0075059

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

DEC 20 2007

08-AMCP-0071

RECEIVED
JAN 02 2008
EDMC

Ms. J. A. Hedges, Program Manager
Nuclear Waste Program
State of Washington
Department of Ecology
3100 Port of Benton
Richland, Washington 99354

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

Addressees:

DEEP VADOSE ZONE TREATABILITY TEST PLAN FOR THE HANFORD CENTRAL PLATEAU, DOE/RL-2007-56, DRAFT A

The purpose of this letter is to transmit to the Deep Vadose Zone Treatability Test Plan for the Hanford Central Plateau, DOE/RL-2007-56, Draft A to the State of Washington Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA) for review and approval.

This Treatability Test Work Plan is submitted in support of Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) Milestone M-015-50, "Submit a Treatability Test Work Plan for Deep Vadose Zone Technetium and Uranium to Ecology and EPA." This Treatability Test Work Plan is an outgrowth of discussions prompted by the Ecology and EPA letter dated December 7, 2004, "Treatability Investigations for Technetium-99," and subsequent workshops and technical meetings leading to the agreement on Tri-Party Agreement Milestone M-015-50. A key aspect of this plan is an upfront 90-day review period in which the U.S. Department of Energy, Richland Operations Office is actively seeking input from regulators, stakeholders, and the Tribes. A workshop will be held mid-way through the review period to facilitate this process.

DEC 2 0 2007

If there are 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:JGM

Attachment

cc w/attach:
G. Bohnee, NPT
L. Buck, Wanapum
C. E. Cameron, EPA
G. P. Davis, Ecology
S. Harris, CTUIR
R. Jim, YN
S. L. Leckband, HAB
K. Niles, ODOE
J. B. Price, Ecology
Administrative Record H-0-11
Environmental Portal

cc w/o attach:
R. E. Piippo, FHI
J. G. Vance, FFS
R. E. Wilkinson, FFS

DOE/RL-2007-56
DRAFT A

Deep Vadose Zone Treatibility Test Plan for the Hanford Central Plateau

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

DOE/RL-2007-56
DRAFT A

Deep Vadose Zone Treatability Test Plan for the Hanford Central Plateau

Date Published
December 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

J. D. Aardal 12/11/2007
Release Approval Date

Printed in the United States of America

Executive Summary

Over decades of operation, the U.S. Department of Energy (DOE) and its predecessors have released nearly 2 trillion liters (450 billion gallons) of liquid into the vadose zone at the Hanford Site. Much of this liquid waste discharge into the vadose zone occurred in the Central Plateau (Figure ES-1), an area of 200 square kilometers (75 square miles) that includes approximately 800 waste sites and 900 facilities that operated to extract and purify plutonium. The byproducts of this activity were effluents contaminated in varying degrees with chemicals and radionuclides. The most dangerous waste was stored in 177 underground tanks. Some of this waste has been released to the vadose zone. Also, concentrated waste was discharged into engineered surface structures and allowed to percolate through the vadose zone. This practice resulted in large-scale contamination of the vadose zone and groundwater underlying the Central Plateau. Some of this contamination remains in the vadose zone and has the potential to contaminate groundwater in the future.

The vadose zone is the area between the surface of the land and the water table. The deep vadose zone is that region of the subsurface where contaminant migration is not affected by surface remediation.

Figure ES-1. This plan focuses on the remediation of technetium-99 and uranium at the Central Plateau of the Hanford Site (shown above in October 2007; photo is looking east).

Treatability studies establish the design and operating parameters necessary to optimize technology performance and implement a sound, cost-effective remedy.

The deeper sections of the vadose zone, herein termed the deep vadose zone, pose unique problems for remediation by the very nature of the vadose zone itself (refer to Section 2.0 for more detail). Because pore spaces are unsaturated (a mixture of air and water), conventional remediation technologies such as pump and treat are ineffective. The heterogeneous nature of the Central Plateau vadose zone confounds detailed understanding of the distribution and extent of contamination. Because of the deepness of the vadose zone, thorough characterization using traditional sampling and analysis is cost prohibitive, and alternative methods of characterization must be developed and employed. Much of the contamination is too deep for conventional surface excavation, so innovative in situ treatment technologies must be implemented. These issues and others combine to make the deep vadose zone at Hanford one of the most challenging remediation problems in the DOE complex today.

To ensure appropriate focus of attention and resources is directed toward the remediation of the deep vadose zone, the Tri-Party Agencies (DOE, U.S. Environmental Protection Agency [EPA], and Washington Department of Ecology [Ecology]) established Milestone M-015-50, which directs DOE to submit a treatability test plan for remediation of technetium-99 and uranium in the deep vadose zone. This document, which comprises the Treatability Test Plan required by Milestone M-015-50, has been written by an integrated project team with members from the DOE Richland Operation Office and Office of River Protection, Fluor Hanford, Inc., Pacific Northwest National Laboratory, and CH2M HILL Hanford Group, Inc. with Fluor Hanford, Inc. being responsible for the overall integration and production of this treatability test plan. Testing of deep vadose zone technologies described in this plan will be conducted to satisfy requirements of *Comprehensive Environmental Response, Compensation, and Liability Act (*CERCLA). The methodology and results of this test plan may also be useful in determining corrective action under *Resource Conservation and Recovery Act (*RCRA). This document also serves as a basis for discussion and input from the regulatory agencies, Tribal Nations, and stakeholders. The DOE considers participation by these parties essential in developing the final version of this test plan. A day-long workshop will be held in February or March 2008 to promote discussion and consideration of review comments.

Why does this test plan focus on technetium-99 and uranium?
This test plan focuses on technetium-99 and uranium as directed by TPA Milestone M-015-50. These contaminants are mobile in the subsurface environment and have been detected at high concentrations deep in the vadose zone, and at some locations have reached groundwater. Testing technologies for remediating technetium-99 and uranium will also provide information relevant for remediating other contaminants in the vadose zone.

The major objective of this treatability test plan is to provide a strategy and a framework to evaluate specific vadose zone remediation technologies and includes a comprehensive set of laboratory, modeling, and field tests to do so. A key element in the strategy is the identification of a suite of six technologies for testing (refer to Section 3). The selection of technologies is based on evaluations documented in previous studies and is briefly described in Table ES-1.

Table ES-1. Technologies Evaluated and Selected in this Treatability Test Plan

What technologies from previous studies were evaluated for this treatability test plan?	What is it?	Was this technology selected for final inclusion in this plan?
Desiccation	Desiccation involves drying a targeted portion of the vadose zone by injecting dry air and extracting soil moisture. Because desiccation removes water already in the vadose zone, it reduces the amount of pore fluid that could transport contaminants into the deep vadose zone, impedes water movement, and augments the impact of surface water infiltration control.	**YES**- Removing water from the vadose zone via desiccation is promising.
In Situ Gaseous Reduction	A reducing gas (e.g., hydrogen sulfide) is used to directly reduce some contaminants and render them less soluble while they remain reduced or can reduce sediment-associated iron which can subsequently reduce contaminants.	**YES** - Because in situ gaseous reduction has the potential to immobilize technetium-99 and uranium and has been demonstrated at the field scale for similar applications, it is included for further study in the treatability test plan.
Multi-Step Geochemical Manipulation	Geochemical manipulation is in the developmental stage. The technique involves introducing gases into the vadose zone that change Eh and/or pH and create conditions for precipitation of minerals with co-precipitation of contaminants.	**YES** - While this multi-step process is still conceptual, it builds on the successful development and demonstration of in situ gaseous reduction and provides a potential for more effective immobilization of contaminants such as technetium-99 and uranium.
Grout Injection	Grout injection is a means of treating subsurface contaminants by injecting grout or a binding agent into the subsurface to physically or chemically bind or encapsulate contaminants. There are multiple types of grout/binding materials. Grouting technologies have the potential for use as part of a remedy for the deep vadose zone.	**YES** - Grouting technologies have the potential for use as part of a remedy for the deep vadose zone.
Soil Flushing	Soil flushing operates by adding water and an appropriate mobilizing agent, if necessary, to mobilize contaminants and flush them from the vadose zone and into the groundwater where they are subsequently captured by a pump-and-treat system.	**YES** - Soil flushing provides a potential mechanism to remove contaminants from the subsurface; however efforts need to determine whether it is feasible to implement soil flushing in a way that minimizes uncertainties for applications to the deep vadose zone.
Surface Barriers	Reduction of water infiltration by surface barriers diminishes the hydraulic driving force for contaminant migration downward through the vadose zone to the water table.	**YES** - Surface barriers are a baseline technology for near-surface contamination and previous technology screening studies identified surface barriers as a promising technology for the deep vadose zone.

A second key element in the strategy is the development of a multi-component, phased treatability testing framework. This framework was developed because of the knowledge gaps inherent in the vadose zone itself, because the six potential technologies are at different levels of technology readiness, and because the different types of remediation technologies require different types of assessment. Additionally, selection of an appropriate field testing site is linked to the need for demonstrating a specific technology, the risk associated with the field demonstration, and the relevance to high priority target site vadose zone problems. The multi-component approach to address these treatability testing needs is discussed in detail in Section 4.

The treatability test plan framework includes two primary phases. The first phase focuses on conducting laboratory work and numerical modeling to address uncertainties associated with technology and employing the technology in the deep vadose zone.

Phase 2 of the framework involves the large-scale design and implementation of treatability testing in the field at carefully selected locations. These tests will be conducted with one or more technologies depending upon the success of Phase 1 testing.

Concurrent with the phased treatability testing will be a series of ongoing related DOE and Hanford activities. These include uranium treatability testing in the 300 Area, a 300 Area Integrated Field Research Center, a variety of technetium-99 and uranium remediation studies performed at universities and national laboratories throughout the country, and a technetium-99 groundwater remediation technology demonstration at Hanford. The information derived from these activities will feed into the overall technology evaluation process. The DOE and Hanford activities are described in more detail in Section 3.0.

Documents describing the treatability test efforts will include reports for specific operable units (e.g., 200-BC-1) and a series of performance evaluation reports. A final performance evaluation report will be prepared in fiscal year 2015 to document all of the treatability test results.

Acronyms and Abbreviations

bgs	below ground surface
CERCLA	*Comprehensive Environmental Response Compensation and Liability Act*
D&D	Deactivation and Decommissioning
DOE	U.S. Department of Energy
DOE-EM	DOE Office of Environmental Management
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FHI	Fluor Hanford, Inc.
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
PUREX	Plutonium-Uranium Extraction (Plant)
RCRA	*Resource Conservation and Recovery Act*
REDOX	Reduction and Oxidation
SALD	State-Approved Liquid Disposal (Facility)
SIM	Soil Inventory Model
TEDF	Treated Effluent Disposal Facility
TPA	Tri-Party Agreement

This page intentionally left blank.

Contents

Figures

Tables

1-0. Project Description

The three agencies responsible for the Tri-Party Agreement (TPA) (Ecology et al. 1989) established Milestone M-015-50, *Submit a Treatability Test Work Plan for Deep Vadose Zone Technetium and Uranium to Ecology and EPA*. To meet the objectives of the TPA milestone, this draft document was developed. This document is a compilation of existing information and establishes a framework for conducting treatability tests and can serve as the basis for discussion and input from the regulatory agencies and stakeholders. The draft was delivered to the U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) at the end of December 2007. DOE considers participation by outside interested parties essential in developing the final version of this test plan. Review by regulatory agencies, Tribal Nations, and stakeholders will begin when this draft is distributed. A workshop to discuss and receive input on this plan will be held during the 90-day review period, and a final document will be prepared by June 2008.

The tests proposed in this document focus on mitigating the contaminants technetium-99 and uranium, as required in the TPA milestone. The improved understanding of subsurface conditions and methods to remediate these principle contaminants will also be used to evaluate the application of specific technologies to other contaminants across the Hanford Site. Specific technologies are recommended here for testing at areas that may affect groundwater in the future, but a strategy to test other technologies is also presented.

1-1. Nature of the Problem

Over decades of operation, the U.S. Department of Energy (DOE) and its predecessors have released nearly 2 trillion liters (450 billion gallons) of liquid into the vadose zone at the Hanford Site. The composition of this liquid ranged from clean Columbia River water to effluent contaminated with chemicals and radionuclides from the plutonium refinement processes conducted on the Central Plateau (Figure 1-1).

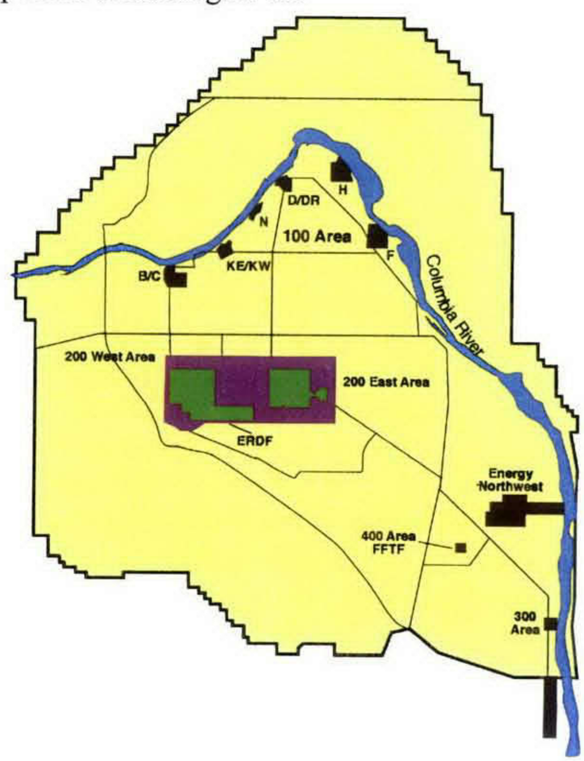

Figure 1-1. The Central Plateau (shown above in purple, an area of approximately 75 square miles) Encompasses the 200 Areas of the Hanford Site.

The deep vadose zone is that region of the subsurface where contaminant migration is not affected by implementation of surface remediation, and thus poses a potential continuing threat to groundwater quality.

This practice resulted in large-scale contamination of the vadose zone and groundwater. Some of this contamination remains in the vadose zone and has the potential to contaminate groundwater in the future. This treatability test plan discusses options to remediate technetium-99 and uranium in portions of the deep vadose zone beneath the Central Plateau.

Conventional technologies, such as pump-and-treat operations, are currently being applied to the remediation of groundwater contamination. Soil contamination near the surface of the Central Plateau may be remediated by removal, treatment, and disposal, surface barriers, or other methods. Contamination held in soil significantly below the surface, however, lies beyond the reach of conventional remediation technologies and is of concern because it has the potential to contaminate groundwater in the future. Figure 1-2 illustrates the region of the vadose zone that is the target of this plan.

The Central Plateau is an area of roughly 200 square kilometers (75 square miles) with approximately 800 waste sites. These waste sites cover 16 square kilometers (6 square miles) near the center of the plateau. The Central Plateau contains

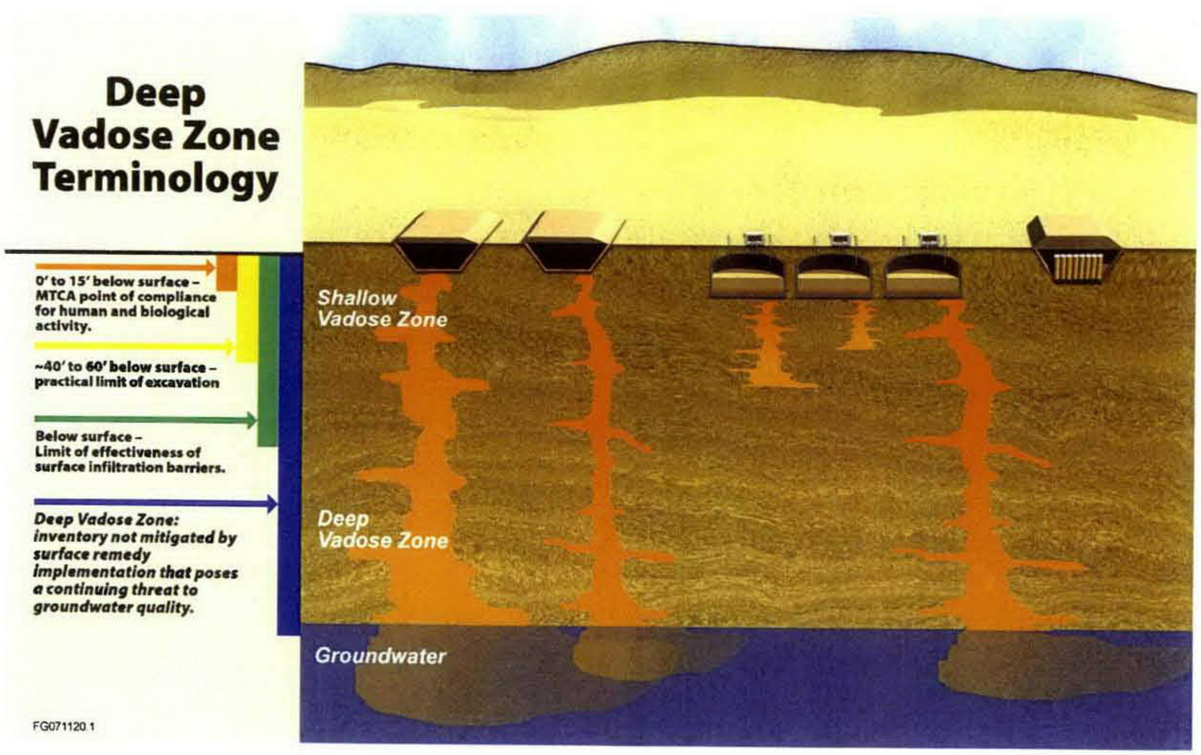

Figure 1-2. The Deep Vadose Zone Is the Target of This Plan.

approximately 900 facilities that operated at Hanford during 1943 to 1989 to process irradiated materials produced in reactors near the Columbia River and extract plutonium. The byproducts of this activity were effluents contaminated in various degrees with chemicals and radionuclides. The most dangerous waste was stored in 177 underground tanks. Some of this waste has been released to the vadose zone. Also, some concentrated waste was discharged into engineered surface structures and allowed to percolate through the vadose zone.

Contamination residing in the deep vadose zone was, in most cases, driven there by the liquid waste and natural recharge or recharge from Hanford operations. Natural recharge could be as high as 100 mm/year or as little as a fraction of a millimeter, depending on soil type and vegetation. Hanford operations-related recharge could be much higher, produced by runoff from roads and structures, leaking water pipes, and dust suppression activities. The volume of fluid discharged to the vadose zone is poorly documented in most cases.

1-2. Goals and Objectives

The overriding objective of this treatability test plan is to provide a strategy to evaluate specific vadose zone remediation technologies for technetium-99 and uranium including the appropriate laboratory, modeling, and field tests to address deep vadose zone issues. Figure 1-3 shows the relationship between this treatability test plan and future remediation efforts. This effort, once implemented, will be used to support remedy selection and post-remedial decision design, deployment, and operation of remediation technologies in the 200 Area, include the following:

- Remediation of contaminated soil and groundwater
- Closure of tank farms
- Closure of cribs and trenches

The objective of this test plan is to provide a strategy to evaluate specific vadose zone remediation technologies including the appropriate laboratory, modeling, and field tests to tackle deep vadose zone issues.

Decisions for contaminated deep vadose zone waste sites regulated under both CERCLA remedial decision making and RCRA corrective action decision making will be supported by this treatability test plan. As stated in Section 7 of the Tri-Party Agreement Action Plan, the CERCLA process is "functionally equivalent" to that of RCRA corrective action. Treatability test plan activities and subsequent activities that will be performed to support deep vadose zone remedy selection will satisfy the purpose of both statutory programs. Where CERCLA terms and processes are used in this document, they are also used to indicate equivalent terms or processes for the tank farm RCRA corrective action program.

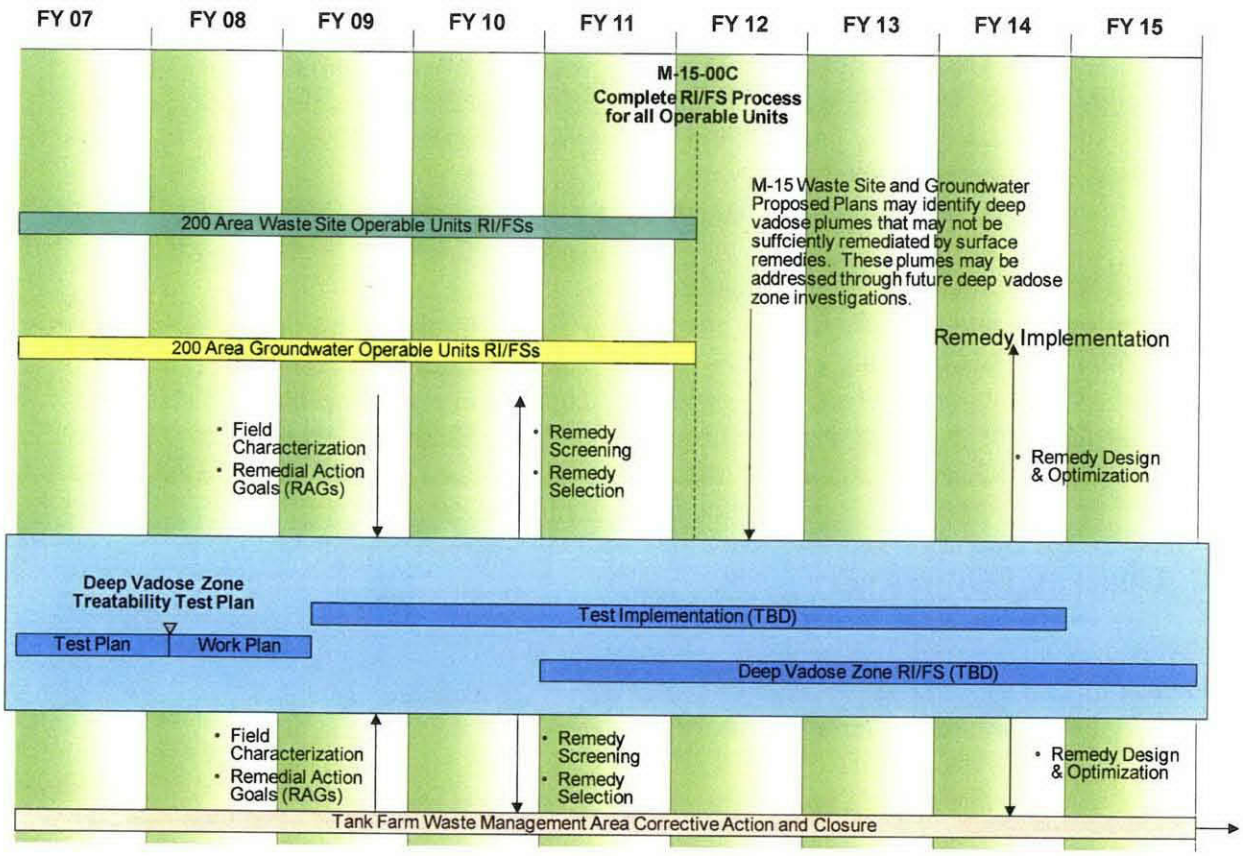

Figure 1-3. Relationship Between This Treatability Test Plan and Future Remediation Efforts.

As guidance for developing specific activities to evaluate technologies, treatability testing objectives, and related decisions were defined. Table 1-1 shows the objectives and decisions for implementing deep vadose zone treatment of technetium-99 and uranium and the type of data that will be collected through treatability tests and related analyses to address these items. Additional data elements may be added based on the results of initial treatability activities.

Table 1-1. Treatability Test Objectives and Related Key Decisions.

Primary Objective	Outcome	Detailed Sub-Objectives
Determine impact of near surface conditions, natural recharge, and remediation activities (e.g., surface barriers) on deep vadose zone contamination	Inclusion of surface elements in design of deep vadose zone remediation	Evaluate transport with no action (baseline)
		Evaluate transport with anticipated changes in surface vegetation due to remediation activities other than installation of surface barriers
		Evaluate impact of surface barriers on transport
		Evaluate impact of episodic events outside normal seasonal variation on transport
Evaluate subsurface properties and their impact on mechanisms of deep vadose zone remediation	Design criteria to address subsurface conditions	Evaluate impact of subsurface properties and heterogeneities for soil gas flow
		Evaluate impact of subsurface properties and heterogeneities for flow of aqueous solutions or fluids other than soil gas
		Evaluate magnitude and longevity of reducing conditions based on subsurface properties
		Define solution chemistry of pore water and evaluate impact on vadose zone remediation
Evaluate subsurface contaminant and moisture distribution and their impact on requirements for deep vadose zone remediation	Design criteria to address subsurface conditions	Define vertical and horizontal extent of contamination and elevated soil moisture
		Define distribution of contaminants and moisture in layers of differing properties
Define and quantify mechanisms for vadose zone remediation	Technical assessment of remediation process effectiveness and implementability	Address current technical uncertainties for remediation mechanisms
		Quantify stoichiometry, kinetics, or other key parameters for remediation mechanisms
Define and quantify impact of vadose zone remediation on subsurface conditions and contaminant transport over time	Technical assessment of remediation process effectiveness and implementability	Evaluate short-term impact of remediation on contaminant transport
		Evaluate longevity of remedy and long-term impact of remediation on contaminant transport

Table 1-1. Treatability Test Objectives and Related Key Decisions (cont.).

Primary Objective	Outcome	Detailed Sub-Objectives
Assess technology implementability	Design requirements for implementation	Equipment and operational requirements to achieve necessary treatment effectiveness
Define cost factors for vadose zone remediation	Cost analysis for specific applications of vadose zone remediation	Provide capital and initial operating cost estimates
		Provide long-term operation and monitoring cost estimates
(1) Specific activities will be determined for each candidate technology based on the multi-element, phased approach described in this test plan (Section 4) and the technical uncertainties or data gaps associated with specific candidate technologies.		

1-3. Regulatory Context

Treatability test plan activities that will be performed to select a deep vadose zone remedy will satisfy the purposes of CERCLA.

Section 121(b) of CERCLA mandates that remedies "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment that "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants is a principal element." Treatability studies provide data to support remedy selection and implementation. Selection of remedial actions involves several risk management decisions. Uncertainties with respect to performance, reliability, and cost of treatment alternatives underscore the need for well-planned, well-conducted, and well-documented treatability studies.

Treatability studies provide valuable site-specific data necessary to support Superfund remedial actions. They serve two primary purposes: (1) to aid in the *selection* of the remedy, and (2) to aid in the *implementation* of the selected remedy. Treatability studies conducted during a remedial investigation/feasibility study indicate whether a given technology can meet the expected cleanup goals for the site and provide important information to aid in remedy selection. Treatability studies conducted during remedial design/remedial action establish the design and operating parameters necessary to optimize technology performance and implement a sound, cost-effective remedy.

Site characterization and treatability investigations are two of the main components of the remedial investigation/feasibility study process. As site and technology information is collected and reviewed, additional data needs for evaluating alternatives are identified. Treatability studies may be required to fill some of these data gaps.

In the absence of data in the available technical literature, treatability studies can provide the critical performance and cost information needed to evaluate and select treatment alternatives. The purpose of a treatability investigation performed prior to a record of decision is to provide the data needed for the detailed analysis of alternatives during the feasibility study. The 1990 revised National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (55 FR 8813), Section 300.430(e), specifies nine evaluation criteria to be considered in this assessment of remedial alternatives:

- Overall protection of human health and environment
- Compliance with applicable or relevant and appropriate requirements
- Long-term effectiveness and permanence
- Reduction of toxicity; mobility or volume through treatment
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance

Treatability studies can generally provide data to address the first seven of these nine criteria.

In the absence of data in available literature, treatability studies can provide the critical performance and cost information needed to evaluate and select treatment alternatives.

