes. Implementability: implementable, but it is an off-site activity so both substantive and administrative requirements apply. Work must be coordinated through the Hanford Transuranic Waste Certification Program. Cost: High relative to transport and disposal at other facilities.	Retained
Ex Situ Treatment (assumes excavation)	Thermal Treatment	Thermal desorption	O	Effectiveness: an EPA presumptive remedy for VOCs, but provides limited benefit because the VOCs are collocated with transuranics, so the soil will still designate as a radioactive waste. Soils expected to meet disposal facility acceptance criteria without treatment. Implementability: difficult to implement because of risks posed by collocated radionuclides. Equipment and personnel are readily available. Concerns with the potential for radiological contamination of the equipment may increase costs or preclude use of certain vendors. Cost: competitive costs for removal of VOCs when used for large soil volumes (greater than 750 m^3 [1,000 yd^3]). Protection of workers and environment from the radiological risks will increase costs substantially.	Not retained

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
Ex Situ Treatment (assumes excavation) (cont)	Thermal Treatment (cont)	Ex situ vitrification	IMRO	Effectiveness: effective for removing organics and stabilizing waste form. Implementability: moderately difficult to implement because of the power requirements. Cost: Relatively expensive because of the infrastructure necessary and the power requirements.	Do not anticipate a need to stabilize excavated soils. Not retained.
	Physical/ Chemical Treatment	Vapor extraction	O	Effectiveness: effective for removing volatile organics. Most effective with coarse-grained materials. Fine-grained soils may need to be disaggregated to make contaminants more accessible. Implementability: readily implemented. Emissions and condensate must be controlled and treated as secondary waste streams. Cost: low capital and operation and maintenance costs. May be able to use existing soil-vapor extraction infrastructure and equipment to support implementation, providing significant cost savings.	Retained
		Soil washing	IMRO	Effectiveness: not shown to be effective with plutonium or americium or with very high concentrations of Cs-137. Implementability: implementable, significant actions for worker protection and environmental protection, generates secondary liquid waste stream. Cost: moderate	Not retained
		Automated segregation based on radioactivity	R	Effectiveness: not a treatment, per se, so minimal impact on achieving protectiveness. Facilitates segregation of radiologically contaminated soils, which helps to minimize waste volume and related management and disposal costs. Implementability: readily implemented. Cost: low cost.	Retained

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
Ex Situ Treatment (assumes excavation) (cont)	Physical/ Chemical Treatment (cont)	Solidification/ stabilization	IMR (Sludge)	Effectiveness: effective Implementability: readily implemented, although as-low-as-reasonably-achievable concerns may add complexities. Cost: moderate	Retained specifically for use on the 241-Z-361 Settling Tank and the analogous 241-Z-8 Settling Tank.
In Situ Treatment	Chemical/ Physical Treatment	Soil-vapor extraction	O	Effectiveness: effective, although it can be slow to achieve preliminary remediation goals if VOCs are in fine-grained soils. Implementability: readily implemented, but does require design work and optimization. Emissions and effluent are regulated. Cost: moderate to high capital costs; moderate to high operation and maintenance cost depending on size, duration of operation, and volume of waste streams.	Retained
		Passive soil-vapor extraction	O	Effectiveness: minimally effective as a primary technology for VOCs in fine-grained material, although useful as supplementary technology. Slow in achieving goals. Implementability: readily implemented. Intended here as a supplementary technology, making use of existing wells. Cost: low capital and operation and maintenance costs as implemented here.	Retained as supplementary technology
		Soil mixing	IMR	Effectiveness: not effective for deeper contamination or with high levels of organic contamination. Implementability: readily implemented. Cost: low to moderate.	Not retained

Table 4-1. Summary of Technology Screening Results. (8 Pages)

General-Response Action	Technology Type	Process Option	Target Contaminants	Evaluation	Results
In Situ Treatment (cont)	Thermal Treatment	Electrical-resistance heating with soil-vapor extraction	O	Effectiveness: effective. Preferentially heats fine-grained soils. Rate of volatilization increases in proportion to the induced increase in temperature. Supports increased VOC removal rate, which supports more rapid attainment of remedial goals. Implementability: moderately difficult to implement, depending on the size, depth, and configuration of the target area, and the availability of infrastructure to support the power demands. Cost: moderate to high.	Retained
		In situ vitrification	IMRO	Effectiveness: effective in mitigating long-term risk. Implementability: moderate level of technical difficulty. Infrastructure requirements. May need treatability studies. Cost: moderate to high.	Retained
Natural Attenuation (not a technology or treatment process)		Monitored natural attenuation	IMRO	Effectiveness: effective for Cs-137, reducing contaminant mass by 50% roughly every 30 yr (radiological decay). Effectiveness for CCl_4 under evaluation by others, but carried forward as potentially viable. Assume 200 years to reduce CCl_4 mass by 50%. Implementability: readily implemented, requiring only monitoring for verifying progress toward preliminary remediation goals. Cost: low	Retained

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980.*
EPA = U.S. Environmental Protection Agency.
ERDF = Environmental Restoration Disposal Facility.
I = inorganic, nonmetallic contaminants.
M = heavy metals contaminants.
O = organic contaminants.
R = radionuclide contaminants.
VOC = volatile organic compound.

Table 4-2. Retained Remedial Technologies.

General-Response Action	Technology Type	Remediation Technology	Target Contaminants
No Action	No Action	No Action	IMRO
Institutional Controls	Land Use Management	Deed Restrictions	IMRO
		Deed Notices	IMRO
		Declaration of Environmental Restrictions	IMRO
		Information Distribution	IMRO
		Restrictive Covenants	IMRO
		Federal/state/county/local registries	IMRO
	Warning Notices and Entry Restrictions	Signs/Fences	IMRO
		Entry Control	IMRO
	Monitoring	Surveillance/Monitoring	IMRO
Containment	Surface Barriers	Monofill and Capillary ET Caps	IMRO
	Intrusion Barriers	Physical Barrier	IMRO
	Vertical Barriers	Slurry Walls and Grout Curtains	IMRO
	Dry Air Barrier	Soil Desiccation	IMRO
Removal	Excavation	Conventional Excavation	IMRO
		Remote Excavation	IMRO
		Soil-Vacuum Excavation	IMR
Disposal	Landfill Disposal	Onsite Landfill	IMRO
		Offsite Repository	IMRO (as transuranic)
Ex Situ Treatment (assumes excavation)	Physical/ Chemical Treatment	Vapor Extraction	O
		Automated Segregation Based on Radioactivity	R
		Solidification/ Stabilization	IMR
In Situ Treatment	Chemical/ Physical Treatment	Soil-Vapor Extraction	O
		Passive Soil-Vapor Extraction	O
	Thermal Treatment	Thermally Enhanced Soil-Vapor Extraction	O
		In Situ Vitrification	IMRO
Attenuation Processes	Natural Attenuation*	Monitored Natural Attenuation	RO

*Not a treatment process
ET = evapotranspiration.
I = inorganic, nonmetallic contaminants.
M = heavy metal contaminants.
R = radionuclide contaminants.
O = organic contaminants.

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