In addition to the technical and scientific value of conducting tests, EPA and Ecology have formally requested that DOE evaluate and test technologies for remediation of deep vadose zone contamination. In a letter dated December 7, 2004 (Appendix A), EPA and Ecology requested that DOE "...develop a strategy for improved methods to understand the nature and extent of vadose zone contamination and to develop remedial options for addressing such contamination..." specifically for technetium-99. The development of improved methods for understanding vadose zone contamination is currently being conducted through the individual waste site programs. Investigations of improved remedial options has been addressed to date by evaluating treatment technologies (e.g., HG 2007) and conducting two technical workshops employing panels of outside experts with input solicited from the regulatory agencies. These panels evaluated the utility of employing electrical resistivity measurements to characterize contamination in the deep vadose zone (FHI 2007), and examined and assessed a number of potential treatment technologies for immobilizing technetium-99 in the deep vadose zone (FHI 2006). Significant efforts in the laboratory addressing the behavior of technetium-99 and the effect of specific remediation techniques have and continue to be performed.

Making cleanup decisions for the deep vadose zone is further complicated by the following factors:

- The Tri-Party Agreement has administratively segregated the investigation and decision making for source operable units from the groundwater operable units that may be affected by those sources.

- Deep vadose zone problems are distributed across many different waste site operable units and tank farm waste management areas so there is not currently a single investigation or decision process address this problem.
- Deep vadose zone contamination from multiple sources, operable units and areas under different regulatory authority is often commingled in the subsurface.
- The TPA calls for completion of pre-record of decision assessments for waste sites and groundwater on the Central Plateau by December 31, 2011. It is unlikely that there will be sufficient information to make deep vadose remedy decisions by that time. Therefore, some deep vadose zone assessments and decision making are likely to extend well beyond this milestone.
- The schedule for addressing potential tank farm sources in the deep vadose zone is many years later than other sources which complicates earlier remedy selection for contaminated groundwater.

As a result of these challenges, DOE, EPA, and Ecology have formed a Tri-Party work group to address the regulatory and decision-making challenges. This work group is known as the Deep Vadose Zone Strategy Working Group, and it is chartered with developing a recommended approach for addressing deep vadose zone investigations and decision making in an integrated manner. One intent of this work group is to better coordinate deep vadose zone investigations so that there is time for incorporating results from this treatability test plan.

1-4. Participation by Regulators, Stakeholders, and Tribes

DOE will be soliciting active participation by interested parties to finalize this test plan.

Throughout the course of development of this plan for technetium-99 and uranium, informational meetings have been held with regulators, stakeholders, Tribes, and State of Oregon Department of Energy to solicit input on its approach and contents (Table 1-2). DOE will be soliciting active participation by interested parties in finalizing this test plan. As portions of this plan are implemented (e.g., laboratory studies of specific remediation technologies), regulatory agencies and stakeholders will continue to be fully informed and their input to the work will be solicited. There will be a 90-day review period with a workshop to facilitate participation by all interested parties. Any field work conducted under this plan will be guided by a work plan approved by the regulatory agencies.

1-5. Test Plan Development Team

This plan has been written by a team with members from the DOE Richland Operation Office and Office of River Protection, Fluor Hanford, Inc., Pacific Northwest National Laboratory, and CH2M HILL Hanford Group, Inc. Fluor Hanford, Inc. has been responsible for the overall integration and production of this Plan.

Table 1-2. Meetings in Which the Deep Vadose Zone Treatability Test Plan was Discussed.

Date	Deep Vadose Zone Integrated Project Team[a]	Deep Vadose Zone Strategy Working Group[a]	Monthly Groundwater Meetings held at Washington Department of Ecology Facilities[b]
Nov. 13 2006	X		
Jan. 16 2007	X		
Feb. 14 2007	X		
Mar. 14 2007	X		
Apr. 24 2007	X		
May 15 2007			X
May 22 2007	X		
Jul. 25 2007		X	
Aug. 15 2007			X
Aug. 23 2007		X	
Oct. 4 2007		X	
Oct. 17 2007			X

(a) Team includes representatives from DOE-RL, DOE-ORP, regulatory agencies, and contractors. Several different integrated project teams have been formed to address various crosscutting issues at the Hanford Site.

(b) Team includes representatives from DOE-RL, DOE-ORP, Tribal Nations, regulatory agencies, contractors, and the state of Oregon.

This page intentionally left blank.

2-0. Considerations for Deep Vadose Zone Remediation

This section discusses the context for application of vadose zone remediation technologies in the Central Plateau at Hanford by identifying technetium-99 and uranium for initial treatability tests (Section 2-1), discussion of relevant subsurface conditions (Section 2-2), and the related uncertainties for application of remediation technology (Section 2-3). Section 2-4 summarizes previous technology evaluation efforts and identifies promising technologies that were identified in those studies.

2-1. Contaminants

Characterization efforts in the Central Plateau have identified a number of radiological and hazardous chemical contaminants in vadose zone soil at Hanford. Tri-Party Agreement Milestone M-015-50 specifies that this treatability test plan focus on remediation of technetium-99 and uranium. Information obtained through this effort can be used to evaluate remediation technologies potentially applicable to a wide range of deep vadose zone contaminants. Technetium-99 and uranium are long lived, have been identified deep in the vadose zone and, in several locations, have reached the aquifer and contaminated groundwater. There are also a number of locations where significant inventories of these contaminants have been detected deep in the vadose zone but apparently have not reached groundwater.

Technetium-99 and uranium were identified in the TPA milestone as the focus for this treatability test.

Technetium-99 is generally considered to have a partition coefficient near zero, which means that it moves through the soil and groundwater with water and is not retarded through interaction with the soil. The behavior of technetium-99, therefore, is representative of other highly mobile contaminants in remediation technologies that rely on physical sequestration or immobilization, such as nitrate.

Unlike technetium-99, the extent to which uranium interacts (e.g., adsorbs) with sediment particles depends on the chemistry of the environment (Zachara et al. 2007). The presence of uranium in the groundwater at several locations beneath the Central Plateau is evidence that uranium and other compounds with similar partitioning behavior can be transported through the vadose zone.

Both uranium and technetium-99 form compounds with transport properties that differ depending on their oxidation-reduction state. As such, these compounds are suitable to test technologies that can alter the oxidation-reduction conditions.

2-2. Subsurface Conditions

Current subsurface conditions have a significant effect on remediation technology performance, yet currently are not sufficiently defined for application of in situ remediation technologies. A brief description of the deep vadose zone beneath the Hanford Central Plateau is provided here to summarize the key features, *Current subsurface conditions have a significant effect on remediation technology performance, yet currently are not sufficiently defined for application of in situ remediation technologies.*

events, and processes that must be considered in applying deep vadose zone remediation. A more in-depth discussion is included in Appendix D. However, for detailed information and descriptions of the Hanford vadose zone the reader should refer directly to the following reports:

- Zachara, J.M., J.N. Christensen, P.E. Dresel, S.D. Kelly, C. Liu, J.P. McKinley, R.J. Serne, W. Um, and C.F. Brown. 2007. *A Site Wide Perspective on Uranium Geochemistry at the Hanford Site*. PNNL-17031, Pacific Northwest National Laboratory, Richland, Washington.
- DOE. 2007a. *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, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE. 2007b. *Vadose Zone Modeling at the Hanford Site: Regulatory Criteria and Compliance for Risk Assessment Applications.* DOE/RL-2007-34, Rev. 0. U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- Reidel, S.P. and M.A. Chamness. 2007. *Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site*. PNNL-15955, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.
- Khaleel, R. 2007. *The Far-Field Hydrology Data Package for the RCRA Facility Investigation RFI Report.* RPP-RPT-35222, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.
- Cantrell, K.J., J.M. Zachara, P.E. Dresel, K.M. Krupka, and R.J. Serne. 2007. *Geochemical Processes Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*. PNNL-16663, Pacific Northwest National Laboratory, Richland, Washington.
- Fayer, M.J. and J.M. Keller. 2007. *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas.* PNNL-16688, Pacific Northwest National Laboratory, Richland, Washington.
- CHG. 2007. *Central Plateau Vadose Zone Remediation Technology Screening Evaluation.* CH2M HILL Hanford Group, Inc. Richland, Washington.
- Ward, A.L., M.E. Conrad, W.D. Daily, J.B. Fink, V.L. Freedman, G.W. Gee, G.M. Hoversten, J.M. Keller, E.L. Majer, C.J. Murray, M.D. White, S.B. Yabusaki, and Z.F. Zhang. 2006. *Vadose Zone Transport Field Study: Summary Report* . PNNL-15443, Pacific Northwest National Laboratory, Richland, Washington.
- Last, G.V., E.J. Freeman, K.J. Cantrell, M.J. Fayer, G.W. Gee, W.E. Nichols, B.N. Bjornstad, and D.G. Horton. 2006b. *Vadose Zone Hydrogeology Data Package for Hanford Assessments* . PNNL-14702 Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

- Kincaid, C.T., P.W. Eslinger, R.L. Aaberg, T.B. Miley, I.C. Nelson, D.L. Strenge, and J.C. Evans, Jr. 2006. *Inventory Data Package for Hanford Assessments*. PNNL-15829, Rev.0, Pacific Northwest National Laboratory, Richland, Washington.
- DOE. 2000. *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas*. DOE/RL-99-36, Rev. 1. U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- Hartman, M.J. 2000. *Hanford Site Groundwater Monitoring: Setting, Sources, and Methods*. PNNL-13080, Pacific Northwest National Laboratory, Richland, Washington.
- DOE. 1999. *200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program*. DOE/RL-98-28, Rev. 0. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

The vadose zone is the region of the subsurface that extends from the ground surface to the water table. The vadose zone beneath the Central Plateau ranges in thickness from about 50 meters (164 feet) in the western portion of the 200 West Area to 104 meters (341 feet) in the southern part of 200 East Area (Last et al. 2006b). The geology and hydrology of the Central Plateau have been extensively studied because these areas are major historic sources of soil and groundwater contamination (Hartman 2000).

The vadose zone beneath the Central Plateau ranges in thickness from ~164 feet in the west to 341 feet in the south, and the stratigraphy varies significantly across this area.

The major stratigraphic units making up the vadose zone are listed below:

- Surface wind-deposited sand and silt deposits
- Unconsolidated sand and gravel of the Hanford formation
- Silt and carbonate-cemented layers of the Cold Creek unit
- Semi-consolidated sand and gravel of the Ringold Formation

The stratigraphy varies significantly across the Central Plateau. The vadose zone beneath 200 West Area consists of the Hanford formation, Cold Creek unit, and Ringold Formation, whereas the vadose zone beneath 200 East Area consists almost solely of the Hanford formation. A geologic cross section showing the general stratigraphy through this region is shown in Figure 2-1 (Hartman 2000).

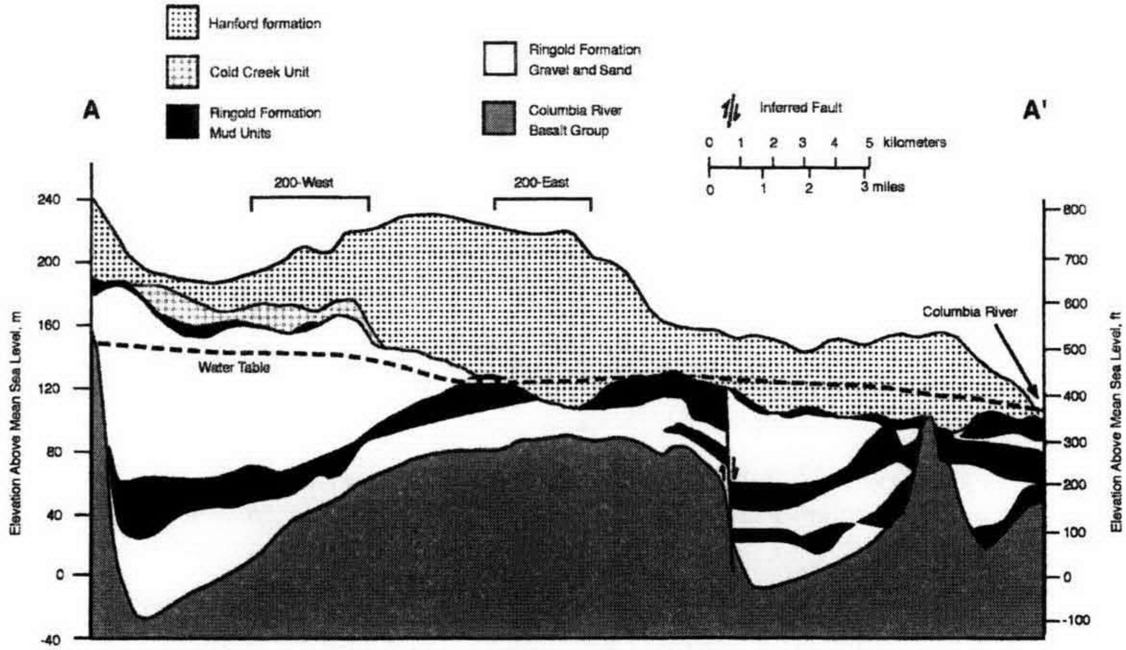

Figure 2-1. Generalized West-to-East Geologic Cross Section through the Hanford Site (after Hartman 2000)

The physical structure and properties of the geologic framework affect contaminant movement and distribution within the vadose zone (DOE 1999c; Last et al. 2006b; Reidel and Chamness 2007) and can have significant impacts on the implementability and effectiveness of remedial technologies. Some of the important subsurface features are the nature and degree of contrast between sediment types and sedimentary features (e.g., silt lenses, buried soil horizons, and clastic dikes). Figure 2-2 illustrates some of these important features of the 200 Area vadose zone.

Contaminants entered the vadose zone through a variety of liquid waste discharges, solid waste burials, and unplanned releases (Gephart 1999). The nature and extent of contamination within the vadose zone was affected by the waste chemistry and type of release. Technetium-99 and uranium were carried into the deep vadose zone due to their mobility and driving forces from previous releases, as well as nearby water releases and natural precipitation events. Technetium-99 and uranium may continue to migrate toward the groundwater when present as a dissolved component of mobile pore fluids and driven by infiltrating water.

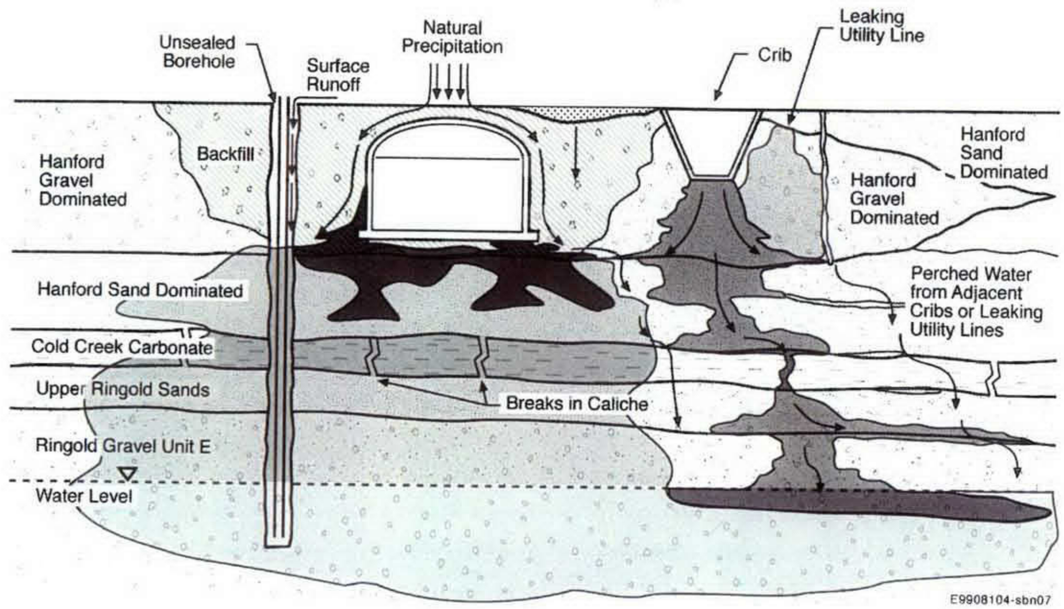

Figure 2-2. General Vadose Zone Conceptual Model Concepts after Last et al. (2006b).

The long-term natural driving force for flow and transport through the vadose zone is "recharge," that fraction of the precipitation that has infiltrated below the zone of evaporation and below the influence of plant roots to eventually recharge the groundwater. Recharge rates range from <0.1 to 92 mm/year based on surface conditions (Fayer and Keller 2007).

Since the discharge of large volumes of water has ceased, the primary processes governing flow and transport through the vadose zone depend on the physical and chemical nature of the geologic materials that make up the vadose zone as well as the types, amounts, and compositions of the fluids that occupy the pore spaces (Looney and Falta 2000, p. 13). The natural transport of technetium-99 and uranium can vary spatially and temporally depending on these factors and variations in geochemical conditions (e.g., oxidation-reduction potential). Remediation techniques are based on changing the subsurface conditions to either minimize the transport of technetium-99 and uranium or enhance their removal from the vadose zone.

2-3. Target Problem Sites

Of most importance to this study are those sites where large inventories of technetium-99 and uranium have penetrated deep in the vadose zone and may migrate to groundwater causing maximum contaminant levels to be exceeded in the aquifer. Disposal inventories (Kincaid et al. 2006; Corbin et al. 2005), depth of contamination (DOE 2007c), and potential risk to groundwater (Eslinger et al. 2006), were evaluated to define the target problem sites to set the basis for evaluating deep vadose zone remediation technologies (see Appendix D). The characteristics of these target problem sites were also used to assess technology applicability and to identify suitable candidate sites for field testing components of the treatability test.

The primary processes governing flow and transport through the vadose zone depend on the subsurface conditions and composition of the fluids that occupy the pore spaces. Remediation techniques are based on changing these subsurface conditions to either minimize the transport of technetium-99 and uranium or enhance their removal from the vadose zone.

One of the primary resources used to evaluate potential target problems was an analysis by Eslinger et al. (2006), which was conducted to better understand the relative threat to the unconfined aquifer from waste sites in the vadose zone of the Central Plateau region. Eslinger et al. (2006) used inventory, contaminant release into and from the vadose zone, and hypothetical concentrations in groundwater to rank the threat posed to the aquifer by individual waste sites and groups of waste sites. Because remedial action decisions will be made for groups of sites, rather than individual sites, Eslinger et al. (2006) grouped individual waste sites into 32 groups that received similar waste and were located in the same geographic area. Based in large part on the analysis by Eslinger et al. (2006), supplemented by site inventories and other information (see Appendix D), the target problem sites for technetium-99 and uranium were identified as follows:

Technetium-99 Target Problems
- BC cribs and trenches (e.g. 216-B-14, -18)
- BY cribs and vicinity (e.g. 216-B-46, -49)
- T Tank Farm and vicinity (e.g. 241-T-106)
- S/SX Tank Farms and vicinity (e.g. 241-SX-108)

Uranium Target Problem Sites
- 200 East Ponds Region (e.g. 216-A-19)
- U cribs (e.g. 216-U-8, -12, -1&2)
- B Plant cribs and trenches (e.g. 216-B-12)
- B, BX, BY Tank Farms (e.g. 241-BX-102)
- Plutonium-Uranium Extraction (PUREX) cribs and trenches (e.g. 216-A-4, -3, -9)
- Reduction and Oxidation (REDOX) cribs and trenches (e.g. 216-S-7, -1 and 2)

The Hanford formation and Ringold Formation are considered the primary targets for this treatability test plan, because these units make up the bulk of the vadose zone beneath the Central Plateau. In the 200 East Area, the Hanford formation comprises nearly the entire thickness of the vadose zone. In the 200 West Area, the vadose zone includes the Hanford formation, Cold Creek unit, and Ringold Formation. The Cold Creek unit is comprised of finer grained and semi-consolidated layers that impact the flow and retention of pore fluids and contaminants. However, the Hanford formation and Ringold Formation are the most permeable materials for potential continued contaminant migration and are the most likely targets for deep vadose zone remediation. Thus, initial treatability efforts focus on technologies appropriate to the Hanford formation and Ringold Formation. Potential approaches for remediation specific to immobilization or removal of contaminants in the Cold Creek unit are not specifically addressed, but may be important as part of future efforts for areas where this unit is present.

2-4. Uncertainties Related to Deep Vadose Zone Remediation

One reason for performing treatability tests for technetium-99 and uranium is that there are uncertainties with all of the in situ deep vadose zone remediation technologies and for the impact of surface or near-surface remediation technologies (e.g., surface barriers). These uncertainties have been described in previous technology reviews, in particular, the vadose zone technical team (FHI 2006) discussed general and specific uncertainties that need to be considered prior to technology implementation. Based on these previous discussions, the key uncertainties that need to be addressed can be categorized as follows:

One reason for performing treatability tests for technetium-99 and uranium is that there are uncertainties with all of the in situ deep vadose zone remediation technologies.

1. **Subsurface Conditions**. Key elements of subsurface uncertainty include (1) geology and distribution/connectivity of layers with contrasting properties, (2) spatial distribution of moisture content and contaminants, and (3) subsurface geochemistry and mineralogy. Each technology has a range of sensitivity to these uncertainties leading to specific treatability test needs for each technology as is reflected in the multi-element phased approach planned for the treatability testing (Section 4).

2. **Remediation Effectiveness.** The effectiveness of each technology depends on the chemical or physical mechanism of the technology and the subsurface conditions. Because the candidate technologies have either not been tested or have only limited testing for deep vadose zone Hanford conditions, the effectiveness is uncertain. The treatability testing will help reduce these uncertainties and provide additional data that will be useful for evaluating the effectiveness of each technology for Hanford applications. Specific uncertainties that were considered the highest priority to evaluate for each technology are discussed in Section 4.

3. **Long-Term Effectiveness**. Technologies based on contaminant immobilization (i.e., versus removal or destruction of contamination) will need to remain effective over long time periods due to the longevity of technetium-99 and uranium. However, the long-term effectiveness of these technologies is uncertain. Components of this type of uncertainty include uncertainty in the longevity and long-term impact of (1) fluid addition and removal on contaminant and moisture movement, (2) geochemical conditions induced by technologies, (3) physical changes induced by technologies, and (4) potential unintended impacts of technologies. Long-term effectiveness of technologies is also affected by the environmental conditions during the treatment time period. Thus, remediation technologies must consider potential natural- or human-induced future changes in the environment that are outside the typical

seasonal variations and the uncertainty in how technologies will perform under these potential extreme conditions.

4. **Technology Implementation.** Application of in situ technologies in the deep vadose zone will require subsurface access and consideration of surface infrastructure. Currently, only conceptual field designs for the potential in situ technologies are possible based on existing data. Key design factors such as well spacing, flow rates, and reagent quantities are still uncertain. These factors will be considered for those technologies selected for Phase 2 field demonstration efforts (see Section 4).

The treatability test approach was developed to include activities that identify uncertainties and estimate their impact on technology implementation in the initial phase of testing. Subsequent treatability activities include laboratory and field testing to provide additional data needed to address these uncertainties so that the technologies can be effectively evaluated for potential use for the Hanford target problems identified in this treatability test plan (Section 2).

2-5. Subsurface Access

Characterization and remediation of the deep vadose zone depends on the ability to gain access to the deep subsurface.

Characterization and remediation of the deep vadose zone depends on the ability to gain access to the deep subsurface. The nature of the Hanford formation, where unconsolidated sediments range from silt to cobbles, limits the type of drilling techniques that can be used and necessitates the use of a temporary steel casing to keep the borehole open while drilling. Finished boreholes or wells must be fitted with a permanent casing that is sealed to the surrounding formation with bentonite and/or cementaceous grouts. Drilling techniques are also limited by the radiological contamination concerns at some locations. Coarse cobble to boulder sediments of the Hanford formation, and the semi-consolidated nature of the Cold Creek unit and Ringold Formation sediments, limit the depth of penetration for direct push technologies (e.g., cone penetrometer). These constraints can affect the cost of subsurface access and the usefulness of some characterization and monitoring technologies (e.g., electrical borehole geophysical methods). Table 2-1 lists the type of drilling and access technologies possible at Hanford and the approximate maximum depth of installation in the vadose zone.

Table 2-1. Potential Technologies to Access the Subsurface at the Hanford Central Plateau

Technique	Well Diameter centimeters (inches)	Approximate Maximum Depth meters (feet)
Conventional Drilling (e.g., cable-tool, air-rotary, sonic)	up to 30 (12)	full vadose zone
Driven Casing (e.g., Becker hammer)	up to 15 (6)	full vadose zone
Cone Penetrometer	up to 5 (2)	~30 (100)
Sonic Cone Penetrometer	up to 5 (2)	~30 (100)
Enhanced Access Penetration System (EAPS)	up to 5 (2)	~46 (150)
Geoprobe	up to 5 (2)	~6 (20)
Hydraulic Hammer Rig	up to 8 (3)	~60 (200)

This page intentionally left blank.

3-0. Evaluation of Technologies for Treatability Testing

Previous Hanford remediation technology studies were used as the starting point for evaluating technologies for treatability testing to address contamination in the deep vadose zone. Remediation technologies for metals and radionuclides (e.g., relevant to technetium-99 and uranium) in the vadose zone have been evaluated as part of these previous efforts. *The 200 Area Remedial Investigation/Feasibility Study Implementation Plan* (DOE 1999a) listed potential technologies. A specific technology study for the BC cribs and trenches was performed and followed by a thorough review of vadose zone technologies by a technical team composed of a group of outside experts (FHI 2006). Vadose zone technology information relevant to the Hanford Tank Farms has also recently been compiled (CHG 2007). Surface barriers are recognized as potential key components of a remediation approach for the vadose zone in all of these studies. A list of all the technologies included in the studies summarized above is included in Appendix B.

This treatability test plan builds on previous studies to identify and evaluate technologies for remediation of the deep vadose zone.

3-1. Identification of Candidate Technologies

The previous studies identified and evaluated technologies for a specific application defined in each study. The technologies identified in these studies as being potentially applicable to remediation of the deep vadose zone at Hanford are those most relevant for consideration in subsequent treatability testing for technetium-99 and uranium. Thus, this treatability test plan uses the underlying technology reviews from these documents to identify candidate technologies. These technologies are then further evaluated to select the priority technologies for near-term testing. However, all of the technologies favorably evaluated in the previous studies could be considered for future testing or additional evaluation.

3-1-1. Underlying Considerations in Technology Evaluation and Selection

There are several underlying considerations used in each of the previous studies and for selection of candidate technologies for treatability testing. These considerations are consistent with the focus of treatability efforts on the Hanford formation and Ringold Formation and evaluation of the technologies based on their ability to address the subsurface conditions (noted in Section 2-0).

First, in all of the previous studies, technologies requiring the addition of significant amounts of water to the vadose zone were less preferred because of the potential for inducing uncontrolled migration of contaminants and difficulties in controlling how added water moves through the vadose zone. Dry technologies were preferred and carried forward to select appropriate technologies for treatability testing. Soil flushing technology was also carried forward at the request of regulatory agencies.

The intent of this treatability test plan is to consider in situ technologies that do not have depth limitations.

Second, several of the studies examined excavation-based technologies and technologies that may be applicable to some limited extent in the vadose zone. For instance, deep excavation, such as excavation with the use of caissons, may be suitable if a contaminated zone of limited areal and depth extent is identified. However, the intent of this treatability test plan is to consider in situ technologies that do not have depth limitations. The exception to this bias toward in situ technologies is the inclusion of surface barriers. Surface barriers are a baseline technology likely important to future remediation efforts in the Central Plateau. Although these barriers are applied at the surface, their effectiveness at reducing infiltration extends into the vadose zone. For this reason, they are considered an important component of remediating the deep vadose zone either alone or in conjunction with in situ technologies.

Third, there are ongoing efforts to examine remediation technologies at the Hanford Site, including studies of uranium at the groundwater/vadose zone interface and the groundwater in the shallower Hanford 300 Areas. The DOE EM-20 program has also initiated several projects relevant to remediation of radionuclides in the deep vadose zone. These efforts may potentially be relevant to the Hanford Central Plateau and, therefore, the ongoing development and demonstration efforts at Hanford and within the DOE are recognized in this test plan.

Previous technology reviews and this treatability test plan focus on evaluation of individual technologies. Each of these technologies might be combined with other technologies as part of a remedial alternative.

Finally, it is recognized that the previous technology reviews and this treatability test plan focus on evaluation of individual technologies. Each of these candidate technologies might be combined with other technologies as part of a remedial alternative. However, the treatability test plan focuses on testing technologies not full remedial alternatives. The performance of an individual technology needs to be evaluated to assist in later determinations of how or whether it should be combined with other technologies within a remedial alternative to meet the remediation objectives for a specific application.

3-1-2. Potential Technologies and Evaluation

The technologies selected for inclusion in this plan are listed below with a brief description and reference to the specific previous study that identified the technology. These candidates were selected as those technologies that were favorably evaluated in a previous study for application to the vadose zone.

Each of the technologies listed was considered as a potential candidate for further treatability testing. Previous evaluations considered technology implementability, effectiveness, and cost for the specific applications targeted in the previous studies. Some of the technologies were identified in one of the previous studies, but eliminated in others.

Technologies based on gas-phase advection/delivery may be preferred for vadose zone treatment at Hanford due to (1) the depth and areal extent of vadose zone contamination at Hanford, (2) the relatively high permeability material and low moisture content associated with a large portion of the vadose zone (especially the Hanford formation), and (3) the risk that water added to the vadose zone may unintentionally move contaminants into the groundwater. Four of the candidate technologies use, or can use, gas-phase advection/delivery as the mechanism for implementing them in the vadose zone: desiccation, in situ gaseous reduction, multi-step geochemical manipulation, and nanoparticles.

3-1-2-1. Desiccation

Desiccation involves drying a targeted portion of the vadose zone by injecting dry air and extracting soil moisture at soil gas extraction wells. Because desiccation removes water already in the vadose zone, it reduces the amount of pore fluid available to support downward transport of contaminants in the deep vadose zone, impedes water movement, and augments the impact of surface water infiltration control. A very limited desiccation test showing that subsurface air flow can be induced in the Central Plateau vadose zone has been performed in conjunction with a leak detection test (Cameron et al. 2002).

Removing water from the vadose zone via desiccation is promising. Thus, desiccation is included for further study.

The impact of desiccation on the movement of technetium-99 and uranium is based on physical removal of water from the subsurface. Removing water from the vadose zone via desiccation is promising. However, there are uncertainties with desiccation related to specific aspects of implementation and long-term effectiveness as described in more detail by the vadose zone technical team (FHI 2006). In spite of these uncertainties, desiccation was recommended by the technical team as a promising technology that should be considered for field testing Thus, desiccation is included for further study in the treatability test plan.

3-1-2-2. In Situ Gaseous Reduction

A reducing gas (e.g., hydrogen sulfide) can be used to directly change the oxidation state of some contaminants and render them less soluble while they remain reduced or can change the oxidation state of sediment-associated iron, which can subsequently reduce contaminants.

In situ gaseous reduction has been successfully demonstrated and is included for further testing.

In situ gaseous reduction has been successfully demonstrated for shallow vadose zone remediation of chromate. Technetium-99 and uranium can be reduced and precipitated through in situ gaseous reduction, although uncertainty remains regarding the stability of the precipitate. Because in situ gaseous reduction has the potential to immobilize technetium-99 and uranium and has been demonstrated at the field scale for similar applications, it is included for further study in the treatability test plan.

3-1-2-3. Multi-Step Geochemical Manipulation

Use of geochemical manipulation (termed "perturbation geochemistry" in the vadose zone technical team report, FHI 2006) is in the developmental stage. The technique involves introducing gases to the vadose zone that induce Eh and/or pH

Multi-step geochemical manipulation can be used to create conditions to co-precipitate contaminants with minerals.

changes and create conditions for precipitation of minerals (e.g., carbonates) with co-precipitation of contaminants. The co-precipitated contaminants are then less available for migration (FHI 2006; CHG 2007).

Geochemical manipulation such as employed by in situ gaseous reduction could be enhanced to provide more stable precipitates through use of multiple geochemical manipulation steps. While this multi-step process is still conceptual, it builds on the successful development and demonstration of in situ gaseous reduction and provides a potential for more effective immobilization of contaminants such as technetium-99 and uranium. Thus efforts to further evaluate multi-step geochemical manipulation are included in the treatability test plan.

3-1-2-4. Nanoparticles

Distribution of nanoparticles is in the conceptual phase and is not included for further testing.

Nanoscale-size particles are under development that have surface chemistry properties and large surface areas purposely designed to sequester selected metals and radionuclides (CHG 2007).

Distribution of nanoparticles in the deep vadose zone is still in the conceptual phase. Dispersal of particles at scales relevant to Hanford is potentially problematic. Thus, nanoparticles efforts are not initially included in the treatability test plan. Pending the results of technology development efforts, nanoparticles could be considered for future efforts.

3-1-2-5. Electrokinetics

Electrokinetics is not included for further testing because it is not effective in dry soil.

Electrokinetic remediation is a process in which a low-voltage direct-current (DC) electric field is applied across a volume of contaminated soil between electrodes inserted into the soil. Under the influence of a DC field, contaminants can be moved toward an electrode and then recovered (CHG 2007).

Electrokinetics has been applied at other sites for moving contaminants to a target zone where they can be extracted by other means. Electrokinetics was eliminated in previous technology (FHI 2006) because it is not effective in dry soils and implementability will likely be poor for a thick vadose zone and technetium-99 and uranium. Key problems for electrokinetics include uncertainty of unintended consequences induced by concentrating contaminants and water in a small area of the vadose zone, limited zone of influence for the electrodes, and applicability limited to fine-grained layers with relatively high moisture content. Because of these significant potential problems, electrokinetics is not included for treatability testing. However, electrokinetics could be considered for specific applications as part of other efforts. For instance, electrokinetics may be considered for application in the Cold Creek unit.

3-1-2-6. Grout Injection Technologies

Grout injection addresses subsurface contaminants by injection of a grout or binding agent into the subsurface to physically or chemically bind or encapsulate contaminants. There are multiple types of grout/binding materials and emplacement techniques that have been developed and demonstrated (CHG 2007).

Grouting technologies have the potential for use as part of a remediation strategy and are included for further testing.

Grout injection technologies using multiple types of grouting materials have been applied and are currently undergoing testing for in situ contaminant stabilization at other sites. Likewise, more standard grouting techniques may also potentially be useful for selected applications. There are significant uncertainties with use of grouting for in situ contaminant stabilization, especially for the deep vadose zone as discussed by the vadose zone technical team (FHI 2006). However, because grouting technologies have the potential for use as part of a remedy for the deep vadose zone, further efforts to evaluate the performance of grouting technologies are included in the treatability test plan.

3-1-2-7. Soil Flushing

Soil flushing operates through addition of water, and an appropriate mobilizing agent if necessary, to mobilize contaminants and flush them from the vadose zone and into the groundwater where they are subsequently captured by a pump-and-treat system (CHG 2007).

Soil flushing provides a potential mechanism to remove contaminants from the subsurface and is included for further testing.

There are significant uncertainties for implementation of soil flushing in the deep vadose zone related to understanding and controlling flow paths for water added to the vadose zone and providing effective capture of flushed contaminants in the groundwater. However, soil flushing provides a potential mechanism to remove contaminants from the subsurface. Efforts are needed to determine whether it is feasible to implement soil flushing in a way that minimizes these uncertainties for applications to the deep vadose zone. Thus, further evaluation of soil flushing is included in the treatability test plan.

3-1-2-8. Surface Barriers

Reduction of surface water infiltration by surface barriers reduces the hydraulic driving force for contaminant migration. The Hanford Prototype Barrier was installed in 1995 and has a significant amount of monitoring data available. A polyurea barrier is being constructed at the 241-T-106 site as of December 2007. The impact of surface barriers has also been simulated in several modeling studies (FHI 2006; CHG 2007).

Surface barriers are a baseline technology for near-surface contamination and previous technology screening studies identified surface barriers as a promising technology for the deep vadose zone. Installation of a surface barrier specifically

Treatability testing of surface barriers is warranted to assess their role in remediation of deep vadose zone contamination.

for the deep vadose zone testing is envisioned as beyond the scope of this treatability test plan. However, there are three surface barrier applications at Hanford with ongoing or planned monitoring that will provide data useful for evaluation with respect to the deep vadose zone. These barriers include the prototype Hanford Barrier constructed over the 216-B-57 crib, the polyurea barrier at the 241-T-106 site, and the surface barriers planned for the 216-U-1 Operable Unit. Testing of surface barriers is warranted to assess their role in treating deep vadose zone contamination.

3-1-2-9. Monitored Natural Attenuation

The EPA Office of Solid Waste and Emergency Response through Directive 9200.4-17P (EPA 1999) recognizes that natural attenuation processes may limit migration of contaminants through the subsurface and constitute all or part of a remedy.

While there is not a specific evaluation of monitored natural attenuation underway for technetium-99 and uranium in the vadose zone at Hanford, there are ongoing field monitoring, characterization, laboratory, and modeling activities that are providing information necessary to understand and predict the fate and transport of contaminants through the vadose zone and groundwater. These efforts related to monitored natural attenuation are by nature site-specific and are not explicitly included as part of this treatability test plan. However, environmental monitoring and site characterization data from field test sites will be used to evaluate the effectiveness of monitored natural attenuation as compared to that of the tested technology.

3-1-3. Technologies Selected for Treatability Testing

Summarizing the discussion in the sections above, the following technologies were selected for inclusion in the treatability test plan:

1. Desiccation
2. In Situ Gaseous Reduction
3. Multi-Step Geochemical Manipulation
4. Grouting Technologies
5. Soil Flushing
6. Surface Barriers

Treatability testing will be coordinated with other ongoing investigations at the Hanford Site.

3-2. Description of Related Efforts at Hanford and Within DOE

Ongoing DOE and Hanford activities are investigating the basic scientific understanding needed to develop remediation technologies. The methods and approaches for these investigations are defined through other projects and will not be provided as part of this treatability test plan. However, the information obtained from these activities will be considered as part of the evaluation process for the deep vadose zone treatability test project as described in the following paragraphs. The process for coordinating activities conducted under this plan with other initiatives is described in Section 4.

Uranium Treatability Testing in the 300 Area. The 300 Area Uranium Plume Treatability Demonstration Project is evaluating the use of polyphosphate infiltration either from ground surface or some depth of excavation to stabilize in situ uranium within the deep vadose zone and the capillary fringe (i.e., zone of water-table fluctuation) above the 300 Area aquifer. The polyphosphate technology was selected for further testing during the 300-FF-5 Phase III Feasibility Study technology screening process. Source treatment in the vadose zone has been shown to accelerate the attenuation of uranium to uranium-phosphate minerals, enhancing the performance of the polyphosphate treatment within the 300 Area aquifer. Data obtained from this study will be used to develop implementation cost estimates, identify implementation challenges, and investigate the ability of the technology to meet remedial objectives. This information will be used to establish the viability of the method and determine how best to implement the technology in the field.

The use of polyphosphate infiltration to treat uranium contamination is being investigated at the 300 Area.

The first phase of the uranium plume treatability demonstration project was a study to integrate site-specific characterization data with laboratory testing to optimize the polyphosphate amendment for implementation of a field-scale demonstration of the technology (Wellman et al. 2006). The second phase of the treatability demonstration is bench scale and field scale treatability testing designed to evaluate the efficacy of using polyphosphate injections to reduce uranium concentrations in the groundwater to meet federal maximum contaminant levels (30 μg/L) in situ (Vermeul et al. 2007).

The overall objectives of the treatability test include the following:

- Conduct a polyphosphate injection to evaluate reduction of aqueous uranium concentrations and to determine the longevity of the treatment zone.
- Demonstrate field-scale application of polyphosphate injections to identify implementation challenges and evaluate whether a full-scale deployment is feasible.
- Determine the number of wells, reagent concentrations, volumes, injection rates, operational strategy, and longevity for polyphosphate injections to remediate uranium such that costs for larger-scale application can be effectively estimated.

DOE's Integrated Field Research Center is investigating the processes that control natural attenuation and engineered remediation at a site in the 300 Area contaminated with uranium.

300 Area Integrated Field Research Center. The 300 Area Integrated Field Research Center is a DOE-funded field site to support research on multi-scale mass transfer processes controlling natural attenuation and engineered remediation. This center is studying the 300 Area uranium plume, but the outcomes will likely be applicable to uranium in the Central Plateau and to physical, chemical, and microbial processes influencing remediation of other contaminants. The research focuses on accurate prediction of dissipation times for groundwater plumes of sorbing contaminants, optimal delivery of remediation reactants, and the effectiveness of remediation technologies.

The center will provide new experimental and field data to understand the controls on uranium distribution, to investigate microbial processes that influence phosphate barrier performance and longevity, and to improve models of reactive transport in the subsurface. The results will be transferred for input to remediation decisions and deployment.

Some of the DOE Environmental Remediation Science Program studies focus on biological remediation.

Technetium-99 and Uranium Remediation Research. A number of projects under the DOE Environmental Remediation Sciences Program are studying technetium-99 and uranium remediation. Many of these efforts focus on biologically mediated reactions. Technetium-99 remedial alternatives for the deep vadose zone are less well developed than those for uranium. This is due, to some extent, to the challenging geochemical properties of technetium-99. Under oxidizing conditions the Tc(VII) forms anionic pertechnetate ion and is highly mobile in the subsurface. Under more reducing condition technetium-99 is present in a Tc(IV) cationic form that is more strongly sorbed to sediments. However, the reduced Tc(IV) is apparently readily re-oxidized to pertechnetate.

Several Environmental Remediation Science Program research projects included in the 2007 DOE Environmental Remediation Sciences Program integration meeting are of note for developing deep vadose remedial alternatives. Although lessons can be extracted from these studies, considerable work needs to be done before they can be considered at Hanford.

- One particularly novel approach to biological sequestration of uranium is being researched by Mark Conrad and coworkers at Lawrence Berkeley National Laboratory. This approach uses gas-phase introduction of triethyl phosphate to stimulate microbial precipitation of uranium (and strontium) bearing phosphate minerals.
- Patricia Sobecky and coworkers at Georgia Institute of Technology are investigating the immobilization of uranium through microbial mediated precipitation of phosphate minerals. Their research is focusing on two bacterial strains isolated from the DOE field research center in Oak Ridge, Tennessee.
- Kathryn Nagy and coworkers from the University of Illinois and Argonne National Laboratory are investigating the formation kinetics of uranium-bearing low temperature silicate minerals.
- Peter Jaffé and others at Princeton University are investigating the reoxidation of uranium after biological precipitation. This is important for evaluating the long-term effectiveness of bioremediation.

- Pacific Northwest National Laboratory (PNNL) workers, led by Alexander Beliaev, are investigating uranium and technetium-99 reduction by bacteria. Their goal is to characterize the metal respiratory system on a genomic scale.
- A team at Georgia Tech University, led by Thomas DiChristina, is investigating uranium and technetium-99 reduction mechanisms by Shewanella bacteria.
- Jim Fredrickson and others at PNNL are also investigating Shewanella reduction of uranium and technetium-99. They are evaluating the reduction mechanisms and the reactivity of the contaminants.
- Jack Istok and coworkers at Oregon State University are developing a thermodynamic network model to predict how substrate additions and environmental perturbations affect the composition and stability of subsurface uranium and technetium-99 reducing microbial communities.

Technetium-99 Remediation Technology Demonstration. The DOE Advanced Remediation Technology Program has funded a project to demonstrate the ability of a bioremediation method to immobilize technetium-99 in the groundwater. The contractor, ARCADIS U.S., Inc., will be testing their Enhanced Anaerobic Reductive Precipitation/Enhanced Reductive Dechlorination technology in the 200-UP-1 Operable Unit, near S-SX Tank Farms.

During tests near the S-SX Tank Farms, a food-grade carbohydrate substrate will be injected into groundwater to alter the microbial population and precipitate metals.

During the test, a food-grade carbohydrate substrate will be injected into groundwater to alter the microbial population, precipitate metals, and enhance the biological and abiotic degradation of chlorinated aliphatic hydrocarbons. Additional ferrous iron and sulfate may be added with the carbohydrate to the subsurface to generate iron sulfide minerals that co-precipitate, sorb, and/or encapsulate the metals to protect them from re-oxidation. The goals of the test are to:

- Demonstrate effective distribution of reagents to the targeted aquifer
- Demonstrate that reducing biogeochemical conditions (i.e., sulfate reducing) can be induced and sustained for a treatment period (i.e., 18 months to 2 years)
- Demonstrate that the concentrations of key contaminants in the groundwater are decreased to below treatment goals in 2 years or less in the reactive zone
- Demonstrate that the precipitated radionuclides and metals remain in insoluble forms
- Show that secondary water quality impacts of the Environmental Remediation Sciences Program technology are limited downgradient of the reactive zone

A combination of groundwater monitoring before, during, and after treatment along with soil sampling for metal/radionuclide speciation and concentration or activity will be used to demonstrate that the goals have been achieved.

The objective of the DOE-EM Engineering & Technology Program is to reduce the technical risk and uncertainty in DOE's clean-up programs and projects.

DOE EM-20 Roadmap Projects. The DOE Office of Environmental Management (EM) established the DOE-EM Engineering & Technology Program to provide applied research and engineering support to the cleanup mission. The objective of the DOE-EM Engineering & Technology Program is to reduce the technical risk and uncertainty in the DOE's clean-up programs and projects. The Engineering & Technology Program efforts are organized using a roadmap approach that documents and identifies the engineering and technical risks the DOE-EM program faces over the next ten years, the strategies DOE-EM will use to minimize these risks, and the planned outcomes of implementing those strategies.

Strategic initiatives that address key technical risk and uncertainty in the DOE-EM program have been developed from the roadmap. The initial efforts are being directed toward the following program areas:

- Waste Processing
- Groundwater and Soil Remediation
- Deactivation and Decommissioning (D&D) and Facility Engineering Strategic Initiatives
- Integration and Crosscutting Initiatives

Strategic initiatives within the Groundwater and Soil Remediation Program (EM-22) and Crosscutting Program described in the roadmap are potentially relevant to deep vadose remediation at Hanford. Roadmap projects for groundwater and soil remediation that were initiated in FY 2007 are listed below. The specific scope and schedule of these efforts is contingent on program budgets that have not yet been established.

- Scientific and Technical Basis for In Situ Treatment Systems for Metals and Radionuclides
- Scientific Basis for Attenuation Based Remedies for Metal and Radionuclide Contaminated Groundwater
- Develop Advanced Fate and Transport Models – Conceptual and Numerical Model Development for High-Risk Contamination and Site(s)
- Idaho Sr-90 Immobilization / Uncertainty Reduction Project (Advanced Strategies for Monitoring and In Situ Remediation of Sr-90)
- Demonstrate Methods to Reduce Transport Rate of Chlorinated Organics through the Deep Vadose Zone
- Enhanced Attenuation for Chlorinated Solvents Technology Alternative Project
- Develop Next Generation Characterization Technologies and Strategies

4-0. Treatability Test Approach

A multi-element approach was selected because potential technologies are at different stages of development, and there are several categories of remediation approaches that require somewhat different types of assessment. Additionally, selection of an appropriate field testing site is linked to the need for demonstrating a specific technology, the risk associated with the field demonstration, and the relevance to high priority target site vadose zone problems. The multi-element approach to address these treatability testing needs is depicted in Figure 4-1. Note that this approach includes plans for field testing at sites contaminated with technetium-99 and uranium. The approach includes two primary phases. The first phase focuses on conducting laboratory work and modeling to understand uncertainties of each technology. Field testing is planned as Phase 2 of the treatability test plan if supported by results from Phase 1.

A multi-element approach was selected because potential technologies are at different stages of development, and there are several categories of remediation approaches that require somewhat different types of assessment.

Table 1-1 summarizes the treatability test objectives and related key decisions addressed in this document. The flow chart in Figure 4-1 provides an overview of the type of efforts that are planned for these technologies. The flow chart depicts the previous technology evaluation efforts and the treatability test plan evaluation at the right side of the chart. Next, Phase 1 efforts are planned to refine the scientific and technical information for the selected technologies through laboratory, modeling, and field parameter measurement activities. The Phase 1 efforts feed into a re-evaluation of the technologies for deep vadose zone application (see Section 4-3). This evaluation is the basis for selecting appropriate technologies to move into the Phase 2 field testing effort. Based on the results of previous efforts (e.g., those described in Section 3-2), gas-phase technologies (Desiccation, In Situ Gaseous Reduction, and Multi-Step Geochemical Manipulation) are a key focus of treatability test efforts and, therefore, the flow chart includes more information about these Phase 2 field efforts.

While the flow chart shows the test elements planned for the selected technologies, there will be overlap for some of these elements depending on the needs for each technology. The treatability test plan schedule (Section 6) describes the anticipated sequence and overlap of activities that are planned to support near term operable unit needs (e.g., the 200-BC-1 Operable Unit) and recognizes the need for a multi-year effort to support longer-term needs.

The elements of the flow chart in Figure 4-1 are described in the following paragraphs. Additional detail for the Phase 1 assessment elements is provided in Section 4-2. The technology selection and evaluation using the results of Phase 1 efforts is further described in Section 4-3. The Phase 2 field testing is further described in Section 4-4. The treatability testing culminates in a performance evaluation. This evaluation will be a comparative analysis from the data and information compiled in each of the elements of the treatability testing. The goal of the performance evaluation will be to define any additional actions that may be needed and to provide information about deep vadose zone remediation relevant for use in remedy selection and implementation processes. Additional detail for the performance evaluation element is provided in Section 5. Candidate field test sites will be evaluated and selected as shown in Figure 4-1. Section 4-1 describes the candidate field test sites identified for this treatability test plan.

The treatability testing culminates in a performance evaluation. The goal of the performance evaluation will be to define any additional actions that may be needed and to provide information about deep vadose zone remediation that may be relevant for use in selecting and implementing a remedy.

For the gas-phase technologies (desiccation, in situ gaseous reduction, and multi-step geochemical manipulation), the approach involves a Phase 1 assessment of the candidate technologies considering the results of previous studies and existing vadose zone property data, laboratory assessment of technical uncertainties as identified by the vadose zone technical team (FHI 2006), and modeling to evaluate conceptual implementation strategies. The Phase 1 assessment will be used to determine the effectiveness, implementability, and cost of candidate technologies for the targeted applications and to select the most appropriate technologies for initial field testing in Phase 2. If modeling and laboratory data indicate that the risk of unintended consequences for a technology application is high, initial field treatability testing will be at a clean site (e.g., the Sisson and Lu site). If the risk of unintended consequences is deemed to be low, field treatability testing will be conducted at a contaminated site.

To support the near-term need of providing technology information to the 200-BC-1 feasibility study, efforts for gas-phase technologies (desiccation, in situ gaseous reduction, and multi-step geochemical manipulation) will focus on technetium-99 and are scheduled to provide initial laboratory, modeling, and field data in a report prior to the milestone date for the 200-BC-1 feasibility study (see schedule in Section 6). Longer-term efforts related to technetium-99 will also be initiated and carried forward to support 200-BC-1 remedial design and other remedy selection and implementation activities as appropriate. Additional efforts for gas-phase technologies (desiccation, in situ gaseous reduction, and multi-step geochemical manipulation) will include assessment for application to uranium sites targeted at the potential for conducting a field test in the 200 B Area in fiscal year 2010. Again, longer-term efforts related to uranium will also be initiated and carried forward to support feasibility study and remedial design activities at operable units as appropriate.

Grouting and soil flushing technologies will be evaluated for effectiveness, implementability, and cost for the targeted applications primarily using existing technology information and modeling.

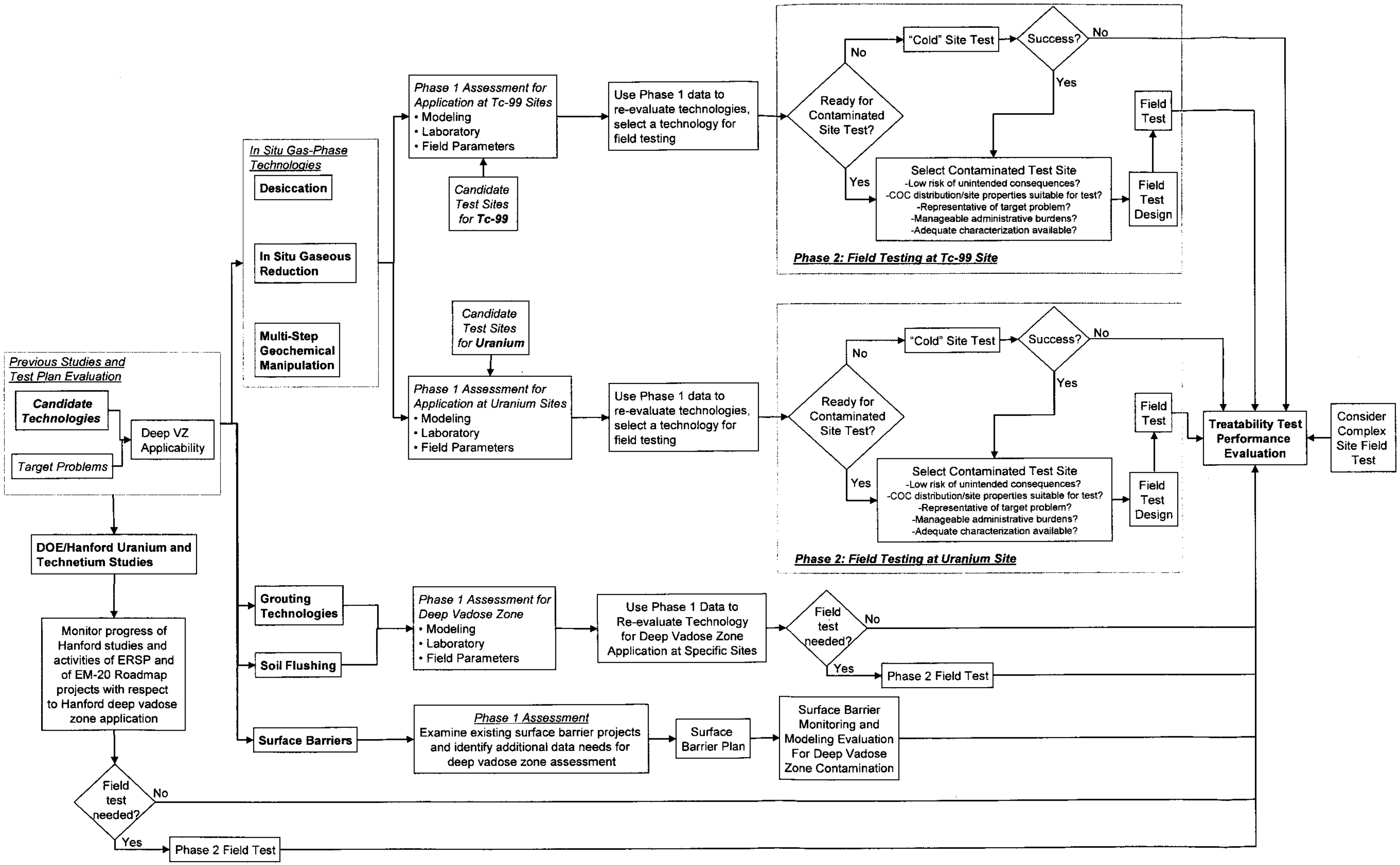

Figure 4-1. Summary of Treatability Testing Approach Elements.

The approach for surface barriers will be to examine existing surface barrier evaluation and monitoring efforts at Hanford (e.g., the Hanford Barrier, planned interim T Tank Farm barrier) and identify any additional monitoring necessary to assess the effectiveness of the barriers for deep vadose zone contamination. A surface barrier plan for these efforts will be prepared. The additional monitoring activities will be implemented to collect data specific to the deep vadose zone and to support modeling evaluations.

The treatability testing efforts will include coordination with other science and technology programs so that relevant results are included in the ongoing assessment of deep vadose zone technologies.

The efforts to advance our knowledge about the deep vadose zone include (1) Hanford technetium-99 and uranium investigations; (2) ongoing science and technology efforts funded through DOE's Engineering and Technology (EM-20) program; (3) Environmental Remediation Science Program; and (4) other programs. The treatability testing efforts will include coordination with these science and technology programs so that relevant results are included in the ongoing assessment of deep vadose zone technologies.

4-1. Potential Field Test Sites

This section uses the information presented in Section 2-3 to identify candidate field test sites for the anticipated field treatability testing of in situ gas-phase technologies for technetium-99 and uranium. Identification and evaluation of potential sites began with a list of the sites identified as having the greatest inventories of technetium-99 and uranium and having the greatest potential for future releases to the groundwater (see Section 2-3 and Appendix D).

Identification and evaluation of potential sites began with a list of the sites having the greatest inventories of technetium-99 and uranium and having the greatest potential for future releases to the groundwater.

Given the administrative and operational requirements of working within the tank farms, those particular sites were given a lower preference as candidate sites. Likewise, solid waste burial sites were given a lower preference due to their lack of characterization, perceived difficulties in implementing the candidate technologies (due the presence of buried waste), and the lack of identified deep contamination. Those sites remaining as preferred candidate sites were then evaluated relative to their geographic location and hydrogeologic conditions.

Finally, the potential candidate sites were then evaluated for their quantity and quality of characterization data, with preference given to waste sites identified as "representative sites" for the waste site operable units, and/or where opportunities exist to leverage the work being done for other programs (i.e. piggyback with other characterization or technology demonstration work). Based on this evaluation process, potential technetium-99 and uranium sites were identified as shown in the following sections. Pending favorable results of initial field testing, similar process will be used to identify a more complex site for subsequent field testing.

Field testing is also included as part of this treatability test plan for assessing the impact of surface barriers on the deep vadose zone. There are three surface barrier applications at Hanford with ongoing or planned monitoring that will provide data useful for evaluation with respect to the deep vadose zone. These barriers include the Hanford Barrier at the 216-B-57 site, the polyurea barrier at the 241-T-106 site, and the planned surface barrier at the 216-U-8 site. Thus, these sites are all candidates for obtaining data relevant to the effectiveness of surface barriers for the deep vadose zone.

4-1-1. Candidate Sites for Technetium-99 Technologies

- Southern 200 E (A Area)
  - BC cribs and trenches (216-B-26, 216-B-14 thru -18)
  - C Tank Farm and vicinity
- Northern 200 E (B Area)
  - BY cribs and vicinity (216-B-46)
- Southern 200 W (S Area)
  - U cribs (216-U-1 and -2, 216-U-8)
- Northern 200 W (T Area)
  - TY cribs and vicinity (216-T-26)
  - T Tank Farm and vicinity (241-T-106)

4-1-2. Candidate Sites for Uranium Technologies

- Southern 200 E (A Area)
  - 200 East Ponds Region (216-A-19)
  - PUREX cribs and trenches (216-A-4)
- Northern 200 E (B Area)
  - B Plant cribs and trenches (216-B-12)
  - BX Tank Farm (241-BX-102)
- Southern 200 W (S Area)
  - U cribs (216-U-8, -12, -1 and -2)
  - REDOX cribs and trenches (216-S-7, -1 and -2)

4-2. Phase 1 Assessment

Phase 1 assessment activities primarily involve laboratory, modeling, and analysis efforts, although efforts to collect the necessary design parameters for field testing are appropriate for some of the technologies.

This section outlines the elements of the Phase 1 assessment described in Figure 4-1. Phase 1 elements focus on providing the information needed to improve the assessment of technology implementability, effectiveness, and cost for application to the deep vadose zone target problems and to support selection of a technology or group of technologies for field-scale demonstration in Phase 2. These Phase 1 assessment activities primarily involve laboratory, modeling, and analysis efforts, although field efforts to collect necessary field design parameters are appropriate for some of the technologies.

The in situ gas-phase technologies (desiccation, in situ gaseous reduction, and multi-step geochemical manipulation) are considered the most likely to proceed to near-term field testing based on the results of previous evaluations as described in Section 3-2. As shown in Figure 4-1, it is expected that the treatability test efforts will extend through field testing for these technologies, culminating in a field demonstration (Phase 2). However, initial laboratory, modeling, and field efforts targeted at determining field design parameters are necessary prior to the full technology demonstration and to select the most appropriate field testing approach (e.g., testing of desiccation alone or in conjunction with another technology). An initial focus of Phase 1 efforts will be to evaluate gas-phase technologies and candidate sites that are relevant to technetium-99 remediation and the 200-BC-1 feasibility study. These efforts are emphasized to meet the timeframe associated with supporting the 200-BC-1 feasibility study. Relatively near-term field efforts are also envisioned for gas-phase technologies to address uranium contamination. Phase 1 assessment efforts will focus on comparative evaluation of the gas-phase technologies for effectiveness with uranium and determining the parameters needed to support a field test design.

While activities to support near-term field testing are important, assessment activities will also initiate longer-term laboratory and modeling studies to evaluate gas-phase and other technologies for the deep vadose zone. Efforts will be focused on compiling information from existing or ongoing studies and conducting additional analyses to improve the ability to assess the implementability, effectiveness, and cost of these technologies for the Hanford deep vadose zone target problems.

Treatability efforts to assess the impact of surface barriers on the deep vadose zone are also a priority and will be conducted in conjunction with existing barrier installations at Hanford.

The approach for each technology as part of Phase 1 is provided in the following sections. As testing proceeds, the objectives and approach will be updated as necessary. Additional information on the planned schedule of activities is provided in Section 6.

4-2-1. Desiccation

Previous technology screening studies identified desiccation as a promising technology, but also identified uncertainties about the technology that need to be addressed for application to the deep vadose zone at Hanford. The following Phase 1 assessment efforts for desiccation result from recommendations in these previous studies:

Uncertainties about desiccation need to be investigated before it can be applied at Hanford.

Modeling Evaluation. Modeling will be used to identify uncertainties that need to be addressed by other complimentary investigation methods. These will include:

- Estimate the location and extent of desiccation needed to achieve remediation goals
- Assess factors that influence the rate of re-wetting
- Assess system configurations (i.e., well spacing and geometry), their relative performance, and factors that effect their performance

Successful design, deployment, and operation of a field-scale soil-desiccation system will require a detailed understanding of mass and energy transport in heterogeneous sediments under transient conditions. The understanding of these processes can be improved through laboratory experimentation and numerical modeling to resolve the issues identified above. There are three major components recommended for the modeling effort as part of the Phase 1 assessment:

1. Evaluating the role of salt concentrations on the desiccation process.
2. Incorporating constitutive theory describing the behavior of air and water during unsaturated flow.
3. Calibrating model parameters with laboratory data and conducting scoping simulations.

The first component is the role of salt concentrations on the desiccation process. Previous studies of the fate and transport of hypersaline fluids in Hanford sediments suggest several important roles. Work by Ward and Gee (2001) suggests that the fine-textured, low-permeability interbeds in the Hanford formation may act to restrict solute transport relative to the flow of water. The mechanisms for this phenomenon include chemical osmosis (e.g., fluid flow in direction of higher salinity) and electro-osmosis (i.e., flow of water, dragged along by ions moving due to an electric potential gradient). The resulting flow of water in response to the concentration gradient could essentially pull water from the surrounding untreated regions, affecting the efficacy of the desiccation system (FHI 2006). It is anticipated that soil desiccation will lead to a concentration of salts in the pore water of the finer-textured sediments in which technetium-99 and nitrate are currently immobilized. The Phase 1 assessment should evaluate the relative importance of these mechanisms.

The second component relates to the constitutive theory describing the behavior of air and water during unsaturated flow. At present, relative air permeability is predicted using the parameters derived for hydraulic permeability. Moldrup et al. (2001) reported that at a given value of soil air content, the tortuosity in the gaseous phase of a wet soil is larger than a completely dry soil and, also, is typically larger than in an undisturbed soil compared to a sieved, repacked soil. At a given value of fluid-phase (water or air) content, the liquid-phase tortuosity is typically equal to or larger than gaseous-phase tortuosity, the likely exception being coarse-textured undisturbed sediments. More recently, Tuli et al. (2005) found that regardless of soil disturbance, values of the tortuosity-connectivity parameter (*l* in the van Genuchten-Mualem model) for water permeability and air permeability were different. There is also increasing evidence that liquid-phase tortuosity is strongly dependent on soil type and related to specific surface area and liquid-phase geometry, whereas gaseous-phase tortuosity is less soil type dependent and related to the connectivity of air-filled pores. Nevertheless, the general practice is to use the same value of *l* for both the water and air permeability functions and the same diffusivity-tortuosity models for both solute and gas diffusivity and without distinction between undisturbed (field soil) and sieved, repacked soils typical of laboratory measurements. Laboratory experiments in conjunction with numerical modeling should be conducted determine the importance of these differences on air transport and the desiccation process.

Following the incorporation of these mechanisms into a model, the third component would be calibrating the model using laboratory flow cell data. The calibrated model would then be run to simulate system response under different operating conditions and well configurations, while varying key parameters, in order to improve our understanding of system performance. Such a parametric analysis is needed to understand the subsurface perturbations in mass and energy distributions caused by the injection and removal of air in different soil types. The results of these types of simulations would be valuable to optimize the system design and operating parameters such as (1) the number of injection/extraction wells; (2) well screen dimensions and positioning; (3) air injection pressure; (4) air injection/extraction rates; (5) air injection mode (pulsed or continuous); (6) input air properties (temperature, humidity); (7) air distribution and zone of influence under different injection modes; (8) the need for impermeable surface seals as well as monitoring and management considerations for homogeneous and heterogeneous soil formations. The initial model assessments will also be useful to define monitoring and management criteria. A major benefit of analyzing the system design criteria and operating parameters is an improved understanding of the influence of heterogeneities and their distribution on air flow rate and changes in soil moisture and temperature. Thus, modeling will play a key role in defining alternative desiccation strategies and ultimately predicting the efficacy of these alternatives.

Laboratory Evaluation. Laboratory tests are needed to evaluate specific processes that occur during desiccation and quantify their impact on the implementation and effectiveness of desiccation. Work has been initiated for two items:

- Energy balance impact on desiccation
- Impact of heterogeneities in hydraulic properties on desiccation

Laboratory tests are needed to evaluate specific processes that occur during desiccation and quantify their impact on the implementation and effectiveness of desiccation.

Continued efforts will be conducted based on the initial results of this work.

Areas of additional study include the following items:

- Factors impacting air permeability
- Water retention parameters relevant to low moisture content
- Solute concentration effect on desiccation
- Solute behavior during rewetting
- Geochemical changes during desiccation (e.g., mineral precipitation)
- Physical effects of desiccation on sediments

A further description of key near-term study items is listed in the following paragraphs:

Differences in Permeability to Air and Water between Disturbed and Undisturbed Soils. Sediment structure and pore geometry dominate flow and transport processes in Hanford sediments but there are few data to quantify the effects of these characteristics on air and water permeability. At present, hydraulic conductivities measured on repacked samples are applied directly to field-scale simulations without consideration for structural effects. Furthermore, air permeability is predicted from water retention functions assuming that the both fluids are impacted in the same way by the pore geometry. Laboratory studies are needed to determine the relationship between permeability and the content of air and water for disturbed and undisturbed sediments. Such studies should measure both water permeability (k_w) and air permeability (k_a) on intact (undisturbed) soil samples after which the samples would be crushed and repacked to create an equivalent disturbed sample of the same sediment. Measurements would be used to quantify differences between intact and repacked samples and role of soil structure on fluid flow. Owing to differences in pore geometry between intact and repacked samples, we anticipate differences in the tortuosity–connectivity parameter for water permeability, l_w, and air permeability, l_a. At present, the same value of the l parameter is used to parameterize both the air and water permeability functions. Ignoring differences in the tortuosity–connectivity parameter for the different fluids will increase the uncertainty in predictions of the efficacy of soil desiccation.

Soil Water Retention and Conductivity Functions Applicable to Vapor Flow. Water flow models typically calculate the hydraulic conductivity, $K(\theta)$, from the water retention curve, $\theta(\psi)$. The two most frequently used $\theta(\psi)$ models are those proposed by Brooks and Corey (1966) and van Genuchten (1980). The popularity of these models is due primarily to their ability to fit water retention experimental data in the wet region, where it is often expected that most flow occurs, and owing to the fact that they can also be readily combined with conductivity models to yield analytic expressions for relative permeability. However, these functions have proven unsuitable for very dry conditions ($\psi < -1.5$ MPa). In fact, one of the disadvantages of the traditional water retention models is that they do not allow water content to fall below the residual water content, θ_r, a physically unrealistic constraint. The residual water content θ_r is defined as the value of θ where $K(\theta) = 0$. During soil desiccation, water transport is a nonisothermal coupled process involving water in the liquid and vapor phases. Under these conditions, retention models in which $\theta_r > 0$ will fail because with vapor transport, $\theta \rightarrow 0$. The issue of predicting flow and transport under hyper-dry conditions have also been identified as a major source of uncertainty in vadose zone modeling at Hanford in a recent U.S. Geological Survey review conducted as part of regulatory review of the 200-UW-1 Operable Unit remedial investigation/feasibility study document. Laboratory studies of steady state, unsaturated, nonisothermal flow in closed columns over the range of soil temperatures expected in desiccation studies are needed to generate data for testing models that extend the water retention and hydraulic conductivity curve to hyper-dry conditions. The product of these studies will be a full-range water retention model that can reliably extrapolate the water retention curve beyond the driest measured point.

Air-Water-Electrolyte Constitutive Relationships. This task will quantify the effects of saline/sodic waste on water and solute migration in response to desiccation of the subsurface. Measurements should be made using sediment samples representative of the BC cribs site. Laboratory experiments should be conducted on specific size fraction and mixtures representative of the major lithofacies to quantify the air-permeability-saturation relationships and to characterize their ability as act as semi-permeable membranes and, thus, impact the osmotic potential gradient. Measurements would be made using different electrolyte concentrations to quantify the importance of osmotically driven water vapor transport in the presence of saline plumes under non-isothermal conditions produced during desiccation. The air-permeability-saturation data and the capillary pressure-saturation data could then be used to extend the current constitutive theory to simultaneous prediction of water permeability, air permeability and diffusive properties as functions of fluid-phase (soil water or soil air) content using unique connectivity/tortuosity parameters (*l*). Data collected with different electrolyte concentrations would then be used to (1) quantify the impact of saline and sodic waters on permeability (2) develop a general procedure for predicting K-θ-h relations for mixed-salt solutions high in Na^+; (3) quantify the importance of osmotic potential gradient on water and salt movement; and (4) develop a robust accounting for the effects of low moisture on constitutive properties.

Field Parameter Test. Tests are needed to define field-scale hydraulic properties relevant to desiccation at targeted field application sites.

Tests are needed to define hydraulic properties of soil that could affect desiccation at field application sites.

Air permeability testing at selected sites and targeted hydrologic zones would complement laboratory parameter development as input to models.

4-2-2. In Situ Gaseous Reduction

While in situ gaseous reduction has been field tested for chromate remediation in the vadose zone (Thornton et al. 1999 and 2003), there are uncertainties for application to the technetium-99 and uranium due to the potential for re-oxidation. For this reason, reductive technologies were not recommended for immediate application in the vadose zone by the vadose zone technical team (FHI 2006). The Phase 1 assessment efforts are focused on the potential of reductive processes for long term mitigation of technetium-99 and uranium in the vadose zone.

Modeling Evaluation. Modeling is needed to evaluate the physical and geochemical factors that influence the design and effectiveness of in situ gaseous reduction. These include:

- Configuring a model for gas-phase transport under an induced flow-gradient with heterogeneities and moisture contents representative of target site conditions
- Up-scaling the results of laboratory evaluations to the relevant field conditions
- Predicting the redistribution of oxygen into a reduced zone taking into account the gas-phase, mass transfer to the pore water, and oxygen sinks in addition to the reduced technetium-99 and uranium compounds. A technical basis for estimating re-oxidation rates based on oxygen mass transfer rates is needed to accompany laboratory data.

Modeling is needed to evaluate the physical and geochemical factors that influence the design and effectiveness of in situ gaseous reduction.

Gas phase processes are expected to have significant advantages over most liquid vadose zone remediation strategies because of the ease of injection and minimal gravitational or channeling effects. However, better tools are needed to evaluate potential designs for vadose zone remediation using reactive gases. Thus, a multi-phase flow model needs to be configured for evaluating the applicability of reactive gas technologies to the deep vadose zone.

The laboratory investigations need to be up-scaled to realistic field conditions for prediction of remedial effectiveness and for design of the field tests. The physical flow model will be coupled to geochemical reaction parameters to evaluate the required reactant concentrations in the gas phase and to predict reactant breakthrough curves for monitoring of the injections. Critical parameters to be addressed include the impacts of channeled flow due to heterogeneities, the extent of reaction in high and low permeability zones, and the relative reductant interaction with oxidized aquifer materials (e.g., iron oxides) technetium-99 and uranium and co-contaminants.

The rate of re-oxidation is a critical issue for in situ reduction of technetium-99 and uranium. The laboratory results will be extended to field scale and extrapolated time scales to evaluate remedial effectiveness.

Laboratory experiments are needed to develop site-specific data regarding in situ reduction of technetium-99 and uranium.

Laboratory Evaluation. Laboratory tests are needed to quantify technetium-99 and uranium sequestration:

- Determine the reductive capacity of technetium-99 and uranium, co-contaminants, and aquifer materials
- Measure the chemical and physical properties of the reduced contaminant species
- Determine the impact of vadose zone sediment properties and moisture content on technetium-99 and uranium reduction and co-precipitates
- Determine the impact of injection rate, carrier gas composition, and relative humidity on the effectiveness of gaseous reduction.
- Investigate the re-oxidation rate of reduced technetium-99 and uranium species.

The practicality of in situ reduction depends on the ability to deliver sufficient reductant to sequester technetium-99 and uranium. Estimates of the subsurface reactions with technetium-99 and uranium, co-contaminants, and sediments are needed. Laboratory experiments are needed to develop site-specific data regarding the these reactions. The overall mass-action for gaseous reduction may be described in terms of reductive capacity of the vadose zone system. This capacity is an additive function of all the oxidized species that will react with the reductant. The reductive capacity can be measured through column experiments with uncontaminated and contaminated sediments similar to experiments conducted for saturated zone reductants.

The properties of the reaction products are important for evaluating the reaction mechanisms and for predicting long-term effectiveness. Advanced microscopic characterization techniques including scanning electron microscopy/energy dispersive spectrometry, x-ray microprobe, and x-ray absorption near-edge spectroscopy can provide data for reaction product characterization. However, with technetium-99 the ultra-low concentrations of concern may challenge the analytical methods more than for uranium or other species.

The fate of the reduced contaminants will also be a function of the sediment composition and the moisture content. The reaction products will be investigated for different size and composition fractions in the sediments. The soil moisture may promote heterogeneous or homogeneous reduction reactions. Thus, the remedial effectiveness may vary with moisture content. The nature and humidity of the carrier gas for the reductant will also have an effect on the relative degree of reaction with technetium-99 and uranium and other species. Column experiments are effective for addressing these issues.

Laboratory re-oxidation rate measurements are important for determining long term remedial effectiveness. A combination of column experiments with stop-flow events and micro-scale characterization data on post-oxidative sediments may be used to evaluate re-oxidation.

Field Parameter Test. Tests are needed to define field-scale hydraulic properties relevant to in situ reduction at targeted field application sites.

Air permeability testing at selected sites and targeted hydrologic zones would complement laboratory parameter development as input to models. The testing strategy would be similar to development of field parameters for desiccation technologies.

4-2-3. Multi-Step Geochemical Manipulation

The vadose zone technical team (FHI 2006) identified multi-step geochemical manipulation using gas-phase reagents (perturbation geochemistry) as a potential means for long-term control of technetium-99 and uranium migration in the vadose zone by sequestering technetium-99 and uranium within a precipitated matrix resistant to resolubilization of technetium-99 and uranium. However, multi-step geochemical manipulation is a conceptual technology still in the developmental phase. Because of the strong potential for long-term control of technetium-99 and uranium, the following Phase 1 laboratory assessment activities are included in the plan.

Laboratory Evaluation. Laboratory tests are needed to quantify the candidate processes for technetium-99 and uranium sequestration in terms of:

- Candidate reactions for manipulation – carbonate vs. silicate systems
- Sequestration mechanism – co-precipitation vs. physical isolation
- types of gases needed to induce technetium-99 and uranium co-precipitation and reaction steps
- Chemical/physical properties of the precipitates
- Impact of vadose zone sediment properties and moisture content on geochemical processes
- Resistance of the precipitates to technetium-99 and uranium remobilization

Laboratory tests are needed to verify the mechanisms and effectiveness of potential multi-step geochemical manipulation processes.

Initial laboratory efforts are needed to verify the mechanisms and effectiveness of potential multi-step geochemical manipulation processes. As discussed in the vadose zone technical team report (FHI 2006), there are several candidate systems that could be manipulated (e.g., carbonate and silicate systems). Testing will need to consider the target site sediment, pore water, and technetium-99 and uranium chemistries because the mechanism of sequestration will depend greatly on the site-specific properties. Little is known regarding technetium-99 as a trace component in carbonate or silicate systems. Somewhat more is known regarding uranium but significant data gaps exist. From theoretical considerations, the incorporation of the technetium-99 and uranium into precipitating solid solutions will likely be favored by higher temperatures and faster precipitation rates. The ability to manipulate the geochemical system will also depend on the extent that the system can be perturbed from the initial state – e.g., by increasing carbon dioxide partial pressure to dissolve calcite.

The presence of magnesium and possibly ferrous iron may be important influences on the incorporation of uranium or technetium-99 into calcite. Thus, laboratory investigations should address the equilibrium and kinetic effects in multi-component systems.

Once a promising sequestration mechanism has been determined, then the conditions and steps needed for effective isolation of technetium-99 and uranium need to be developed. This effort involves developing a detailed understanding of the reaction mechanisms, rates, and products. Resistance to remobilization must also be evaluated. These laboratory investigations will likely include batch and column experiments, advanced microscale characterization, and equilibrium/kinetic geochemical modeling.

Field Parameter Test. Tests are needed to define field-scale hydraulic properties relevant to multi-step geochemical manipulation at targeted field application sites. Air permeability testing at selected sites and targeted hydrologic zones would complement laboratory parameter development as input to models. The testing strategy would be similar to development of field parameters for desiccation technologies.

4-2-4. Grouting Technologies

Grout injection is the subsurface placement of an encapsulating slurry mixture that, when cured or reacted, stabilizes or isolates the contaminant in a permanent matrix solid. Application, transport of the grout to the deep vadose sediment contaminant sites, and verification of proper placement are the principal challenges to implement the technology. The vertical variation in stratigraphy, with some levels having relatively low potential permeability to grout flow, pose significant challenges for the technology. The following Phase 1 assessment efforts for grout injection are included in the plan:

Grout injection involves placing a slurry mixture into the subsurface that, when cured, stabilizes or isolates a contaminant in a permanent solid.

Modeling Evaluation. Using site information in modeling is needed to:

- Assess the distribution, location, and stratigraphic factors that control the distribution of vadose zone contaminants and associated grouting targets so that specific scenarios for grout application can be developed
- Evaluate impact of targeted grouting zone and introduced fluids on the surrounding vadose zone

Laboratory Evaluation. Laboratory tests are needed to examine grout material candidates in terms of:

- Injection properties of candidate materials with different viscosity, density, and composition for targeted Hanford materials
- Technetium-99 and uranium sequestration mechanism through interaction with the grout and quantification of the resultant chemical leaching potential.
- Impact of vadose zone sediment properties and moisture content on technetium-99 and uranium and co-precipitates

4-2-5. Soil Flushing

The effectiveness and implementability of soil flushing is immediately controlled by the technical ability to contact targeted contamination in the vadose zone with the leaching solution. Soil flushing mobilizes contaminants in the vadose zone with the intention of recovering them in the groundwater using pump-and-treat technologies. The application and distribution of the leaching solution in an unsaturated zone poses a significant challenge. One application strategy is to release the leaching solution near the surface in former waste disposal locations to mimic the original contaminant release and subsequent transport through the vadose zone. Such an application approach may be complicated by the extended travel time of the leaching solution with associated intermediate reactions before

Soil flushing mobilizes contaminants in the vadose zone with the intention of recovering them in the groundwater using pump-and-treat technologies.

arriving to the targeted zone of contamination. Undesired secondary mobilization of non-targeted mineral components complicates the process and at best make the reagent recovery efforts even more difficult and extensive in the receiving groundwater. A second approach would be to introduce the leaching solution at targeted locations and depths through boreholes. The site specific details will control the success of deployment of soil flushing. Phase 1 assessment activities are included in this plan to provide a basis for evaluation of the technology and associated risks with mobilizing contaminants.

Modeling Evaluation. Using site information in modeling is needed to:

- Assess the distribution, location and stratigraphic factors that control the distribution of vadose zone contaminants and movement of injected fluids.
- Assess system configurations, their relative performance, and factors that effect their performance.

Laboratory Evaluation. Laboratory tests are needed to examine leaching solution candidates in terms of:

- Kinetics and stability of solubilization of technetium-99 and uranium and non-target compounds.
- Transport properties of solubilized technetium-99 and uranium and non-target compounds.
- Impact of vadose zone sediment properties on leaching solution processes.

4-2-6. Surface Barrier Technologies

To assess the surface barriers in the context of deep vadose zone contamination, the following activities are needed:

The Phase 1 assessment activities will focus on using existing or planned surface barrier sites to address these objectives.

- Determine how deep the effect of surface infiltration control extends into the vadose zone as a function of the areal extent of the surface barrier, including side slopes.
- Determine the impact of surface infiltration control on water and technetium-99 and uranium already located in the deep vadose zone.
- Identify the constituents and/or conditions that should be monitored to assess barrier impact on the deep vadose zone.
- Identify monitoring systems that can provide data on changes in the baseline conditions for the long-term application necessary for the deep vadose zone applications.
- Link performance of the barrier in the deep vadose zone to barrier performance elements such as the following:
  - Performance of alternative covers in limiting deep percolation.
  - Performance of alternative covers in limiting contaminant migration through the vadose zone.
    - Establishing and maintaining appropriate vegetation diversity on the barrier.

The data that are needed to verify or confirm barrier performance and assess the effects of the barrier cannot be realistically obtained in the time period typically associated with a treatability test. Therefore, a simulation model is the only tool available to assess the long-term performance related to the deep vadose zone. Phase 1 assessments of barrier technology will focus on collecting data to support configuration of a model and using the model to assess barrier performance.

The prototype Hanford barrier, deployed over the 216-B-57 crib, was constructed in 1994 to evaluate surface-barrier constructability, construction costs, and physical and hydrologic performance at the field scale. The barrier was routinely monitored between November 1994 and September 1998 as part of a CERCLA treatability test of barrier performance for the 200 BP 1 Operable Unit. The results of the 4-year (fiscal years [FY] 1995 to 1998) treatability tests are documented in the *200-BP-1 Prototype Barrier Treatability Test Report* (DOE 1999b). Since FY 1998, monitoring has focused on a more limited set of key water balance, stability, and biotic parameters with results summarized in annual letter reports. These reports typically summarize the results of energy and water-balance monitoring including precipitation, soil moisture, soil temperatures, and drainage measurements; barrier-stability monitoring, consisting of asphalt-layer-settlement, basalt-side-slope-stability, and surface-elevation measurements; and surveys for vegetation characteristics and evidence of animal-intrusion survey. There are also data of the baseline vadose zone conditions prior to construction of the barrier. The Phase 1 assessment will, therefore, focus on two initiatives: (1) inverse modeling to calibrate the numerical model using the 13-year dataset from the 200-BP-1 barrier, and (2) borehole or surface geophysical logging at the site to determine whether there have been changes in the vadose zone baseline conditions, including changes in the apparent distribution of moisture and contaminants in the 13 years following construction, and to identify any possible surrogates that can be monitored in the vadose zone in the near term to predict long-term efficacy.

4-2-7. Related Efforts at Hanford and Within DOE

The ongoing related DOE and Hanford activities for technetium-99 and uranium described in Section 3-2 are being conducted for other purposes. The Phase 1 assessment activities associated with these efforts will coordinate and interface with these projects to identify relevant data and results for application to the deep vadose zone in Hanford's Central Plateau.

The Phase 1 assessment will be used to re-evaluate the technologies and select appropriate field tests.

4-3. Selection of Technology for Field Demonstration and Treatability Testing

The Phase 1 assessment activities described in Section 4-2 will be used to support re-evaluation of the technologies and selection of appropriate field testing. The re-evaluation process will consider the following criteria related to evaluations conducted for remedy selection:

- Overall protectiveness of the remedy to human and environmental receptors
- Ability to prevent contamination of groundwater at concentrations above the maximum contaminant level for technetium-99 and uranium
- Short- and long-term effectiveness and the actions required to maintain effectiveness
- Ability to measure and monitor technology effectiveness
- Risk of unintended consequences or risk to workers and the public during implementation
- Technical difficulty for technology implementation and, if necessary, difficulty in maintaining effectiveness of the technology.
- Anticipated capital and operating cost
- Regulatory and stakeholder acceptance

Additional emphasis in selecting technologies for field testing will be placed on the technical uncertainties of conducting a field test and the data available to support a field test design.

The 200-BC-1 Operable Unit is a leading candidate as a field test site because work is already underway to complete a feasibility study of that area.

The initial focus for field testing will be on gas-phase technologies for technetium-99 to support the 200-BC-1 feasibility study. As such, the 200-BC-1 Operable Unit is a leading candidate as a field test site. However, this and other candidate sites will be evaluated using the information compiled during the Phase 1 assessment and from site characterization efforts to determine the best field test site. The first decision related to test site selection is evaluation of whether or not the technology is ready for testing at a contaminated site. This determination will be based primarily on assessment of the risk of unintended consequences at the candidate contaminated test sites. An uncontaminated site may be selected for initial testing if the risks at a contaminated site are deemed unacceptable. If a contaminated site is deemed appropriate, the candidate sites will be compared with respect to the contaminant distribution, knowledge of relevant subsurface properties, administrative burdens, available infrastructure, and the amount of characterization data available. The most appropriate test site will be selected based on these criteria and usefulness of the anticipated data for supporting the 200-BC-1 feasibility study.

Field testing at a uranium-contaminated site is also a near-term objective for the treatability test plan. The evaluation process will be the same as described above for the technetium-99 field test site, also with a focus on gas-phase technologies. The final criteria, however, will be evaluation of the usefulness of the anticipated data for supporting operable units with uranium contamination.

4-4. Field Treatability Testing (Phase 2)

Field testing of gas-phase technologies is anticipated to investigate their applicability to technetium-99 and uranium contamination (see Figure 4-1 and Section 6). Field tests will evaluate the technology for implementability and short-term effectiveness so that data can be collected within a timeframe to be considered in near-term feasibility study efforts. These field tests will also include collecting data that can enhance evaluation of related technologies. For instance, if desiccation is field tested, data relevant to distribution of other gases will be collected to support improved assessments of all gas-phase technologies. The field tests will also monitor parameters that can indicate long-term effectiveness and monitor these parameters over suitable time periods. While these data may not be available to support near-term feasibility studies, the data will be targeted at supporting later feasibility studies, remedial design, and other remedy selection efforts.

Field tests will be conducted on gas-phase technologies and surface barriers to evaluate their effectiveness and implementability.

Field efforts to evaluate the effect of surface barriers on the deep vadose zone are also anticipated. These efforts will be conducted in conjunction with existing and planned surface barriers at Hanford. A specific field testing and analysis plan (see Section 6) will be developed for this effort.

Field testing of the other deep vadose zone technologies is not initially planned as part of this treatability test plan. However, the need for field testing of these technologies will be re-evaluated using the Phase 1 assessment information collected as part of the treatability test plan efforts (see Section 4-3).

This page intentionally left blank.

5-0. Evaluation of Treatability Test Performance

Results from the treatability tests will be evaluated in a series of reports that discuss the Phase 1 assessments (e.g., modeling, laboratory data) and the field work (Phase 2). The goals of these reports will be to document the tasks performed and data produced during the course of testing, interpret the data, evaluate the results against the objectives of the test, and provide information to be used in CERCLA decision processes, including design and implementation of a larger-scale test or deployment of the technology. The pertinent design information will include a detailed evaluation of testing costs and how these should be considered for full-scale technology implementation.

Information gathered during treatability tests will also be used in the technology evaluation process conducted for the CERCLA feasibility study process. Field and modeling information is used during this process to evaluate risk mitigation associated with various treatment technologies.

An essential element of a thorough treatability testing analysis is verification of the technology's effectiveness. A number of indirect measurements can be made to evaluate effectiveness, but only direct physical measurements can be used for verification. Because the schedule for the initial treatability test has been optimized to provide information to the 200-BC-1 feasibility study, verification information will likely not be available for that phase of the CERCLA process. Appropriate physical samples of the deep vadose zone at the field test site(s) will be collected after the treatability test, and the resulting data will be included in the evaluation report.

This page intentionally left blank.

6-0. Schedule

A schedule for treatability test plan activities is shown in Figure 6-1. After the test plan is finalized, there are six categories of activities shown on the schedule: technetium-99 efforts, uranium efforts, grouting and soil flushing technology efforts, surface barrier efforts, and performance evaluation.

The technetium-99 efforts have an initial target of providing input to the 200-BC-1 feasibility study. Some relevant laboratory, modeling, and field characterization efforts are already underway. Additional efforts will be initiated to address technical items needed to support a field test for an appropriate technology. The goal is to conduct field testing for an in situ gas-phase technology using an approach that provides near-term implementability, effectiveness, and cost information for the selected technology and related gas-phase technologies. It is anticipated that field testing will continue as needed with long-term monitoring to assess technology effectiveness. It is also anticipated that there will be a continuation of laboratory tests, modeling, and potentially other field activities related to investigating technology and technical uncertainty for the 200-BC-1 feasibility study and other technetium-99 applications at Hanford. These longer-term efforts will include reporting to support these other applications as appropriate. Efforts for uranium technologies are similar to those for technetium-99 with the goal of conducting a near-term field test and with inclusion of continuing activities.

Efforts for grouting and soil flushing technologies will be conducted in parallel with the above activities. Currently, field testing of these technologies is not anticipated. However, the need for field testing will be evaluated as new information is obtained through the planned laboratory and modeling efforts.

Surface barrier activities will be coordinated with ongoing and planned surface barrier activities at Hanford. A surface barrier plan for the deep vadose zone will describe the activities specific to assessing the impact of surface barriers on the deep vadose zone.

Documents describing the treatability test efforts will include reports for specific operable units (e.g., 200-BC-1) and a series of performance evaluation reports. A final performance evaluation report will be prepared in fiscal year 2015 to document all of the treatability test results.

This page intentionally left blank.

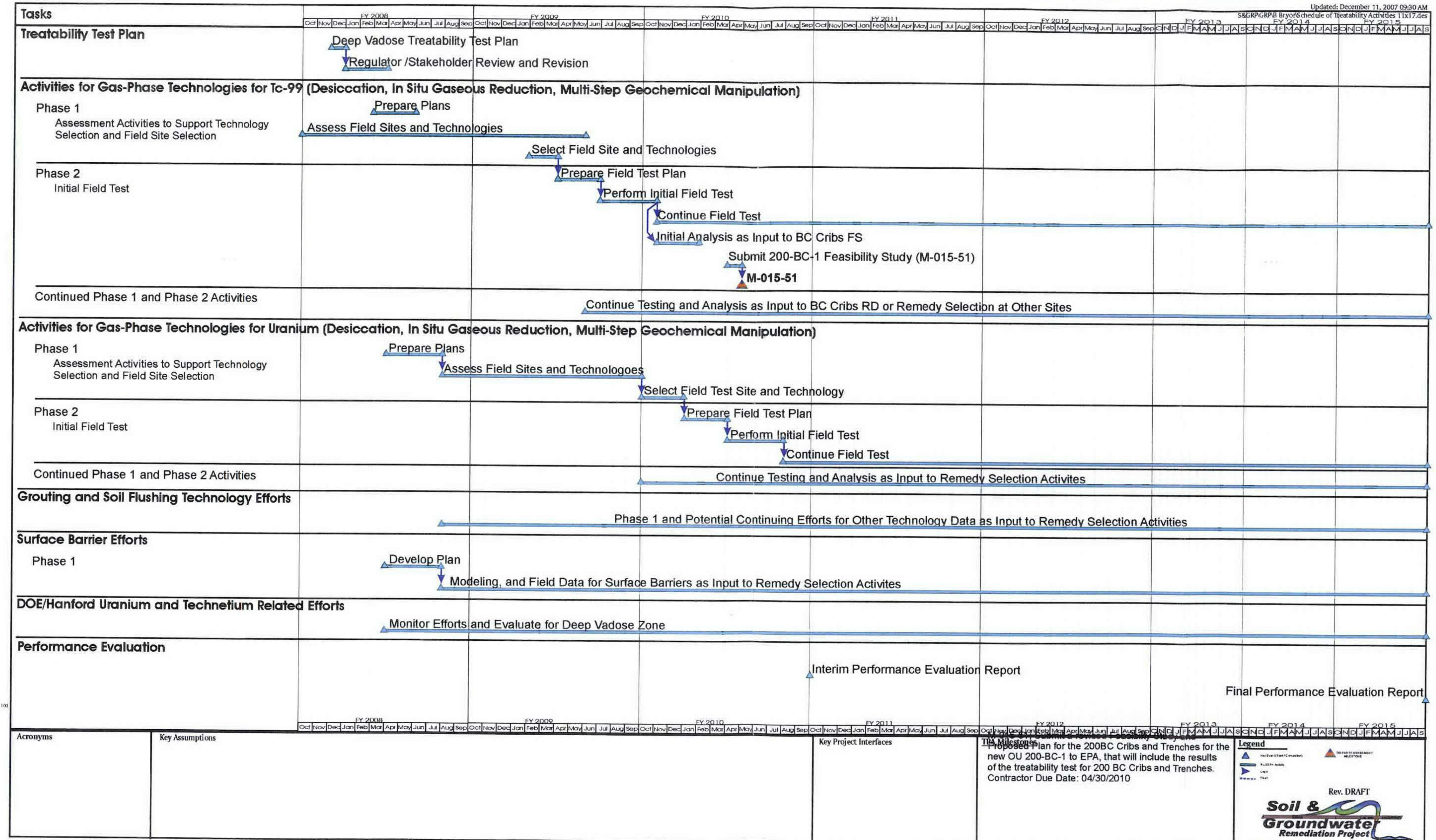

Figure 6-1. Schedule of Treatability Test Activities.

7-0. References

55 FR 8813, Section 300.430(e). "The 1990 Revised National Oil and Hazardous Substances Pollution Contingency Plan. Section 300.430: Remedial Investigation/Feasibility Study and Selection of Remedy." U.S. Environmental Protection Agency, *Federal Register.*

Brooks, R.H. and A.T. Corey. 1966. "Properties of Porous Media Affecting Fluid Flow." *J. Irrig. Drain. Eng*, Div. Am. Soc. Civ. Eng. 92:61–89.

Cameron, R.J., J.C. Evans, Jr, M.D. Johnson, and T.L. Liikala. 2002. *Summary of Hanford Subsurface Air Flow and Extraction (SAFE) Activities for Fiscal Year 2001.* PNNL-13820, Pacific Northwest National Laboratory, Richland, Washington.

Cantrell, K.J., J.M. Zachara, P.E. Dresel, K.M. Krupka, and R.J. Serne. 2007. *Geochemical Processes Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.* PNNL-16663, Pacific Northwest National Laboratory, Richland, Washington.

CERCLA - *Comprehensive Environmental Response, Compensation, and Liability Act.* 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq. Accessed at http://www.epa.gov/region5/defs/html/cercla.htm.

CHG. 2007. *Central Plateau Vadose Zone Remediation Technology Screening Evaluation.* CH2M HILL Hanford Group, Richland, Washington.

Corbin, R. A., B. C. Simpson, M. J. Anderson, W. F. Danielson, II, J. G. Field, T. E Jones, and CT Kincaid. 2005. *Hanford Soil Inventory Model, Rev. 1.* RPP-26744, Rev. 0 and PNNL-15367. CH2M HILL Hanford Group, Inc., Richland, Washington.

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

DOE. 1999b. *200-BP-1 Prototype Barrier Treatability Test Report.* DOE/RL-99-11, Rev. 0, U.S. Department of Energy, Richland, Washington.

DOE. 1999c. *Groundwater/Vadose Zone Integration Project Background Information and State of Knowledge.* DOE/RL-98-48, Vol. II, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2000. *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas*. DOE/RL-99-36, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2007a. *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, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2007b. *Vadose Zone Modeling at the Hanford Site: Regulatory Criteria and Compliance for Risk Assessment Applications*. DOE/RL-2007-34, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2007c. *Supplemental Remedial Investigation Work Plan for the 200 Area Central Plateau Operable Units,* Vol. I, *Work Plans and Appendices,* Vol. II, *Site-Specific Field-Sampling Plan Addenda*. DOE/RL-2007-02, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Ecology - Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy. 1989. *Hanford Federal Facility Agreement and Consent Order*. Document No 89-10, as amended (The Tri-Party Agreement), Olympia, Washington. Accessed at http://www.hanford.gov/?page=91&parent=0.

EPA. 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*. EPA Directive 9200.4-17P, U.S. Environmental Protection Agency, Washington, D.C.

Eslinger, P.W., C.T. Kincaid, W.E. Nichols, and S.K. Wurstner. 2006. *A Demonstration of the System Assessment Capability (SAC) Rev. 1 Software for the Hanford Remediation Assessment Project*. PNNL-16209, Pacific Northwest National Laboratory, Richland, Washington.

Fayer, M.J., and J.M. Keller. 2007. *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas* PNNL-16688, Pacific Northwest National Laboratory, Richland, Washington.

FHI. 2006. *Evaluation of Vadose Zone Treatment Technologies to Immobilize Technetium-99*. WMP-27397, Rev. 1, Fluor Hanford, Inc., Richland, Washington.

FHI. 2007. *Technical Evaluation of Electrical Resistivity Methods*. SGW-34795, Fluor Hanford, Inc., Richland, Washington.

Gephart, R.E. 1999. *Hanford, A Conversation About Nuclear Waste and Cleanup*. Battelle Press, Columbus, Ohio.
Hartman, M.J. 2000. *Hanford Site Groundwater Monitoring: Setting, Sources, and Methods*. PNNL-13080, Pacific Northwest National Laboratory, Richland, Washington.

Khaleel, R. 2007. *The Far-Field Hydrology Data Package for the RCRA Facility Investigation RFI Report*. RPP-RPT-35222, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

Kincaid, C.T., P.W. Eslinger, R.L. Aaberg, T.B. Miley, I.C. Nelson, D.L. Strenge, and J.C. Evans, Jr. 2006. *Inventory Data Package for Hanford Assessments*. PNNL-15829, Rev.0, Pacific Northwest National Laboratory, Richland, Washington.

Last, G.V., W.E. Nichols, and C.T. Kincaid. 2006a. *Geographic and Operational Site Parameters List (GOSPL) for Hanford Assessments*. PNNL-14725, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Last, G. V., E. J. Freeman, K. J. Cantrell, M. J. Fayer, G. W. Gee, W. E. Nichols, B. N. Bjornstad, and D. G. Horton. 2006b. *Vadose Zone Hydrogeology Data Package for Hanford Assessments*. PNNL-14702, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Looney, B.B. and R.W. Falta (eds.). 2000. *Vadose Zone, Science and Technology Solutions*. Two Volumes, Battelle Press, Columbus, Ohio.

Moldrup, P., T. Olesen, T. Komatsu, P. Schjønning, and D.E. Rolston. 2001. "Gas Permeability in Undisturbed Soils: Measurements and Predictive Models." *Soil Sci*. 163:180–189.

RCRA - *Resource Conservation and Recovery Act*. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq. Accessed at http://www.epa.gov/region5/defs/html/rcra.htm.

Reidel, S. P. and M. A. Chamness. 2007. *Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site*. PNNL-15955, Rev. 1 Pacific Northwest National Laboratory, Richland, Washington.

Thornton, E.C., J.T. Giblin, T.J. Gilmore, K.B. Olsen, J.M. Phelan, and R.D. Miller. 1999. *In Situ Gaseous Reduction Pilot Demonstration – Final Report*. PNNL-12121, Pacific Northwest National Laboratory, Richland, Washington.

Thornton, E.C., V.L. Gore, and K.B. Olsen. 2003. "Immobilization of Chromium, Technetium, and Uranium by Gaseous Reduction in Soil from the Hanford Site." In M.J. Hartman, L.F. Morasch, and W.D. Webber (eds.), *Hanford Site Groundwater Monitoring for Fiscal Year 2002*, PNNL-14187, p. 3.3-10 to 3.3-14, Pacific Northwest National Laboratory, Richland, Washington.

Tuli, A., J.W. Hopmans, D.E. Rolston, and P. Moldrup. 2005. "Comparison of Air and Water Permeability between Disturbed and Undisturbed Soils." *Soil Sci. Soc. Am.* J. 69:1361–1371.

van Genuchten, M. 1980. "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils." *Soil Sci. Am. J.* 44:892-898.

Vermeul, V.R., M.D. Williams, B.G. Fritz, R.D. Mackley, D.P. Mendoza, D.R. Newcomer, M.L. Rockhold, B.A. Williams, and D.M. Wellman. 2007. *Treatability Test Plan for 300 Area Uranium Stabilization through Polyphosphate Injection*. PNNL-16571, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A.L. and G.W. Gee. 2001. *Vadose Zone Transport Field Study: FY 2001 Test Plan*. PNNL-13451, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A.L., M.E. Conrad, W.D. Daily, J.B. Fink, V.L. Freedman, G.W. Gee, G.M. Hoversten, J.M. Keller, E.L. Majer, C.J. Murray, M.D. White, S.B. Yabusaki, and Z.F. Zhang. 2006. *Vadose Zone Transport Field Study: Summary Report*. PNNL-15443, Pacific Northwest National Laboratory, Richland, Washington.

Wellman, D.M., J.S. Fruchter, and V.R. Vermeul. 2006. *Experimental Plan: Uranium Stabilization Through Polyphosphate Injection 300 Area Uranium Plume Treatability Demonstration Project*. PNNL-16101, Pacific Northwest National Laboratory, Richland, Washington.

Zachara, J.M., J.N. Christensen, P.E. Dresel, S.D. Kelly, C. Liu, J.P. McKinley, R.J. Serne, W. Um, and C.F. Brown. 2007. *A Site Wide Perspective on Uranium Geochemistry at the Hanford Site*. PNNL-17031, Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Letter on Treatability Investigations for Technetium-99

This page intentionally left blank.

0053301

December 7, 2004

Mr. Roy J. Schepens, Manager
U.S. Department of Energy
Office of River Protection
P.O. Box 450
Richland, Washington 99352

Mr. Keith A. Klein, Manager
U.S. Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

RECEIVED
JAN 14 2005
EDMC

Re: Treatability Investigations for Technetium-99

Dear Messrs. Schepens and Klein:

The Washington Department of Ecology (Ecology), the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Energy (DOE) have acknowledged the cleanup challenges posed by technetium-99 in the deep vadose zone. Recent characterization information from the 200-TW-1 (216-T-26 Crib and BC Cribs) and 200-UW-1 soil operable units and the 200-UP-1 groundwater and S/SX tank farms has indicated subsurface fate and transport of technetium-99 that is not consistent with modeling results. While progress has been made in explaining what physical processes may be responsible for the retention of technetium-99 in the vadose zone, not all of the modeling efforts and characterization plans reflect the latest findings.

The task of selecting effective and efficient cleanup remedies for vadose zone contamination may prove even more challenging than addressing the modeling and characterization issues we currently face. This is especially true for technetium-99 very deep in the vadose zone where the effectiveness of remedies employed at the surface is being questioned. Ecology and EPA believe that it is imperative that the Richland Operations Office and the Office of River Protection work with EPA and Ecology to develop a strategy for improved methods to understand the nature and extent of vadose zone contamination and to develop remedial options for addressing such contamination in order to restore and protect groundwater resources.

The effort will likely include a science and technology development component as there is no readily deployable technology to treat technetium-99 in the deep vadose zone. We also believe that treatability studies will be necessary to arrive at effective remedies at the operable units mentioned earlier. Hopefully, a waste site and tank farm management areas joint effort can lead to lessons learned and an efficient use of cleanup budget through coordinated treatability studies and subsequent cleanup remedies.

As a first step, Ecology and EPA would like to work with DOE to sponsor a technical forum on this issue in order to identify a path forward for developing more effective tools to address this important issue. We would anticipate that this initial effort would serve as the cornerstone for meeting regulatory requirements and public expectations for an effective cleanup of Hanford's vadose zone and protection of underlying groundwater resources. While we understand the difficulties associated with this work, we believe it is crucial to move forward with this effort as soon as possible and look forward to working constructively with you to rise to the challenge of technetium-99 in the vadose zone.

If you have any questions or comments, please contact John Price of Ecology (509/372-7921) or Craig Cameron of EPA (509/376-8665).

Sincerely,

Michael A. Wilson
NWP, Program Manager

Nicholas Ceto, Program Manager
Hanford Project Office

cc: L. Romine, DOE
L. Dusek, FH
K. Niles, OOE
M. Jarayasi, CHG
B. Ford, FH
P. Kruger, DOE
J. Lyon, Ecology
Admin. Record: 200-TW-1, 200-UW-1, 200-UP-1

Appendix B

List of Remediation Technologies

This page intentionally left blank.

Appendix B

Table B-1. Remediation Technologies Listing

General Response Action	Technology Type	Remediation Technology	Contaminants Treated
No Action	No Action	No Action	NA
Institutional Controls	Land Use Restrictions	Deed Restrictions	NA
	Access Controls	Signs/Fences	NA
		Entry Control	NA
	Monitoring	Monitoring	NA
Containment	Surface Barriers	Arid Climate Engineered Cap	I, M, R, O
		Asphalt, Concrete, or Cement Type Cap	I, M, R, O
		RCRA Cap	I, M, R, O
	Subsurface Barriers	Slurry Walls	I, M, R, O
		Grout Curtains	I, M, R, O
		Cryogenic Walls	I, M, R, O
		Sheet Pile	I, M, R, O
	Soil Stabilization	Membranes/Sealants/Wind Breaks/Wetting Agents	I, M, R, O
Removal	Excavation	Conventional	I, M, R, O, T
		Remote Processes	I, M, R, O, T
		Stabilization and Retrieval	I, M, R, O, T
		Soil Vacuum	I, M, R, O
Disposal	Landfill Disposal	Onsite Landfill	I, M, R, O
		Offsite Landfill/Repository	I, M, O, R (mixed with T), T

Table B.1. Remediation Technologies Listing (page 2 of 2)

General Response Action	Technology Type	Remediation Technology	Contaminants Treated
Ex Situ Treatment (assumes excavation)	Thermal Treatment	Calcination	I, O
		Thermal Desorption	O
		Incineration	O
		Pyrolysis	O
		Steam Reforming	O
		Vitrification	I, M, R, O
		In-Container Vitrification	I, M, R, O
	Physical/Chemical Treatment	Chemical Leaching	I, M, R, O
		Dehalonization	O
		Vapor Extraction	O
		Soil Washing	I, M, R, O
		Mechanical Separation	I, M, R, O
		Solvent Extraction	O
		Chemical Reduction/Oxidation	I, M, O
		Solidification/ Stabilization	I, M, R, O
		Automated radionuclide segregation	I, M, R, O, T
	Biological Treatment	Composting	O
		Biological Treatment	O
		Landfarming	O
		Slurry Phase Bio Treatment	O
		Phytoremediation	M, R, O
In Situ Treatment	Thermal Treatment	Vitrification	I, M, R, O
		Thermally Enhanced SVE	O
	Chemical/Physical Treatment	Soil Flushing	I, M, R, O
		Active and Passive Vapor Extraction	O
		Grout Injection	I, M, R, O
		Soil Mixing	I, M, R, O
		Vapor Extraction	O
		Supersaturated Grouts	I, M, R, O
		Soil Desiccation	I, M, R, O
		Electrokinetics	I, M, R
		Reactive gases (H2S)	I, M, R, O
		Nanoparticles	I, M, R, O
		Geochemical Manipulation	I, M, R
		Phosphate- or calcite-based immobilization	I, M, R
	Biological Treatment	Biodegradation	O
		Bioventing	O
		Phytoremediation	M, R, O
	Natural Attenuation	Monitored Natural Attenuation	I, M, R, O

Notes: I = Other inorganic contaminants; M = Heavy metal contaminants; NA = Not applicable; R = Radionuclide contaminants; T = Transuranic radionuclides; O = Organic contaminants

Appendix C

Conceptual Model of the Deep Vadose Zone Beneath the Central Plateau

This page intentionally left blank.

Appendix C

Conceptual Model of the Deep Vadose Zone Beneath the Central Plateau

Transport of technetium-99 and uranium through the vadose zone is contingent on their release into and flow with vadose zone water (i.e., aqueous phase drainage). The processes governing flow and transport through the vadose zone depend on infiltration, the physical and chemical nature of the geologic materials that make up the vadose zone and the types, amounts, and compositions of the fluids that occupy the pore spaces.

Technologies being considered for testing predominantly involve those that affect infiltration or that reduce or immobilize the vadose zone water, thereby leaving contaminants in the vadose zone without significant transport potential. An exception to these technology approaches is flushing the contaminants out of the vadose zone.

The implementability, effectiveness, and cost of remediation technologies that target deep vadose-zone contaminants strongly depend on the subsurface conditions, in particular, the associated contaminant, co-contaminant, and moisture distribution, and the disposal history. Many of these in-situ remediation technologies require the ability to deliver amendments to or remove moisture or contaminants from targeted subsurface zones. Implementation of these in-situ treatment technologies, must consider the following items:

- The amount of water introduced to the subsurface
- The impact on water distribution in the subsurface, if the hydraulic conductivity is changed by the in situ technology
- Contrasts in permeability at multiple intervals within and immediately below the contaminated zone; the layers of finer-grained material are typically very thin (mm to 15 cm); layers identified as generally coarse may be laminated by very thin lenses of finer-grained material
- Depth and thickness of the contaminated zone in the subsurface
- Spatial extent of contamination

Key components of the subsurface conditions and processes are summarized below to provide a context for the subsurface conditions and processes that may influence the success of potential remedial technologies and the selection of appropriate treatability test sites. This section provides general background information related to the hydrogeology, recharge events, and geochemistry. Further discussion and detail regarding the general site conditions can be found in the following documents:

- Zachara, J.M., J.N. Christensen, P.E. Dresel, S.D. Kelly, C. Liu, J.P. McKinley, R.J. Serne, W. Um, and C.F. Brown. 2007. *A Site Wide Perspective on Uranium Geochemistry at the Hanford Site*. PNNL-17031, Pacific Northwest National Laboratory, Richland, Washington.

- DOE. 2007a. *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, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

- DOE. 2007b. *Vadose Zone Modeling at the Hanford Site: Regulatory Criteria and Compliance for Risk Assessment Applications*. DOE/RL-2007-34, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

- Reidel, S. P. and M. A. Chamness. 2007. *Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site*. PNNL-15955, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

- Khaleel, R. 2007. *The Far-Field Hydrology Data Package for the RCRA Facility Investigation RFI Report*. RPP-RPT-35222, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

- Cantrell, K.J., J.M. Zachara, P.E. Dresel, K.M. Krupka, and R.J. Serne. 2007. *Geochemical Processes Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*. PNNL-16663, Pacific Northwest National Laboratory, Richland, Washington.

- Fayer, M.J., and J.M. Keller. 2007. *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas* PNNL-16688, Pacific Northwest National Laboratory, Richland, Washington.

- CHG. 2007. *Central Plateau Vadose Zone Remediation Technology Screening Evaluation.* CH2M HILL Hanford Group, Richland, Washington.

- Ward, A.L., M.E. Conrad, W.D. Daily, J.B. Fink, V.L. Freedman, G.W. Gee, G.M. Hoversten, J.M. Keller, E.L. Majer, C.J. Murray, M.D. White, S.B. Yabusaki, and Z.F. Zhang. 2006. *Vadose Zone Transport Field Study: Summary Report* . PNNL-15443, Pacific Northwest National Laboratory, Richland, Washington.

- Last, G. V., E. J. Freeman, K. J. Cantrell, M. J. Fayer, G. W. Gee, W. E. Nichols, B. N. Bjornstad, and D. G. Horton. 2006b. *Vadose Zone Hydrogeology Data Package for Hanford Assessments*. PNNL-14702, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

- Kincaid, C.T., P.W. Eslinger, R.L. Aaberg, T.B. Miley, I.C. Nelson, D.L. Strenge, and J.C. Evans, Jr. 2006. *Inventory Data Package for Hanford Assessments*. PNNL-15829, Rev.0, Pacific Northwest National Laboratory, Richland, Washington.

- DOE. 2000. *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas*. DOE/RL-99-36, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

- Hartman, M.J. 2000. *Hanford Site Groundwater Monitoring: Setting, Sources, and Methods*. PNNL-13080, Pacific Northwest National Laboratory, Richland, Washington.

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

C-1 Hydrogeology

The vadose zone is the region of the subsurface that extends from the ground surface to the water table. Historic effluent discharges to U-Pond and other major liquid waste disposal facilities raised the water table as much as 24 meters (80 feet) above the estimated water-table elevation prior to the start of Hanford operations. With the cessation of liquid discharges in the mid-1990s, the water table has been declining. The vadose zone beneath the Central Plateau ranges in thickness from about 50 meters (164 feet) in the western portion of the 200 West Area (beneath the former U Pond) to 104 meters (341 feet) in the southern part of 200 East Area (Last et al. 2006b). The geology and hydrology of the Central Plateau have been extensively studied because these areas are major historic sources of soil and groundwater contamination (Hartman 2000).

The major stratigraphic units making up the vadose zone include the following:

- Surface eolian sand and silt deposits of Holocene-Age
- Glacio-fluvial deposits of the Pleistocene-Age Hanford formation
- Fluvial, eolian, and pedogenic deposits of the Pliocene/Pleistocene-Age Cold Creek unit
- Fluvial, overbank, and lacustrine deposits of the Miocene/Pliocene-Age Ringold Formation

The stratigraphy varies significantly across the up to 100-meter- (328-foot-) thick Cold Creek flood bar that makes up the Central Plateau. A generalized geologic cross section showing the general stratigraphy through the Central Plateau is shown in Figure C-1 (Hartman 2000). The physical structure and properties of the geologic framework and its principal transport pathways affect contaminant movement and distribution within the vadose zone (DOE 1999c; Last et al. 2006b; Reidel and Chamness 2007) and can have significant effects on the implementability and effectiveness of remedial technologies. Some of the important subsurface features are the nature and degree of contrast between sediment types and sedimentary features (e.g. silt lenses, buried soil horizons, clastic dikes, etc.). Figure C-2 illustrates some of these important features of the Central Plateau vadose zone.

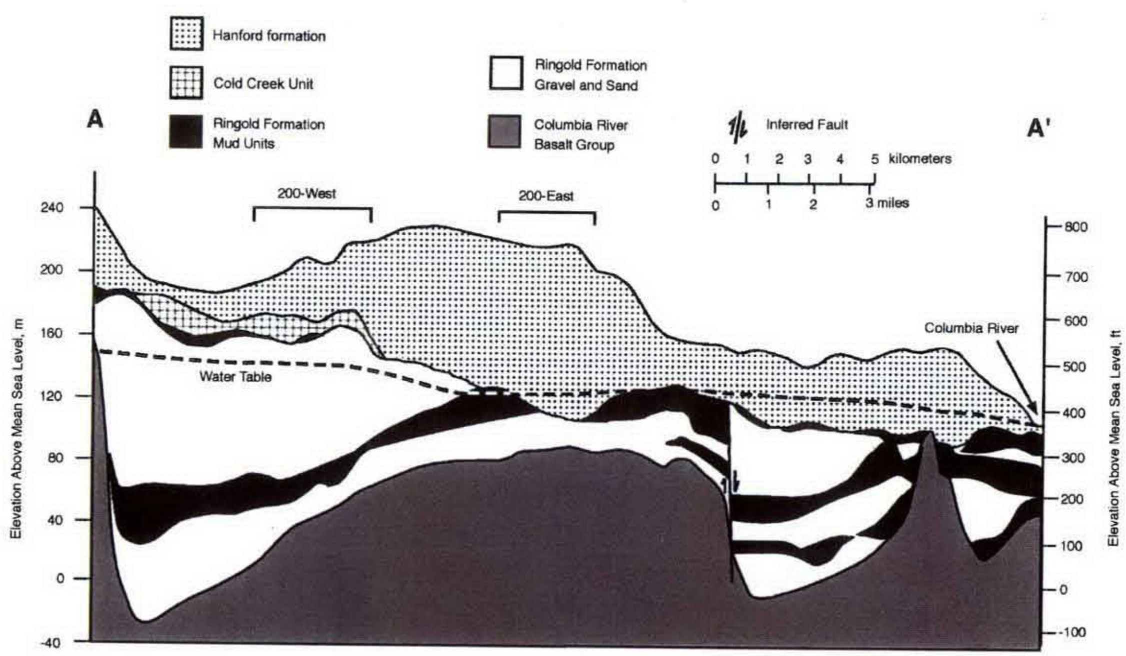

Figure C-1. Generalized West-to-East Geologic Cross Section Through the Hanford Site (after Hartman 2000)

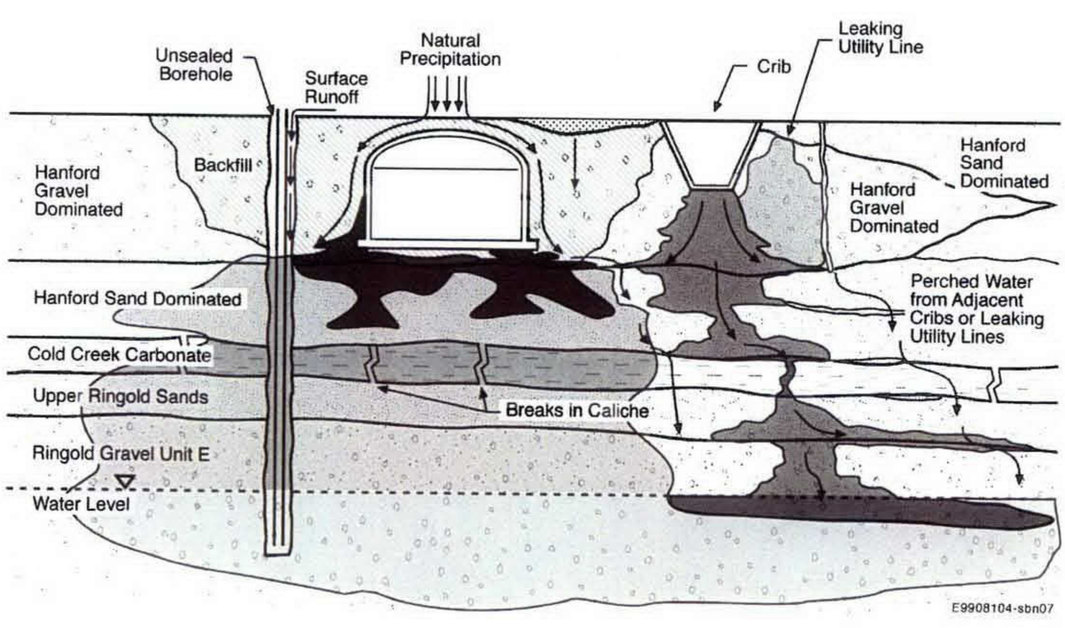

Figure C-2. General Vadose Zone Conceptual Model Concepts after Last et al. (2006b).

The vadose zone beneath 200 West Area ranges from 50 to 80 meters (164 to 262 feet) thick and can be subdivided into six principal hydrostratigraphic units (Lindsey et al. 1992a; Connelly et al. 1992a; Thorne et al. 1993; Williams et al. 2002; DOE 2002; Reidel and Chamness 2007). These units include the following:

- Two facies associations of the Hanford formation:
  - Gravel-dominated
  - Sand-dominated
- Two lithofacies of the Cold Creek unit:
  - Fine-grained, laminated to massive facies
  - Coarse to fine-grained carbonate-cemented facies
- Two members of the Ringold Formation:
  - Taylor Flat
  - Wooded Island, Unit E

Not all of these units are present everywhere within the 200 West Area; as in any depositional system, the thickness, distribution, and continuity of these units vary significantly from site to site.

Clastic dikes (Figure C-3) are present, primarily in the finer-grained Hanford formation sediments in the southern portions of 200 East and 200 West Area (Fecht et al. 1999; Reidel and Chamness 2007). They occur as near-vertical sediment-filled structures that cut across bedding planes and have been observed to form multi-sided polygonal cells (up to 150 meters [492 feet] across) enclosing the host sediment (Fecht et al. 1999). Their effect on the transport of deep vadose zone contaminants is expected to be minimal except under a restricted set of conditions (Murray et al. 2003; Ward et al. 2006; DOE 1999d, 2006; Mann et al. 2001; CHG 2002). However, their potential effect on active in situ remediation technologies should be considered.

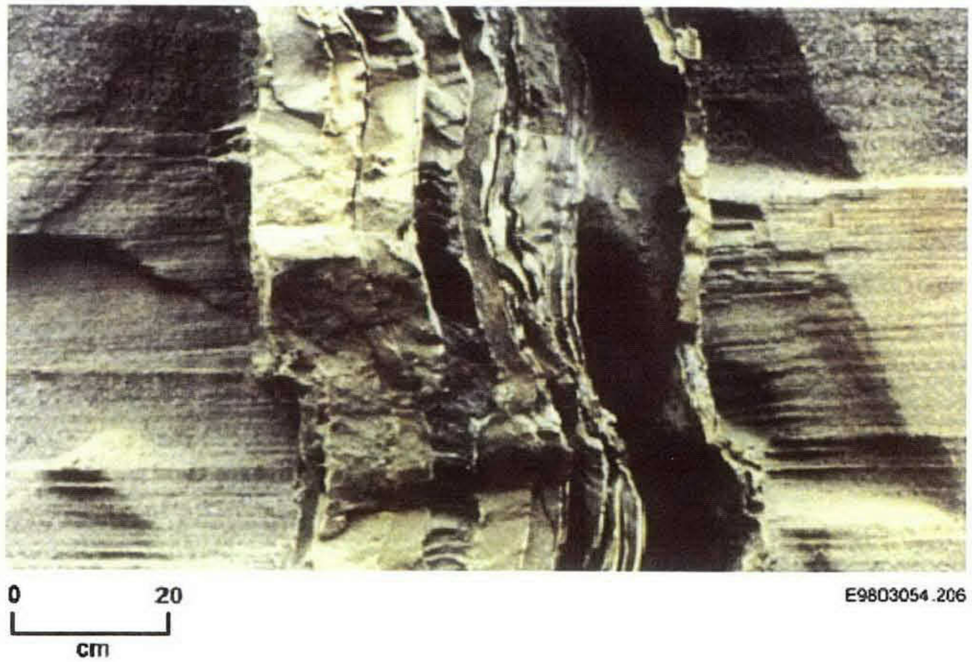

Figure C-3. Photograph of a Typical Clastic Dike as Found at the U.S. Ecology Site in Central Plateau (after Fecht et al. 1999)

Perhaps the most significant feature in the 200 West Area affecting vadose zone transport is the fine-grained siliciclastic and carbonate-cemented facies of the Cold Creek unit, previously referred to as the Plio-Pleistocene unit, (Rohay et al. 1994; DOE 2002), which represents an ancient buried calcic paleosol sequence (Slate 1996, 2000). This unit is encountered about midway between the ground surface and the water table in the 200 West Area, where substantial volumes of perched water have been encountered (CHG 2007). Because of the cemented nature of the Cold Creek unit, it is often considered impervious; however, it is also structurally brittle and may contain abundant fractures that have developed during or since soil development. The degree of cementation varies considerably within the Cold Creek unit so that contaminants could breach the unit through discontinuities. The Cold Creek unit contains abundant weathering products (e.g., oxides and carbonates) and may chemically react on contact with transported waste. Immediately overlying the carbonate-cemented facies of the Cold Creek unit is the fine-grained, laminated to massive facies (formerly referred to as the "early Palouse soil") that has a relatively high moisture-retention capacity with a corresponding low permeability that tends to retard the downward movement of moisture and contaminants.

The vadose zone beneath 200 East Area ranges from 50 to 104 meters (164 to 341 feet) thick and can also be subdivided into six principal hydrostratigraphic units (Last et al. 2006b; Reidel and Chamness 2007):

- Three units within the Hanford formation:
  - An upper gravel-dominated facies
  - A sand-dominated facies
  - A lower gravel-dominated facies
- A fluvial gravel facies of the Cold Creek unit (equivalent to the Pre-Missoula Gravels of Webster and Crosby 1982; Delaney et al. 1991)
- Two units belonging to the Ringold Formation (Lindsey et al. 1992b; Connelly et al. 1992b; Thorne et al. 1993; Williams et al. 2000; DOE 2002)
  - Member of Wooded Island, Unit A gravels
  - Member of Wooded Island, Unit E gravels

Over most of the 200 East Area, the Hanford sand-dominated facies lies between the upper and lower gravel-dominated facies (Lindsey et al. 1992b; Connelly et al. 1992b). The Ringold Formation in the 200 East Area is, for the most part, eroded away in the northern half of 200 East Area. Here, the Hanford formation lies directly on top of basalt bedrock. As the water table continues to drop in response to the cessation of effluent discharges in the mid-1990s, it is falling below the top of basalt beneath the northeastern portion of 200 East Area. Just south of 200 East Area, the top of the unconfined aquifer lies within the Ringold Formation.

Sublinear to anastamosing (braided-stream like), channel-cut scour and fill features occur within the Hanford formation and may act as preferential pathways in the horizontal direction. Other types of heterogeneity are associated with stratigraphic pinch out or offlapping/onlapping of facies. Both the Ringold and the Hanford formations often contain thin fine-grained stringers that can result in lateral spreading of moisture and may slow the vertical movement of contaminants within the vadose zone (Figures C-4 and C-5).

Figure C-4. Gravel-Dominated Sediments of the Hanford formation Exposed in Pit #30.

Figure C-5. Sand-Dominated Sediments of the Hanford formation Exposed at the Integrated Disposal Facility.

Last et al. (2006b) subdivided both 200 East and 200 West Area into two different geographic areas (a northern area and a southern area) that could be represented by a similar hydrostratigraphic column. A fifth geographic area was also defined to the northeast of 200 East Area, where high volumes of dilute waste water were disposed, and is of little interest to this study. Last et al. (2006b) defined the hydrostratigraphic units and thicknesses for each geographic area and assigned hydraulic and geochemical properties to each unit. Reidel and Chamness (2007) defined the hydrostratigraphic units and thicknesses for each single-shell tank farm.

Data on particle-size distribution, moisture retention, and saturated hydraulic conductivity (K_s) have been cataloged for hundreds of samples from throughout the Hanford Site (Khaleel and Freeman 1995; Khaleel et al. 1995; Khaleel and Relyea 1997; Freeman et al. 2001, 2002; Freeman and Last 2003; Khaleel and Heller 2003). Last et al. (2006b) and Khaleel et al. (2007) summarize the hydraulic properties for various sediment classes. Khaleel (1999) estimated a longitudinal macrodispersivity of about 100 centimeters (39 inches) for the sand-dominated facies of the Hanford formation in 200 East Area.

Data on the mineralogy of the suprabasalt sediments has been cataloged for hundreds of samples (Tallman et al. 1979; Bjornstad 1990; Serne et al. 1993, 2002; DOE 2002; Xie et al. 2003; Reidel 2004; Reidel et al. 2006). Empirical distribution coefficient (K_d) data for Hanford formation and Ringold Formation sediments are fairly abundant for dilute waste solutions and groundwater (Cantrell et al. 2002, 2003a, 2007; Last et al. 2006b). Fewer K_d data are available for the Cold Creek unit sediments or for high ionic strength waste solutions with slightly acidic to slightly basic pH values. A relatively small amount of K_d data exist for the combined high ionic-strength/highly basic tank liquors for many common radionuclides. Differences between adsorption and desorption K_d measurements are also well documented. These K_d data have been well tabulated by Cantrell et al. (2003), Kincaid et al. (1998), Serne and Wood (1990), Kaplan and Serne (1995), Kaplan et al. (1996, 1998), Krupka et al. (2004), Um et al. (2005), Um and Serne (2006), and Serne (2007). In the far-field, adsorption appears to be the controlling geochemical process, but in the near-field, neutralization of acid waste by the alkaline sediment and neutralization of basic tank waste can cause precipitation of a few macro and numerous minor contaminant species within the sediment pores. In the far-field, outside the zone of pH neutralization, adsorption is considered to be the dominant contaminant retardation process in the vadose zone.

C-2 Recharge

Contamination residing in the deep vadose zone was in most cases driven there primarily by the liquid waste discharges themselves and/or other unplanned liquid releases (e.g. water line leaks). With the cessation of liquid waste disposal and improved water management controls, the primary driving force has been shifting to drainage of meteoric water from natural precipitation events (also as known as natural recharge).

The long-term natural driving force for flow and transport through the vadose zone is that fraction of the precipitation that has infiltrated below the zone of evaporation and below the influence of plant roots. That fraction of meteoric water that is eventually transported through the vadose zone flows to the water table, recharging the unconfined aquifer and carrying with it any dissolved species. Gee et al. (1992) presented evidence from multiple experiments showing that measurable diffuse natural recharge occurs across the lower elevations of the Hanford Site, with rates ranging from near zero in undisturbed shrub-steppe plant communities to more than 100 mm/year beneath the unvegetated graveled surfaces. Fayer and Walters (1995) presented a recharge distribution map for the Hanford Site that suggests recharge rates could range from over 50 mm/year for unvegetated sand to about 25 mm/year for cheatgrass covered sand. Last et al. (2006a and b) presented a number of recharge classes for individual waste sites, based on soil or surface barrier conditions and degree of vegetation coverage. Gee et al. (2005) estimated average drainage (recharge) rates for unvegetated sand at the 300 North Lysimeter Site for two different time periods (1982-1993 and 1995-2004) at 54 and 73 mm/yr, respectively. Fayer and Keller (2007) updated these previous estimates as shown in Table C-1.

Table C-1 Estimated Long-Term Drainage Rates for Use in Hanford Assessments (after Fayer and Keller 2007).

Soil Type	Estimated Long-Term Drainage Rates (mm/yr)	
	Shrub	No Plants
Rupert sand (near U.S. Ecology)	5.0	30
Rupert sand (near IDF)	0.9	45
Rupert sand (elsewhere on Central Plateau)	1.7	45
Burbank loamy sand	1.9	53
Ephrata sandy loam	2.8	23
Hezel sand	<0.1	8.7
Esquatzel silt loam	<0.1	8.6
Hanford formation sand	np	62
Graveled surface	np	92
Modified RCRA C barrier	0.1	0.1
Gravel side slope on surface barrier	1.9	33(a)

np = Not provided by Last et al. (2006a and b) or this data package.
(a) Tentative

Historically, billions of gallons of contaminated water were disposed to subsurface infiltration structures and surface ditches and ponds. Most waste water disposal ceased by the mid-1990s. Currently, two facilities are permitted to discharge to the vadose zone: the State-Approved Liquid Disposal (SALD) Facility and the Treated Effluent Disposal Facility (TEDF). Numerous discharges of water, collectively called miscellaneous streams, are also permitted but do not need to be monitored unless they exceed certain discharge rates and annual amounts (DOE 1999a). Other possible sources of additional recharge water are roads, road shoulders and ditches, parking lots, power and fire lines, flushing of potable water lines, and all structures that do not have precipitation controls. These also fall under the miscellaneous streams permit. Source events include accidental or intentional discharges of fluids, gases, and contaminants to the environment. Unintentional releases include spills, tank leaks, and distribution pipe leaks. The quantity, quality, duration, and phases of waste or fluid released are generally unknown. Other potential source events include remediation activities that involve the injection or extraction of liquid, chemicals, gases, and heat.

C-3 Contaminant Fate and Transport Processes

Contaminants entered the vadose zone through a variety of liquid waste discharges, buried solid waste, and unplanned releases. The nature and extent of contamination within the vadose zone was affected by the waste chemistry and type of release. Technetium-99 and uranium were carried into the deep vadose zone due to their mobility and driving forces from previous releases, as well as nearby water releases and natural precipitation events. Technetium-99 and uranium are expected to continue to migrate toward the groundwater when present as a dissolved component of mobile pore fluids and driven by infiltrating water.

The primary processes governing flow and transport through the vadose zone depend on the physical and chemical nature of the geologic materials that make up the vadose zone (described above) as well as the types, amounts, and compositions of the fluids that occupy the pore spaces (Looney and Falta 2000, p. 13). Chemicals move through the vadose zone by a variety of mechanisms, including advection with the bulk flow of the fluid phases, diffusion, and dispersion within the fluid phases, and mass transfer between the phases. Many compounds interact physically or chemically with the solid phase matrix of the vadose zone. For technetium-99 and uranium, movement through the vadose zone is contingent on being dissolved within flowing water (i.e., aqueous phase drainage). The flow of water through unsaturated soil depends on interactions between rate of water infiltration, moisture content of the soil, textural heterogeneity, and soil hydraulic properties. Infiltrating water provides the primary driving force for downward migration of contaminants. Perched water zones and lateral spreading may develop when vadose water accumulates on top of low-permeability soil lenses, highly cemented horizons, or above contacts between fine-grained horizons and underlying coarse-grained horizons (where the high matric potential of fine-grained horizons promotes lateral movement). Unsaturated hydraulic conductivities may vary by several orders of magnitude depending on the water content of the soils. The geothermal gradient has a small but steady impact on the movement of water upward through the vadose zone. Enfield et al. (1973) used field measurements of temperature and matric (matix) potential at a site about 1 km (0.62 mile) to the south of the 200 East Area to calculate an upward water flux of 0.04 mm/year.

Some of the liquids disposed or leaked to the vadose zone had properties that differed significantly from the properties of pure water, and their rates and routes of movement through the vadose zone may differ as well. The specific gravity of some waste leaked from single-shell tanks ranged from 1.1 to 1.65 (Anderson 1990; Ward et al. 1997), which could enhance the transport of contaminants. Increased density has been demonstrated to elongate contaminant plumes vertically and reduce lateral spreading caused by stratigraphic variations in hydraulic properties (Ward et al. 1997). Viscosity of the liquids also influenced their movement through the vadose zone, generally inhibiting flow due to viscosities often several times higher than water. The properties of these fluids will change as contaminants are diluted, sorbed, or the fluid evaporates into the sediment air space.

The rate of gas movement in the vadose zone is affected by the magnitude of any barometric pressure changes and temperature gradients. The vadose zone across the entire Hanford Site experiences temperature changes due to diurnal and seasonal temperature changes at the soil surface. The magnitude of the temperature changes diminishes with depth; at 10 meters (32.8 feet), the seasonal change appears to be less than 1°C (33.8° F) (Hsieh et al. 1973). In addition to the near-surface temperature changes, a steady upward geothermal gradient exists that drives gas (and water vapor) upward. The elevated temperatures of waste in the single-shell tanks are calculated to have induced local movement of both liquids and vapor (CHG 2002 – Appendix D).

The formation of colloids and occurrence of colloid-facilitated transport of contaminants were identified by the Vadose Zone Expert Panel as a potentially important processes affecting vadose zone transport (DOE 1997). At waste sites that received highly concentrated waste from leaking tanks, conditions may have existed for colloid formation (Mashal et al. 2004). However, data are insufficient to adequately characterize the potential for colloidal transport. Zhuang et al. (2004) found that several interacting mechanisms might be involved simultaneously during colloid transport, but that their importance depends on the chemical and physical properties of the colloids and transport media as well as the environmental conditions. Current understanding of colloid-soil interactions and the ability to predict transport of colloids in natural subsurface media is limited. However, for most waste sites at Hanford, the low water contents and relatively simple geochemistry are not conducive to colloid formation or colloid-facilitated transport. Zhuang et al. (2007) suggest that colloid transport and mobilization in the deep soils at Hanford might be limited or insignificant except under instable water flow conditions.

The predominant direction for contaminant movement is downward, due to gravity. Variations in the hydraulic properties and the presence of impeding features such as bedding interfaces, caliche layers, and man-made features (e.g., underground tanks, pipelines) can locally alter and redirect the movement laterally. Relatively simple stratigraphic layering can give rise to significant variations in water content distributions and enhanced lateral spreading that impedes vertical migration of contaminants. Various preferential pathways such as clastic dikes and fractures are capable of concentrating or contributing to phenomena such as fingering and funnel flow. Preferential flow has been documented along poorly sealed well casings at the Hanford Site (Baker et al. 1988) and transport along clastic dikes may be potentially important (DOE 1997). Murray et al. (2003) suggest that clastic dikes might serve as a conduit for more rapid movement of mobile contaminants to the water table, but only under a restricted set of recharge (or leak) conditions. The Vadose Zone Expert Panel (DOE 1997) stated that a likely mode of transport for leaked or disposed tank waste in the Hanford geology is along preferential, vertical, and possibly tortuous pathways. Simulations of the effects of clastic dikes have been performed in many risk assessments (DOE 1999d, 2006; Mann et al. 2001; CHG 2002), but any effects have a small influence (< 5%) on total risk, even when the clastic dikes are placed to optimize contaminant movement.

The fate of contaminants in the vadose zone depends on geochemical conditions and processes (e.g., solubility, desorption, advection) controlling the release and migration of contaminants such as uranium, the speciation of the contaminant, residence time, and microbial activity. Sediment has the capacity to sorb many contaminants from solution. The amount of sorption is a function of many factors, including mineral surface area and type, contaminant type (speciation) and concentration, overall solution concentration, pH, Eh, and reaction rates for the controlling adsorption or precipitation, dissolution, and hydrolysis reactions. Some contaminants do not sorb at all (i.e., soluble anions such as nitrate, chromate, and pertechnetate) and are moved along with the bulk solution. The flux rate of contaminants through the vadose zone is affected by both the physical mechanisms of fluid transport (e.g., advection vs. diffusion) and the processes that control solute concentrations of contaminants of concern. The linear isotherm K_d construct has been shown to adequately describe contaminant behavior for most vadose zone fate and transport in the Hanford Site sediments (Cantrell et al. 2002, 2003; Serne and Kaplan 2000; Krupka et al. 2004). Contaminant solute concentrations are affected by sorption in the far-field and sometimes by dissolution/precipitation reactions between waste liquids of extreme pH and the slightly alkaline sediment in the near field. Sorption delays downward movement of the contaminant and allows degradation processes to occur (e.g., radioactive decay) and, for some, irreversible incorporation into the sediment. For conditions that involve dilute pore water chemistry, sorption can generally be described using a simple linear relationship (i.e., a distribution coefficient or K_d) that is determined empirically. However, conditions near some waste sources (near-field) are so variable due to the strong influence of the waste chemistry that the K_d approach may not be appropriate for predicting the retardation of contaminants. This is the case for hot, highly concentrated tank wastes in contact with Hanford sediment. Reactions between the sediment and highly acidic or highly basic waste are also important.

C-4 Waste Sites of Potential Concern

Waste disposal in the Central Plateau evolved over time and relied on a number of different types of waste sites and disposal strategies. These included (1) high volume low-concentration liquid discharges primarily associated with cooling water, (2) low-volume highly concentrated liquid waste from chemical separation processes or leaks and (3) solid waste burial. Significant concentrations of constituents such as technetium-99, uranium, and nitrate are generally not found in the vadose zone beneath the highest volume liquid discharge sites. These constituents are easily transported and were likely flushed through the vadose zone by the large volumes of water discharged. However, significant concentrations and inventories of mobile constituents are found beneath the low-volume high concentration liquid release sites. Significant inventories of mobile constituents have also been identified for some solid waste sites (Kincaid et al. 2006). The extent of contamination that may have been released from these sites is unknown; however, the release of contaminants from these solid waste forms and waste packages as well as the relatively low driving force suggests that the majority of the contaminants associated with solid waste is unlikely to have migrated deep into the vadose zone (Eslinger et al. 2006).

The purpose of this section is to review available information on waste sites with deep vadose zone contamination (inventories, potential risk to groundwater, and depth of contamination). The focus of this assessment is on low-volume high-concentration liquid waste sites where technetium-99 and uranium are believed to have migrated and still remain deep in the vadose zone. Information related to nitrate in the vadose zone was not sufficient to use as a distinguishing factor in assessing the target problems. However, information about nitrate for sites with technetium-99 and uranium is included in the tabulation of target problems.

The nature of the subsurface geologic materials playing host to the deep vadose zone contamination was considered in the waste site assessment. As shown in Figure C-1, by far the predominant geologic materials impacted by waste site releases, is the Hanford formation, although significant concentrations can also be found in the Cold Creek unit beneath 200 West Area. The nature of Hanford formation materials varies from 200 East Area to 200 West Area and from north to south. Thus, four main geographic areas are considered for defining target problems. In keeping with the geographic areas defined by Last et al. (2006a), these are:

1. A, Southern 200 East Area
2. B, Northwestern 200 East Area
3. S, Southern 200 West Area
4. T, Northern 200 West Area

Waste sites where constituents of interest to this study (uranium, technetium-99, and nitrate) have penetrated deep in the vadose zone, present a potential threat to degradation of the unconfined aquifer. A recent analysis by Eslinger et al. (2006), conducted to better understand the relative threat to the unconfined aquifer from waste sites in the vadose zone of the Central Plateau region, used inventory, contaminant release into and from the vadose zone, and hypothetical concentrations in groundwater to rank the threat posed to the aquifer by individual waste sites and groups of waste sites. Note that recharge rates and groundwater flow rates play an important roll in predicting the hypothetical groundwater concentrations. Because remedial action decisions will be made for groups of sites, rather than individual sites, Eslinger et al. (2006) grouped individual waste sites into 32 groups that received similar wastes and were located in the same geographic area. Note also that Eslinger et al. (2006) included future solid waste disposal in their analysis, much of which would be derived from cleanout and closure of high-level waste tanks. However, since solid waste and in particular future solid waste is not expected result in deep vadose zone contamination, solid waste was excluded from this analysis.

C-4-1 Inventory

Corbin et al. (2005) published the results of the Soil Inventory Model (SIM), Rev. 1 to provide insight into contaminated soil inventories associated with the liquid waste disposal sites, unplanned releases, and tank leaks at the Hanford Site and their associated uncertainty. Further information on the design and users guide for SIM are documented by Anderson et al. (2007) and Simpson et al. (2007). Kincaid et al. (2006) used the SIM results in combination with other records and projections to produce a best-estimate cumulative inventory of radioactive contaminants for all potentially significant waste sites through 2005.

Eslinger et al. (2006) found that based on the cumulative inventories, the waste site groups listed below (along with some representative sites), excluding solid waste, pose the greatest threat to groundwater from technetium-99 (see Figure C-6).

- BC cribs and trenches (e.g., 216-B-14, -18)
- BY cribs and vicinity (e.g., 216-B-46, -49)
- T Tank Farm and vicinity (e.g., 241-T-106)
- S/SX Tank Farms and vicinity (e.g., 241-SX-108)
- U cribs (e.g., 216-U-1 and -2)

Examination of the cumulative inventories for uranium (e.g., uranium-234 through -238) suggest that the following groups of sites (along with some representative sites), excluding solid waste, pose the greatest potential impact/risk to groundwater from uranium:

- 200 East Ponds Region (216-A-19, -25)
- U cribs (216-U-8, -12 -1and -2)
- B Plant cribs and trenches (216-B-12)
- B/BX/BY Tank Farms (241-BX-102)
- PUREX cribs and trenches (216-A-4)

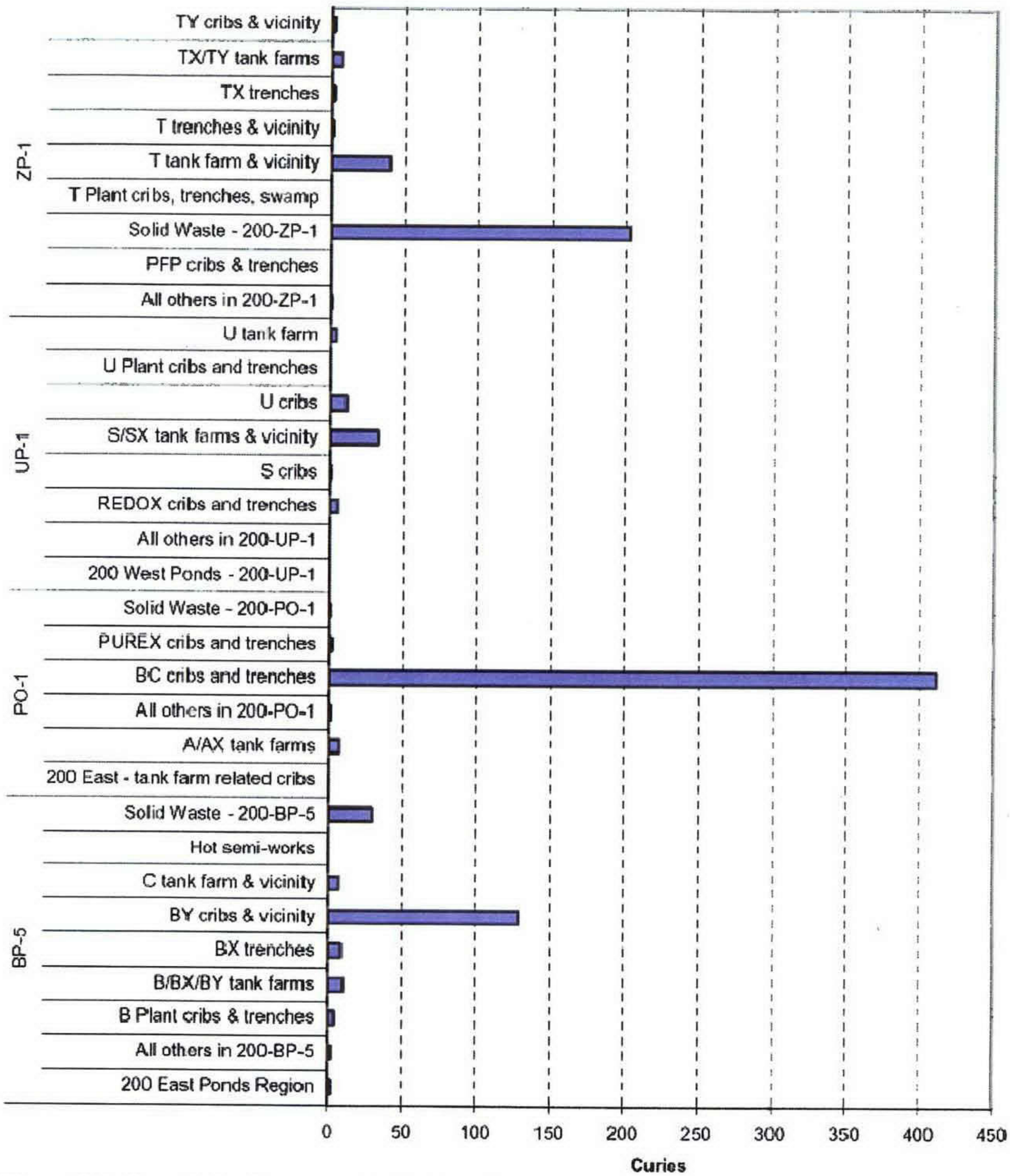

Figure C-6. Cumulative Inventory, in Curies, of Technetium-99 (decay corrected to 2007) by Site Group (after Eslinger et al. 2006).

C-4-2 Potential Releases Into and Through the Vadose Zone

Eslinger et al. (2006) conducted additional analyses of releases into and through the vadose zone, to examine the threat of contaminants to the unconfined aquifer each year. This analysis examined cumulative releases of selected radionclides (in curies) that might occur over four time periods: (1) 1944 through 2005, (2) 2006 through 2100, (3) 2101 through 3100, and (4) 3101 through 12000. Figure C-7 shows the results for the cumulative release of technetium-99 from each group of waste sites into the vadose zone. This analysis found that the following waste sites, excluding solid waste, pose the greatest threat to groundwater from technetium-99:

- BC cribs and trenches
- BY cribs and vicinity
- T Tank Farm and vicinity
- S/SX Tank Farms and vicinity

They further suggested that the greatest impact and risk to groundwater from uranium was from the PUREX cribs and trenches, the U cribs, REDOX cribs and trenches, TY cribs and vicinity, and past releases from the B/BX/BY and U Tank Farms.

This analysis found that the largest, early impacts of technetium-99 on the groundwater may come from:

1. S/SX Tank Farms and vicinity
2. BY cribs and vicinity
3. BC cribs and trenches
4. T Tank Farm and vicinity
5. Solid Waste overlying the 200-ZP-1 Operable Unit

Future threats to groundwater from uranium isotopes were found to arise from:

1. B/BX/BY Tank Farms
2. PUREX cribs and trenches
3. U cribs

C-4-3 Depth of Contamination in the Vadose Zone

DOE (2007c) in their efforts to evaluate supplemental data needs for the Central Plateau Operable Units, binned the waste sites into several model groups based on an updated understanding gained from the remedial investigations. This analysis did not include a number of waste sites that were on a different remedial investigation/feasibility study path. These included the tank farm areas, the BC cribs and trenches and the U cribs and trenches (all of which are known to have deep contamination). Each bin (i.e., model group) contained waste sites with similar features regarding contaminant distribution and potential risk pathways. Two of these model groups include sites with contaminants of concern in the deep vadose zone (generally defined as greater than 4.6 meters (15 feet) below ground surface [bgs]).

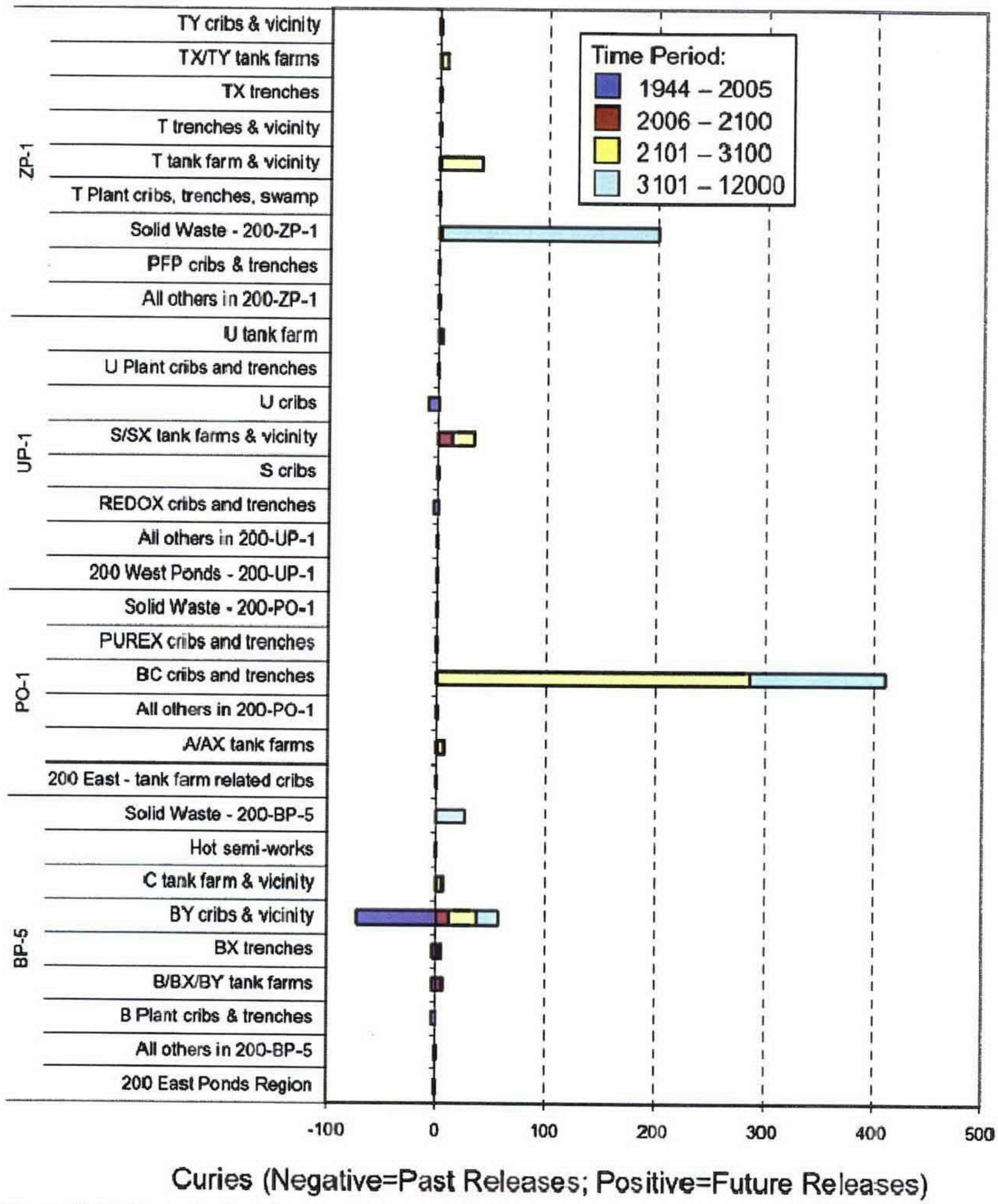

Figure C-7. Numerically Simulated Cumulative Release (not decay-corrected) of Technetium-99 from the Vadose Zone into the Groundwater by Site Group (after Eslinger et al. 2006).

Model Group 2, Deep Sites (e.g., 216-B-43 through 216-B-50 cribs, also known as the BY cribs) are sites characterized by deeper contamination (generally below 4.6 meters [15 feet] bgs). These sites do not pose risk to human or ecological receptors for the 0 to 4.6 meter (15 foot) zone; however, deeper contaminants likely are present and may pose risk to groundwater and potential future intruders.

Model Group 6, Shallow and Deep Sites (e.g., 216-T-14 through 216-T-17 trenches) are characterized by both deep and shallow contamination (DOE 2007c). Site contaminants may pose risk to human and ecological receptors, potential future intruders, and the groundwater. A summary of the sites identified as having deep vadose zone contamination as depicted by the three model groups is provided in Table C-2.

A comparison of the sites included in the waste site groupings of Eslinger et al. (2006) found to have technetium-99, uranium, and/or nitrate likely to impact groundwater (i.e., within model groups 2 and 6 of DOE (2007c) as well as the Tank Farm sites, the BC cribs and trenches, and the U cribs and trenches believed to have deep vadose zone contamination, yields a fairly comprehensive list of sites with these constituents deep in the vadose zone (see Table C-2). Table C-2 also bins the sites by geographic area and corresponding hydrogeologic conceptual models based on those used by Last et al. (2006b).

C-4-4 Primary Target Problem Sites

Of most importance to this study are those sites where large inventories of key constituents (i.e. technetium-99 and uranium) have penetrated deep in the vadose zone and present an eminent threat to degradation of the unconfined aquifer. Disposal inventories (Kincaid et al. 2006; Corbin et al. 2005), depth of contamination (DOE 2007c), and potential risk to groundwater (Eslinger et al. 2006), were evaluated to define the target problem sites to define the basis for evaluation of deep vadose zone remediation technologies (see Table C-2. The characteristics of these target problem sites were also used to assess technology applicability and to identify suitable candidate sites for field testing components of the treatability test.

One of the primary resources used to evaluate potential target problems was an analysis by Eslinger et al. (2006). This analysis was conducted to better understand the relative threat to the unconfined aquifer from waste sites in the vadose zone of the Central Plateau region, and used inventory, contaminant release into and from the vadose zone, and hypothetical concentrations in groundwater to rank the threat posed to the aquifer by individual waste sites and groups of waste sites. Because remedial action decisions will be made for groups of sites, rather than individual sites, Eslinger et al. (2006) grouped individual waste sites into 32 groups that received similar wastes and were located in the same geographic area. Based in large part on the analysis by Eslinger et al. (2006) (see Table C-2) supplemented by site inventories and other information, the target problem sites for technetium-99 and uranium were identified as follows:

Technetium-99

- BC cribs and trenches (216-B-14, -18)
- BY cribs and vicinity (216-B-46, -49)

- T Tank Farm and vicinity (241-T-106)
    - S/SX Tank Farms and vicinity (241-SX-108)

Uranium

- 200 East Ponds Region (216-A-19)
- U cribs (216-U-8, -12, -1 and -2)
- B Plant cribs and trenches (216-B-12)
- B, BX, BY Tank Farms (241-BX-102)
- PUREX cribs and trenches (216-A-4, -3, -9)
- REDOX cribs and trenches (216-S-7, -1 and -2)

C-5 References

Anderson, J. D. 1990. *A History of the 200 Area Tank Farms.* WHC-MR-0132, Westinghouse Hanford Company, Richland, Washington.

Anderson MJ, BC Simpson, RA Corbin, and CT Kincaid. 2007. *Hanford Soil Inventory Model (SIM) Rev. 2 Software Documentation – Requirements, Design, and Limitations.* PNNL-16940, Pacific Northwest National Laboratory, Richland, Washington.

Baker, S.M., R.F. Lorang, R.P. Elmore, A.J. Rossi, and M.D. Freshley. 1988. *U1/U2 Uranium Plume Characterization, Remedial Action Review and Recommendation for Future Action.* WHC-EP-0133, Westinghouse Hanford Company, Richland, Washington.

Bjornstad, B.N. 1990. *Geohydrology of the 218-W-5 Burial Ground, 200-West Area, Hanford Site.* PNL-7336, Pacific Northwest Laboratory, Richland, Washington.

Cantrell, K.J., R.J. Serne, and G.V. Last. 2002. *Hanford Contaminant Distribution Coefficient Database and Users Guide.* PNNL-13895, Pacific Northwest National Laboratory, Richland, Washington.

Cantrell, K.J., R.J. Serne, and G.V. Last. 2003. *Hanford Contaminant Distribution Coefficient Database and Users Guide.* PNNL-13895, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Cantrell, K.J., J.M. Zachara, P.E. Dresel, K.M. Krupka, and R.J. Serne. 2007. *Geochemical Processes Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.* PNNL-16663, Pacific Northwest National Laboratory, Richland, Washington.

CHG. 2002. *Field Investigation Report for Waste Management Area S-SX;* Volume 1, Main Text and Appendices A – C, Volume 2, Appendices D – I. RPP-7884, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

CHG. 2007. *Central Plateau Vadose Zone Remediation Technology Screening Evaluation.* CH2M HILL Hanford Group, Richland, Washington.

Connelly, M.P., B.H. Ford, and J.V. Borghese. 1992a. *Hydrogeologic Model for the 200 West Area Groundwater Aggregate Area.* WHC-SD-EN-TI-014, Westinghouse Hanford Company, Richland, Washington.

Connelly, M.P., J.V. Borghese, C.D. Delaney, B.H. Ford, J.W. Lindberg, and S.J. Trent. 1992b. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area.* WHC-SD-EN-TI-019, Westinghouse Hanford Company, Richland, Washington.

Corbin, R.A., B.C. Simpson, M.J. Anderson, W.F. Danielson, II, J.G. Field, T.E Jones, and C.T. Kincaid. 2005. *Hanford Soil Inventory Model, Rev. 1.* RPP-26744, Rev. 0 and PNNL-15367. CH2M HILL Hanford Group, Inc., Richland, Washington.

Delaney, C.D., K.A. Lindsey, and S.P. Reidel. 1991. *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports.*

DOE. 1997. *TWRS Vadose Zone Contamination Issue, Expert Panel Status Report.* DOE/RL-97-49, Rev. 0, U.S. Department of Energy, Richland, Washington.

DOE. 1998. *Groundwater/Vadose Zone Integration Project Specification.* DOE/RL-98-48, Draft C, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

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

DOE. 1999b. *200-BP-1 Prototype Barrier Treatability Test Report.* DOE/RL-99-11, Rev. 0, U.S. Department of Energy, Richland, Washington.

DOE. 1999c. *Groundwater/Vadose Zone Integration Project Background Information and State of Knowledge.* DOE/RL-98-48, Vol. II, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 1999d. *Retrieval Performance Evaluation Methodology for the AX Tank Farm.* DOE/RL-98-72, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2000. *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas.* DOE/RL-99-36, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2002. *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments within the Central Pasco Basin.* DOE/RL-2002-39, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2006. *Initial Single-Shell Tank System Performance Assessment for the Hanford Site.* DOE/ORP-2005-01, Rev. 0, U.S. Department of Energy, Office of River Protection, Richland, Washington.

DOE. 2007a. *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, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2007b. *Vadose Zone Modeling at the Hanford Site: Regulatory Criteria and Compliance for Risk Assessment Applications.* DOE/RL-2007-34, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE. 2007c. *Supplemental Remedial Investigation Work Plan for the 200 Area Central Plateau Operable Units,* Vol. I, *Work Plans and Appendices,* Vol. II, *Site-Specific Field-Sampling Plan Addenda.* DOE/RL-2007-02, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Enfield, C.G., J.J.C. Hsieh, and A.W. Warrick. 1973. "Evaluation of Water Flux above a Deep Water Table Using Thermocouple Psychrometers" in *Soil Sci. Soc. Amer. Proc.* 37:968-970.

Eslinger, P.W., C.T. Kincaid, W.E. Nichols, and S.K. Wurstner. 2006. *A Demonstration of the System Assessment Capability (SAC) Rev. 1 Software for the Hanford Remediation Assessment Project.* PNNL-16209, Pacific Northwest National Laboratory, Richland, Washington.

Fayer, M.J., and J.M. Keller. 2007. *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas* PNNL-16688, Pacific Northwest National Laboratory, Richland, Washington.

Fayer, M.J. and T.B. Walters. 1995. *Estimated Recharge Rates at the Hanford Site.* PNL-10285, Pacific Northwest Laboratory, Richland, Washington.

Fecht, K.R., K.A. Lindsey, D.G. Horton, G.V. Last, and S.P. Reidel. 1999. *An Atlas of Clastic Injection Dikes of the Pasco Basin and Vicinity.* BHI-01103, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Freeman, E.J., R. Khaleel, and P.R. Heller. 2001. *A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site.* PNNL-13672, Pacific Northwest National Laboratory, Richland, Washington.

Freeman, E.J., R. Khaleel, and P.R. Heller. 2002. *A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site.* PNNL-13672, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Gee, G.W., M.J. Fayer, M.L. Rockhold, and M.D. Campbell. 1992. "Variations in Recharge at the Hanford Site" in *Northwest Science* 66:237-250.

Gee, G.W., J.M. Keller, and A.L. Ward. 2005. "Measurement and Prediction of Deep Drainage from Bare Sediments at a Semiarid Site ." Vadose Zone Journal 4(1):32-40

Hartman, M.J. 2000. *Hanford Site Groundwater Monitoring: Setting, Sources, and Methods.* PNNL-13080, Pacific Northwest National Laboratory, Richland, Washington.

Hsieh, J. J. C., L. E. Brownell, and A. E. Reisenauer. 1973. *Lysimeter Experiment Description and Progress Report on Neutron Measurements.* BNWL-1711. Battelle Pacific Northwest Laboratories, Richland, Washington.

Kaplan, D.I. and R.J. Serne. 1995. *Distribution Coefficient Values Describing Iodine, Neptunium, Selenium, Technetium, and Uranium Sorption to Hanford Sediments.* PNL-10379, SUP. 1, Pacific Northwest Laboratory, Richland, Washington.

Kaplan, D.I., R.J. Serne, A.T. Owen, J.A. Conca, T.W. Wietsma, and T.L. Gervais. 1996. *Radionuclide Adsorption Distribution Coefficients Measured in Hanford Sediments for the Low Level Waste Performance Assessment Project.* PNNL-11385, Pacific Northwest National Laboratory, Richland, Washington.

Kaplan, D.I., K.E. Parker, and J.C. Ritter. 1998. *Effects of Aging a Hanford Sediment and Quartz Sand with Sodium Hydroxide on Radionuclide Sorption Coefficients and Sediment Physical and Hydrological Properties: Final Report for Subtask 2a.* PNNL-11965, Pacific Northwest National Laboratory, Richland, Washington.

Khaleel, R. 1999. *Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste Performance Assessment.* HNF-4769, Rev. 1, Fluor Daniel Northwest, Inc., Richland, Washington.

Khaleel, R. 2007. *The Far-Field Hydrology Data Package for the RCRA Facility Investigation RFI Report.* RPP-RPT-35222, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

Khaleel, R. and E.J. Freeman. 1995. *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site.* WHC-EP-0883, Westinghouse Hanford Company, Richland, Washington.

Khaleel, R. and P.R. Heller. 2003. "On the Hydraulic Properties of Coarse-Textured Sediments at Intermediate Water Contents" In *Water Resource Research* 39(9):1233.

Khaleel, R. and J.F. Relyea. 1997. "Correcting Laboratory-Measured Moisture Retention Data for Gravel" in *Water Resources Research* 33(8):1875-1878.

Khaleel, R., J.F. Relyea, and J.L. Conca. 1995. "Evaluation of van Genuchten-Mualem Relationships to Estimate Unsaturated Hydraulic Conductivity at Low Water Contents" in *Water Resources Research* 31(11):2659-2668.

Kincaid, C.T., M.P. Bergeron, C.R. Cole, M.D. Freshley, N.L. Hassig, V.G. Johnson, D.I. Kaplan, R.J. Serne, G.P. Streile, D.L. Strenge, P.D. Thorne, L.W. Vail, G.A. Whyatt, and S.K. Wurstner. 1998. *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site.* PNNL-11800, Pacific Northwest National Laboratory, Richland, Washington.

Kincaid, C.T., P.W. Eslinger, R.L. Aaberg, T.B. Miley, I.C. Nelson, D.L. Strenge, and J.C. Evans, Jr. 2006. *Inventory Data Package for Hanford Assessments.* PNNL-15829, Rev.0, Pacific Northwest National Laboratory, Richland, Washington.

Krupka, K.M., R.J. Serne, and D.I. Kaplan. 2004. *Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment.* PNNL-13037, Rev. 2. Pacific Northwest National Laboratory, Richland, Washington.

Last, G.V., W.E. Nichols, and C.T. Kincaid. 2006a. *Geographic and Operational Site Parameters List (GOSPL) for Hanford Assessments.* PNNL-14725, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Last, G. V., E. J. Freeman, K. J. Cantrell, M. J. Fayer, G. W. Gee, W. E. Nichols, B. N. Bjornstad, and D. G. Horton. 2006b. *Vadose Zone Hydrogeology Data Package for Hanford Assessments.* PNNL-14702, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

Lindsey, K.A., M.P. Connelly, and B.N. Bjornstad. 1992a. *Geologic Setting of the 200 West Area: An Update.* WHC-SD-EN-TI-008, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K.A., B.N. Bjornstad, J.W. Lindberg, and K.M. Hoffmann. 1992b. *Geologic Setting of the 200 East Area: An Update.* WHC-SD-EN-TI-012, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Looney, B.B. and R.W. Falta (eds.). 2000. *Vadose Zone, Science and Technology Solutions.* Two Volumes, Battelle Press, Columbus, Ohio.

Mann, F.M., K.C. Burgard, W.R. Root, P.J. Puigh, S.H. Finfrock, R. Khaleel, D.H. Bacon, E.J. Freeman, B.P. McGrail, S.K. Wurstner, and P.E. LaMont. 2001. *Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version.* DOE/ORP-2000-24, Rev. 0, U.S. Department of Energy, Office of River Protection, Richland, Washington.

Mashal, K., J.B. Harsh, M. FLury, A.R. Felmy, and H. Zhao. 2004. "Collid Formation in Hanford Sediments Reacted with Simulated Tank Waste" in *Environmental Science Technology* 38:5750-5756.

Murray, C.J., A.L. Ward, and J.L. Wilson. 2003. *Influence of Clastic Dikes on Vertical Migration of Contaminants in the Vadose Zone at Hanford.* PNNL-14224, Pacific Northwest National Laboratory, Richland, Washington.

Reidel, S.P. 2004. *Geologic Data Package for 2005 Integrated Disposal Facility Waste Performance Assessment.* PNNL-14586. Pacific Northwest National Laboratory, Richland, Washington.

Reidel, S.P., D.G. Horton, Y. Chien, D.B. Barnett, and K. Singleton. 2006. *Geology, Hydrogeology, Geochemistry, and Mineralogy Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site.* RPP-23748, Rev. 0. CH2MHill Hanford Group, Inc. Richland, Washington.

Reidel, S. P. and M. A. Chamness. 2007. *Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site*. PNNL-15955, Rev. 1. Pacific Northwest National Laboratory, Richland, Washington.

Rohay, V.J., K.J. Swett, and G.V. Last. 1994. *1994 Conceptual Model of the Carbon Tetrachloride Contamination in the 200 West Area at the Hanford Site.* WHC-SD-EN-TI-248, Westinghouse Hanford Company, Richland, Washington.

Serne, R.J., J.L. Conca, V.L. LeGore, K.J. Cantrell, C.W. Lindenmeier, J.A. Campbell, J.E. Amonette, and M.I. Wood. 1993. *Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions, Volume 1: Batch Leach and Adsorption Tests and Sediment Characterization.* PNL-8889, Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

Serne, R.J., and D.I. Kaplan. 2000. *Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (ILAWPA) . PNNL-13037, REV. 1, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R.J., B.N. Bjornstad, H.T. Schaef, B.A. Williams, D.C. Lanigan, D.G. Horton, R.E. Clayton, A.V. Mitroshkov, V.L. Legore, M.J. O'Hara, C.F. Brown, K.E. Parker, I.V. Kutnyakov, J.N. Serne, G.V. Last, S.C. Smith, C.W. Lindenmeier, J.M. Zachara, and D. Burke. 2002. *Characterization of Vadose Zone Sediment: Uncontaminated RCRA Borehole Core Samples and Composite Samples* . PNNL-13757-1, Pacific Northwest National Laboratory, Richland, Washington.

Serne, R.J. and M.I. Wood. 1990. *Hanford Waste-Form Release and Sediment Interaction: A Status Report with Rationale and Recommendations for Additional Studies.* PNL-7297, Pacific Northwest Laboratory, Richland, Washington.

Serne, R.J. 2007. *Kd Values for Agricultural and Surface Soils for Use in Hanford Site Farm, Residential, and River Shoreline Scenarios.* PNNL-16531, Pacific Northwest National Laboratory, Richland, Washington.

Simpson, B.C., R.A. Corbin, M. Anderson, and C.T. Kincaid. 2007. *Hanford Soil Inventory Model (SIM) Rev. 2 User's Guide.* PNNL-16925, Pacific Northwest National Laboratory, Richland, Washington.

Slate, J.L. 1996. "Buried Carbonate Paleosols Developed in Plio-Pleistocene Deposits of the Pasco Basin, South-Central Washington" in *Quaternary International* 34-36:191-196.

Slate, J.L. 2000. *Nature and Variability of the Plio-Pleistocene Unit in the 200 West Area of the Hanford Site.* BHI-01203, Bechtel Hanford, Inc., Richland, Washington.

Tallman, A.M., K.R. Fecht, M.C. Marratt, and G.V. Last. 1979. *Geology of the Separation Areas, Hanford Site, South-Central Washington.* RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

Thorne, P.D., M.A. Chamness, F.A. Spane, Jr., V.R. Vermeul, and W.D. Webber. 1993. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY93 Status Report.* PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Um, W. and R.J. Serne. 2006. *Characterization of 200-UP-1 and 200-ZP-1 Operable Unit Aquifer Sediments and Batch Adsorption Distribution Coefficients for Contaminants of Concern--Fiscal Year 2006 Progress.* PNNL-16102, Pacific Northwest National Laboratory, Richland, Washington.

Um, W., R.J. Serne, B.N. Bjornstad, H.T. Schaef, C.F. Brown, V.L. Legore, K.N. Geiszler, S.R. Baum, M.M. Valenta, I.V. Kutnyakov, T.S. Vickerman, and M.J. Lindberg. 2005. *Characterization of 200-UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spiked Uncontaminated Groundwater.* PNNL-15502, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A.L., G.W. Gee, and M.D. White. 1997. *A Comprehensive Analysis of Contaminant Transport in the Vadose Zone Beneath Tank SX-109.* PNNL-11463, Pacific Northwest National Laboratory, Richland, Washington.

Ward, A.L., M.E. Conrad, W.D. Daily, J.B. Fink, V.L. Freedman, G.W. Gee, G.M. Hoversten, J.M. Keller, E.L. Majer, C.J. Murray, M.D. White, S.B. Yabusaki, and Z.F. Zhang. 2006. *Vadose Zone Transport Field Study: Summary Report*. PNNL-15443, Pacific Northwest National Laboratory, Richland, Washington.

Webster, G. D. and J. W. Cosby. 1982. "Appendix 2R – Stratigraphic Investigation of the Skagit/Hanford Nuclear Project" In Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report. Volume 5. Puget Power, Puget Sound Power and Light Company, Bellevue, Washington.

Williams, B.A., B.N. Bjornstad, R. Schalla, and W.D. Webber. 2000. *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington.* PNNL-12261, Pacific Northwest National Laboratory, Richland, Washington.

Williams B.A., B.N. Bjornstad, R. Schalla, and W.D. Webber. 2002. *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford Site, Washington.* PNNL-13858, Pacific Northwest National Laboratory, Richland, Washington.

Xie, Y., C.J. Murray, G.V. Last, and R. Mackley. 2003. *Mineralogical and Bulk-Rock Geochemical Signatures of Ringold and Hanford Formation Sediments.* PNNL-14202, Pacific Northwest National Laboratory, Richland, Washington.

Zachara, J.M., J.N. Christensen, P.E. Dresel, S.D. Kelly, C. Liu, J.P. McKinley, R.J. Serne, W. Um, and C.F. Brown. 2007. *A Site Wide Perspective on Uranium Geochemistry at the Hanford Site.* PNNL-17031, Pacific Northwest National Laboratory, Richland, Washington.

Zhuang, J., Y. Jin, and M. Flury. 2004. "Comparison of Hanford Colloids and Kaolinite Transport in Porous Media" in *Vadose Zone Journal* 3:395-402. Soil Science Society of America, Madison, Wisconsin.

Zhuang, J., J.F. McCarthy, J.S. Tyner, E. Perfect, and M. Flury. 2007. "In Situ Colloid Mobilization in Hanford Sediments under Unsaturated Transient Flow Conditions: Effect of Irrigation Pattern" in *Environmental Science Technology* 41:3199-3204.

Table C-2. Relative Rank from Largest (#1) to Smallest Inventory Estimates for Each Analyte (cumulative inventory through December 31, 2005 that is decay correct to that date, based on that used by Eslinger et al. 2006).

Waste Site	Operable Unit	Model Group	SAC Demonstration Waste Site Grouping	Geographic Area (after Last et al. 2006a)	Tc-99	Sum U-234/U238	Nitrate	I-129	Identified By Test Plan Development Team
200-E-102	200-MW-1	4	All others in 200-PO-1	A		24			
200-E-56		NA	All others in 200-BP-5	A	82				
200-E-57		NA	All others in 200-BP-5	A	69				
200-E-60		NA	B, BX, BY Tank Farms	B			Y		
200-W-52	200-TW-2	4	T Tank Farm & vicinity	T					
216-A-10	200-PW-2	2	PUREX cribs and trenches	A	77			1	X
216-A-15	200-LW-2	2	All others in 200-PO-1	A					
216-A-19	200-PW-2	6	200 East Ponds Region	A		7			
216-A-2	200-PW-3	4	PUREX cribs and trenches	A					X
216-A-21	200-MW-1	6	All others in 200-PO-1	A					
216-A-24	200-PW-3	6	200 East Ponds Region	A					
216-A-25	200-CW-1	5	200 East Ponds Region	G	55	11		48	
216-A-27	200-MW-1	6	PUREX cribs and trenches	A					X
216-A-3		NA	All others in 200-PO-1	A		19			
216-A-30	200-SC-1	6	PUREX cribs and trenches	A				52	X
216-A-31	200-PW-3	2	All others in 200-PO-1	A					
216-A-36A	200-PW-2	2	All others in 200-PO-1	A	78				
216-A-36B	200-PW-2	2	PUREX cribs and trenches	A				53	X
216-A-37-1	200-PW-4	6	200 East - tank farm related cribs	A					
216-A-37-2	200-SC-1	6	All others in 200-PO-1	A					
216-A-4	200-MW-1	4	PUREX cribs and trenches	A	72	14			X
216-A-45	200-PW-4	2	PUREX cribs and trenches	A				19	X
216-A-5	200-PW-2	2	PUREX cribs and trenches	A				2	X
216-A-6	200-SC-1	6	PUREX cribs and trenches	A				8	X
216-A-7	200-PW-3	6	200 East - tank farm related cribs	A					
216-A-8	200-PW-3	6	200 East Ponds Region	A					
216-A-9		NA	All others in 200-PO-1	A		20			
216-B-10A	200-LW-2	2	All others in 200-BP-5	B					
216-B-10B	200-LW-2	2	All others in 200-BP-5	B					
216-B-11A&B	200-PW-5	6	BY cribs & vicinity	B					X
216-B-12	200-PW-2	2	B Plant cribs & trenches	B	56	9			
216-B-14	200-BC-1	NA	BC cribs & trenches	A	4		Y	11	X
216-B-15	200-BC-1	NA	BC cribs & trenches	A	10		Y	20	X
216-B-16	200-BC-1	NA	BC cribs & trenches	A	13		Y	22	X
216-B-17	200-BC-1	NA	BC cribs & trenches	A	34		Y	43	X
216-B-18	200-BC-1	NA	BC cribs & trenches	A	5		Y	12	X
216-B-19	200-BC-1	NA	BC cribs & trenches	A	12		Y	14	X
216-B-20	200-BC-1	NA	BC cribs & trenches	A	27		Y	30	X
216-B-21	200-BC-1	NA	BC cribs & trenches	A	21		Y	38	X
216-B-22	200-BC-1	NA	BC cribs & trenches	A	23		Y	31	X

Table C-2. Relative Rank from Largest (#1) to Smallest Inventory Estimates for Each Analyte (cumulative inventory through December 31, 2005 that is decay correct to that date, based on that used by Eslinger et al. 2006).

Waste Site	Operable Unit	Model Group	SAC Demonstration Waste Site Grouping	Geographic Area (after Last et al. 2006a)	Tc-99	Sum U-234/U238	Nitrate	I-129	Identified By Test Plan Development Team
216-B-23	200-BC-1	NA	BC cribs & trenches	A	25		Y	32	X
216-B-24	200-BC-1	NA	BC cribs & trenches	A	16		Y	39	X
216-B-25	200-BC-1	NA	BC cribs & trenches	A	15		Y	36	X
216-B-26	200-BC-1	NA	BC cribs & trenches	A	18		Y	41	XX
216-B-27	200-BC-1	NA	BC cribs & trenches	A	22		Y	44	X
216-B-28	200-BC-1	NA	BC cribs & trenches	A	19		Y	29	X
216-B-29	200-BC-1	NA	BC cribs & trenches	A	17		Y	40	X
216-B-3	200-CW-1	5	All others in 200-BP-5	E		23			
216-B-30	200-BC-1	NA	BC cribs & trenches	A	28		Y	27	X
216-B-31	200-BC-1	NA	BC cribs & trenches	A	26		Y	25	X
216-B-32	200-BC-1	NA	BC cribs & trenches	A	29		Y	26	X
216-B-33	200-BC-1	NA	BC cribs & trenches	A	31		Y	24	X
216-B-34	200-BC-1	NA	BC cribs & trenches	A	30		Y	21	X
216-B-35	200-TW-2	6	BX trenches	B					
216-B-36	200-TW-2	6	BX trenches	B				67	
216-B-37	200-TW-2	6	BX trenches	B	64			58	
216-B-38	200-TW-2	6	BX trenches	B					XX
216-B-39	200-TW-2	6	BX trenches	B				71	
216-B-3C_Rad	200-CW-1	5	All others in 200-BP-5	E		27			
216-B-4	200-MW-1	2	BX trenches	B					
216-B-40	200-TW-2	6	BX trenches	B	88			68	
216-B-41	200-TW-2	6	BX trenches	B					
216-B-42	200-TW-1	6	BX trenches	B	38			59	
216-B-43	200-TW-1	2	BY cribs & vicinity	B	35			50	X
216-B-44	200-TW-1	2	BY cribs & vicinity	B	11			28	X
216-B-45	200-TW-1	2	BY cribs & vicinity	B	14			35	X
216-B-46	200-TW-1	2	BY cribs & vicinity	B	7			18	X
216-B-47	200-TW-1	2	BY cribs & vicinity	B	33			46	X
216-B-48	200-TW-1	2	BY cribs & vicinity	B	24			45	X
216-B-49	200-TW-1	2	BY cribs & vicinity	B	8			17	X
216-B-50	200-PW-5	2	BY cribs & vicinity	B					X
216-B-52		NA	BC cribs & trenches	A	6			9	X
216-B-53A	200-BC-1	NA	BC cribs & trenches	A			Y		X
216-B-53B	200-BC-1	NA	BC cribs & trenches	A			Y		X
216-B-54	200-BC-1	NA	BC cribs & trenches	A			Y		X
216-B-55	200-SC-1	6	All others in 200-BP-5	B					
216-B-57	200-PW-5	2	BY cribs & vicinity	B					X-barrier
216-B-58	200-BC-1	NA	BC cribs & trenches	A			Y		X
216-B-6	200-LW-2	2	B Plant cribs & trenches	B					
216-B-62	200-PW-5	6	B Plant cribs & trenches	B	50				X

Table C-2. Relative Rank from Largest (#1) to Smallest Inventory Estimates for Each Analyte (cumulative inventory through December 31, 2005 that is decay correct to that date, based on that used by Eslinger et al. 2006).

Waste Site	Operable Unit	Model Group	SAC Demonstration Waste Site Grouping	Geographic Area (after Last et al. 2006a)	Tc-99	Sum U-234/U238	Nitrate	I-129	Identified By Test Plan Development Team
216-B-7A&B	200-TW-2	4	BY cribs & vicinity	B					X
216-B-8	200-TW-2	6	BY cribs & vicinity	B					X
216-B-9	200-TW-2	6	B Plant cribs & trenches	B					
216-C-1	200-PW-2	6	Hot Semi-works	A		29			
216-C-2	200-MW-1	2	All others in 200-BP-5	A					
216-S-1&2	200-PW-2	4	REDOX cribs and trenches	S	48	21		7	X
216-S-13	200-PW-3	2	S cribs	S	81				
216-S-14	200-PW-3	6	S cribs	S					
216-S-20	200-LW-2	2	S cribs	S			Y	57	
216-S-21	200-PW-5	2	S/SX Tank Farms & vicinity	S			Y		
216-S-23	200-PW-4	2	REDOX cribs and trenches	S					
216-S-26	200-LW-2	6	S cribs	S					
216-S-5	200-SC-1	6	200 West Ponds - 200-UP-1	S		26			
216-S-6	200-SC-1	6	200 West Ponds - 200-UP-1	S				69	
216-S-7	200-PW-2	2	REDOX cribs and trenches	S	49	16		5	
216-S-9	200-PW-5	6	REDOX cribs and trenches	S				23	
216-T-14	200-TW-2	6	T trenches & vicinity	T			Y		X
216-T-15	200-TW-2	6	T trenches & vicinity	T					X
216-T-16	200-TW-2	6	T trenches & vicinity	T					X
216-T-17	200-TW-2	6	T trenches & vicinity	T					X
216-T-18	200-TW-1	4	TY cribs and vicinity	T			Y		
216-T-19	200-PW-1	6	TY cribs and vicinity	T			Y		
216-T-2	200-LW-2	2	T Plant cribs, trenches, swamp	T			Y		X
216-T-21	200-TW-2	6	TX tenches	T			Y		X
216-T-22	200-TW-2	6	TX tenches	T	89		Y	70	X
216-T-23	200-TW-2	6	TX tenches	T			Y		X
216-T-24	200-TW-2	6	TX tenches	T	90		Y	72	X
216-T-25	200-TW-2	6	TX tenches	T	71		Y	62	X
216-T-26	200-TW-1	2	TY cribs and vicinity	T	54		Y	47	
216-T-27	200-LW-1	2	TY cribs and vicinity	T			Y		
216-T-28	200-LW-1	2	TY cribs and vicinity	T			Y		
216-T-32	200-TW-2	4	T Tank Farm & vicinity	T			Y		
216-T-34	200-LW-1	6	T Plant cribs, trenches, swamp	T			Y	56	X
216-T-35	200-LW-1	6	T Plant cribs, trenches, swamp	T			Y		X
216-T-36	200-SC-1	6	All others in 200-ZP-1	T	84				
216-T-5	200-TW-2	4	T Tank Farm & vicinity	T			Y		
216-T-6	200-TW-2	4	T Plant cribs, trenches, swamp	T			Y		X
216-T-7	200-TW-2	4	T Tank Farm & vicinity	T			Y		
216-T-8	200-LW-2	6	T Plant cribs, trenches, swamp	T			Y		X
216-U-1&2	200-UP-2	NA	U cribs	S	36	15	Y		X

Table C-2. Relative Rank from Largest (#1) to Smallest Inventory Estimates for Each Analyte (cumulative inventory through December 31, 2005 that is decay correct to that date, based on that used by Eslinger et al. 2006).

Waste Site	Operable Unit	Model Group	SAC Demonstration Waste Site Grouping	Geographic Area (after Last et al. 2006a)	Tc-99	Sum U-234/U238	Nitrate	I-129	Identified By Test Plan Development Team
216-U-10	200-CW-5	5	200 West Ponds - 200-UP-1	S		22		6	
216-U-12	200-UP-2	NA	U cribs	S	68	13	Y		X
216-U-14		NA	All others in 200-UP-1	S				54	
216-U-8	200-UP-2	NA	U cribs	S	47	8	Y	63	X
216-W-LWC		NA	All others in 200-UP-1	T				10	
216-Z-1&2	200-PW-1	4	PFP cribs & trenches	S			Y		
216-Z-12	200-PW-1	4	PFP cribs & trenches	S			Y		
216-Z-16	200-LW-2	6	PFP cribs & trenches	S			Y		
216-Z-17	200-LW-2	6	PFP cribs & trenches	S			Y		
216-Z-18	200-PW-1	4	PFP cribs & trenches	S			Y		
216-Z-1A	200-PW-1	4	PFP cribs & trenches	S			Y		
216-Z-3	200-PW-1	4	PFP cribs & trenches	S			Y		
216-Z-5	200-PW-6	2	PFP cribs & trenches	S			Y		
216-Z-7	200-LW-2	4	PFP cribs & trenches	S			Y	66	
216-Z-8	200-PW-6	4	PFP cribs & trenches	S			Y		
216-Z-9	200-PW-1	4	PFP cribs & trenches	S			Y		
218-E-10		NA	Solid waste - 200-BP-5	B	9			4	
218-E-12A		NA	Solid waste - 200-BP-5	B		28			
218-E-12B		NA	Solid waste - 200-BP-5	B	44			49	
218-W-1	200-ZP-3	NA	Solid Waste - 200-ZP-1	T					
218-W-11	200-ZP-3	NA	Solid Waste - 200-ZP-1	T		10			
218-W-1A	200-ZP-3	NA	Solid Waste - 200-ZP-1	T		30			
218-W-2	200-ZP-3	NA	Solid Waste - 200-ZP-1	T		25			
218-W-2A	200-ZP-3	NA	Solid Waste - 200-ZP-1	T	67	18			
218-W-3	200-ZP-3	NA	Solid Waste - 200-ZP-1	T		5			
218-W-3A	200-ZP-3	NA	Solid Waste - 200-ZP-1	T	41	6		34	
218-W-3AE	200-ZP-3	NA	Solid Waste - 200-ZP-1	T	3	3		16	
218-W-4A	200-ZP-3	NA	Solid Waste - 200-ZP-1	T		2			
218-W-4B	200-ZP-3	NA	Solid Waste - 200-ZP-1	T	53	17		3	
218-W-4C	200-ZP-3	NA	Solid Waste - 200-ZP-1	T	20	4		15	
218-W-5	200-ZP-3	NA	Solid Waste - 200-ZP-1	T	1	1		13	
241-A-103		NA	A/AX Tank Farms	A	39		Y	61	
241-A-104		NA	A/AX Tank Farms	A	73		Y		
241-A-105		NA	A/AX Tank Farms	A	75		Y		
241-AX-102		NA	A/AX Tank Farms	A	65		Y		
241-B-107		NA	B, BX, BY Tank Farms	B			Y	55	
241-B-110		NA	B, BX, BY Tank Farms	B	74		Y		
241-B-112		NA	B, BX, BY Tank Farms	B	61		Y		
241-B-201		NA	B, BX, BY Tank Farms	B			Y		
241-B-203		NA	B, BX, BY Tank Farms	B			Y		

Table C-2. Relative Rank from Largest (#1) to Smallest Inventory Estimates for Each Analyte (cumulative inventory through December 31, 2005 that is decay correct to that date, based on that used by Eslinger et al. 2006).

Waste Site	Operable Unit	Model Group	SAC Demonstration Waste Site Grouping	Geographic Area (after Last et al. 2006a)	Tc-99	Sum U-234/U238	Nitrate	I-129	Identified By Test Plan Development Team
241-B-204		NA	B, BX, BY Tank Farms	B			Y		
241-B-361	200-TW-2	4	NA	B					
241-BX-101		NA	B, BX, BY Tank Farms	B			Y		
241-BX-102		NA	B, BX, BY Tank Farms	B	51	12	Y		X
241-BX-108		NA	B, BX, BY Tank Farms	B			Y		
241-BY-103		NA	B, BX, BY Tank Farms	B			Y		
241-BY-107		NA	B, BX, BY Tank Farms	B	63		Y		
241-BY-108		NA	B, BX, BY Tank Farms	B	60		Y		
241-C-101		NA	C Tank Farm & vicinity	A			Y		
241-C-105		NA	C Tank Farm & vicinity	A			Y		
241-C-110		NA	C Tank Farm & vicinity	A			Y		
241-C-111		NA	C Tank Farm & vicinity	A			Y		
241-C-201		NA	C Tank Farm & vicinity	A			Y		
241-C-202		NA	C Tank Farm & vicinity	A			Y		
241-C-203		NA	C Tank Farm & vicinity	A			Y		
241-C-204		NA	C Tank Farm & vicinity	A			Y		
241-SX-104		NA	S/SX Tank Farms & vicinity	S	43			65	
241-SX-107		NA	S/SX Tank Farms & vicinity	S	37			51	
241-SX-108		NA	S/SX Tank Farms & vicinity	S	32			42	X
241-SX-109		NA	S/SX Tank Farms & vicinity	S	66				
241-SX-110		NA	S/SX Tank Farms & vicinity	S	87				
241-SX-112		NA	S/SX Tank Farms & vicinity	S	83				
241-SX-113		NA	S/SX Tank Farms & vicinity	S	58				
241-SX-115		NA	S/SX Tank Farms & vicinity	S	42			60	
241-T-103		NA	T Tank Farm & vicinity	T	62				
241-T-106		NA	T Tank Farm & vicinity	T	2			33	X
241-T-361	200-TW-2	4	NA	T			Y		
241-TX-107		NA	TX/TY Tank Farms	T	45			64	
241-TY-101		NA	TX/TY Tank Farms	T	80				
241-TY-101		NA	TX/TY Tank Farms	T			Y		
241-TY-103		NA	TX/TY Tank Farms	T	57				
241-TY-103		NA	TX/TY Tank Farms	T			Y		
241-TY-104		NA	TX/TY Tank Farms	T			Y		
241-TY-105		NA	TX/TY Tank Farms	T	76				
241-TY-105		NA	TX/TY Tank Farms	T			Y		
241-TY-106		NA	TX/TY Tank Farms	T			Y		
241-U-101		NA	U Tank farm	S	79		Y		X
241-U-104		NA	U Tank farm	S	52		Y		X
241-U-110		NA	U Tank farm	S	85		Y		X
241-U-112		NA	U Tank farm	S	70		Y		X

Table C-2. Relative Rank from Largest (#1) to Smallest Inventory Estimates for Each Analyte (cumulative inventory through December 31, 2005 that is decay correct to that date, based on that used by Eslinger et al. 2006).

Waste Site	Operable Unit	Model Group	SAC Demonstration Waste Site Grouping	Geographic Area (after Last et al. 2006a)	Tc-99	Sum U-234/U238	Nitrate	I-129	Identified By Test Plan Development Team
241-Z-361	200-PW-1	4	NA	S			Y		
241-Z-8	200-PW-6	4	NA	S			Y		
UPR-200-E-105		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-107		NA	C Tank Farm & vicinity	A			Y		
UPR-200-E-108		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-109		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-110		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-144	200-UR-1	4	NA	NA			Y		
UPR-200-E-19	200-SC-1	6	NA	NA			Y		
UPR-200-E-21	200-SC-1	6	NA	NA			Y		
UPR-200-E-29	200-SC-1	6	NA	A			Y		
UPR-200-E-38		NA	B, BX, BY Tank Farms	B	46		Y		
UPR-200-E-56	200-PW-3	6	NA	A			Y		
UPR-200-E-6		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-73		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-74		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-75		NA	B, BX, BY Tank Farms	B			Y		
UPR-200-E-81		NA	C Tank Farm & vicinity	A			Y	37	X
UPR-200-E-82		NA	C Tank Farm & vicinity	A	59		Y		X
UPR-200-E-85			All others in 200-BP-5	B	86				
UPR-200-E-86		NA	C Tank Farm & vicinity	A	40		Y		X
UPR-200-E-9	200-TW-1	6	All others in 200-BP-5	B			Y		
UPR-200-W-100		NA	TX/TY Tank Farms	T			Y		
UPR-200-W-12		NA	TX/TY Tank Farms	T			Y		
UPR-200-W-132		NA	U Tank farm	S			Y		X
UPR-200W-163		NA	U cribs	S			Y		X
UPR-200-W-166	200-UR-1	6	NA	NA			Y		
UPR-200-W-36	200-PW-2	2	NA	NA			Y		
UPR-200-W-4		NA	U Tank farm	S			Y		X

	Green shaded cells indicate previously identified as likely a significant waste site.
	Purple shaded cells indicate previously identified as possibly a significant waste site.
NA	Not Applicable
SAC	System Assessment Capability.
Y	Yes, a contaminant of interest.
X	Identified as a potential site of interest.

This page intentionally left blank.

Distribution List

DOE-RL

B Charboneau	A6-38
D Hildebrand	A6-38
JG Morse	A6-38
M Thompson	A6-38
AC Tortoso	A6-38

DOE-ORP

RW Lober	H6-60
S Wiegman	H6-60

CHG

JG Kristofzski	H6-03
M Jarayssi	H6-03
F Mann	H6-03
DA Myers	H6-03
CD Wittreich	H6-03

Fluor Hanford

MW Benecke	E6-44
JD Hoover	E6-35
DS Miller	E6-35
SW Petersen (5)	E6-35
C Sutton	E6-35
JD Williams	E6-35

PNNL

RW Bryce	K6-75
GV Last	K6-81
MB Triplett	K6-52
MJ Truex	K6-96

This page intentionally left blank.