RPP-33441
Revision 0

An Evaluation of Hanford Site Tank Farm Subsurface Contamination, FY 2007

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

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-99RL14047

CH2MHILL
Hanford Group, Inc.

P.O. Box 1500
Richland, Washington

Approved for Public Release;
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                    Date

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EXECUTIVE SUMMARY

The Tank Farm Vadose Zone (TFVZ) Project conducts activities to characterize and analyze the long-term environmental and human health impacts from tank waste releases to the vadose zone. The project also implements interim measures to mitigate impacts, and plans the remediation of waste releases from tank farms and associated facilities. The scope of this document is to report data needs that are important to estimating long-term human health and environmental risks. The scope does not include technologies needed to remediate contaminated soils and facilities, technologies needed to close tank farms, or management and regulatory decisions that will impact remediation and closure. This document is an update of *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination.*[1] That 1998 document summarized knowledge of subsurface contamination beneath the tank farms at the time. It included a preliminary conceptual model for migration of tank wastes through the vadose zone and an assessment of data and analysis gaps needed to update the conceptual model. This document provides a status of the data and analysis gaps previously defined and discussion of the gaps and needs that currently exist to support the stated mission of the TFVZ Project.

The first data-gaps document provided the basis for TFVZ Project activities over the previous eight years. Fourteen of the nineteen knowledge gaps identified in the previous document have been investigated to the point that the project defines the current status as acceptable. In the process of filling these gaps, significant accomplishments were made in field work and characterization, laboratory investigations, modeling, and implementation of interim measures.

The current data gaps are organized in groups that reflect components of the tank farm vadose zone conceptual model: inventory, release, recharge, geohydrology, geochemistry, and modeling. The inventory and release components address residual wastes that will remain in the tanks and tank-farm infrastructure after closure and potential losses from leaks during waste retrieval. Recharge addresses the impacts of current conditions in the tank farms (i.e. gravel covers that affect infiltration and recharge) as well as the impacts of surface barriers. The geohydrology and geochemistry components address the extent of the existing subsurface contaminant inventory and drivers and pathways for contaminants to be transported through the vadose zone and groundwater. Geochemistry addresses the mobility of key reactive contaminants such as uranium. Modeling addresses conceptual models and how they are simulated in computers.

The data gaps will be used to provide input to planning (including the upcoming C Farm Data Quality Objective meetings scheduled this year).

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[1] T.E. Jones, R. Khaleel, D. A. Myers, J. W. Shade, and M. I. Wood. 1998. *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination.* HNF-2603, Rev. 0, Lockheed Martin Hanford Company Corporation, Richland, Washington.

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ACKNOWLEDGEMENTS

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ABBREVIATIONS AND ACRONYMS

bgs	below ground surface
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*
CMS	corrective measures study
CoC	contaminant of concern
DOE	U.S. Department of Energy
DOE SC	DOE Office of Science
Ecology	Washington State Department of Ecology
EMSP	Environmental Management Science Project
EPA	U.S. Environmental Protection Agency
FHI	Fluor Hanford, Inc.
FIR	Field Investigation Report
FY	fiscal year
Health	Washington State Department of Health
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HRR	high resolution resistivity
HTWOS	Hanford Tank Waste Operations Simulator
IDF	Integrated Disposal Facility
LDMM	leak detection, monitoring, and mitigation
MUST	miscellaneous underground storage tank
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORP	DOE Office of River Protection
PA	performance assessment
PNNL	Pacific Northwest National Laboratory
RCRA	*Resource Conservation and Recovery Act of 1976*
RDR	Retrieval Data Report
RFI	RCRA Facility Investigation (report)
RL	DOE Richland Operations Office
SGE	surface geophysical exploration
SGL	spectral gamma logging
SST	single-shell tank
SST PA	*Initial Single-Shell Tank Performance Assessment* (DOE-ORP 2006)
TDR	time domain reflectometry
TFVZ	tank farm vadose zone
TWRS	Tank Waste Remediation System
TWRWP	Tank Waste Retrieval Work Plan
WMA	waste management area

Units

foot	ft (1 foot = 0.3048 meter)

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1.0   INTRODUCTION

The Tank Farm Vadose Zone (TFVZ) Project conducts activities to characterize and analyze the long-term environmental and human health impacts from tank waste releases to the vadose zone for the purpose of remediating past tank farm releases. The project is implementing interim measures to mitigate impacts, and planning remediation of waste releases from tank farms and associated facilities. The TFVZ Project supports *Resource Conservation and Recovery Act of 1976* (RCRA) Corrective Actions for past releases from tank farm facilities, remediation of soil and subsurface facilities (other than the large underground tanks) in the tank farms, and final closure of the tank farms. The U.S. Department of Energy (DOE) Office of River Protection (ORP) at the Hanford Site is responsible for waste tank remediation and closure, including the TFVZ Project.

1.1   SCOPE

The scope of this document is to report data needs that are important to estimating future risks in performance assessments. The scope does not include technologies needed to remediate contaminated soils and facilities, technologies needed to close tank farms, or management and regulatory decisions that will impact remediation and closure. Those technology needs and decisions will be discussed in the program plan *Tank Farm Vadose Remediation System Vadose Zone Program Plan* (DOE/RL 1998), which is being updated. These data gaps will also be used as inputs to data quality objectives processes, with the first such effort (for C farm) planned for this year.

This document is an update of *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination* (Jones et al. 1998). That document summarized knowledge of subsurface contamination beneath the tank farms at the time. It included a preliminary conceptual model for migration of tank wastes through the vadose zone and an assessment of data and analysis gaps needed to update the conceptual model (see Figure 1-1 for the current conceptual model). The current effort is to provide a status of the data and analysis gaps outlined in Jones et al. (1998) and discussion of the gaps and needs that currently exist to support the stated mission of the TFVZ Project.

1.2   BACKGROUND

The Hanford Site, operated by the DOE, encompasses approximately 1517 square kilometers along the Columbia River in southeast Washington State (see Figure 1-2). The Federal Government acquired the site in 1943 for the production of plutonium, which continued until the 1980s. Production reactors were constructed and operated along the Columbia River and three large radiochemical separation plants were built on the Central Plateau, along with an initial 64 large underground, high-level waste storage tanks. In the early 1950's, additional facilities were constructed (another reactor along the Columbia River, a new separations facility, and 18 more underground tanks). In the mid-1950s, two additional reactors were constructed, as was

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Figure 1-1. Current Conceptual Model for Hanford Tank Farms Used for the Single-Shell Tank Farm Performance Assessment (DOE-ORP 2006).

2
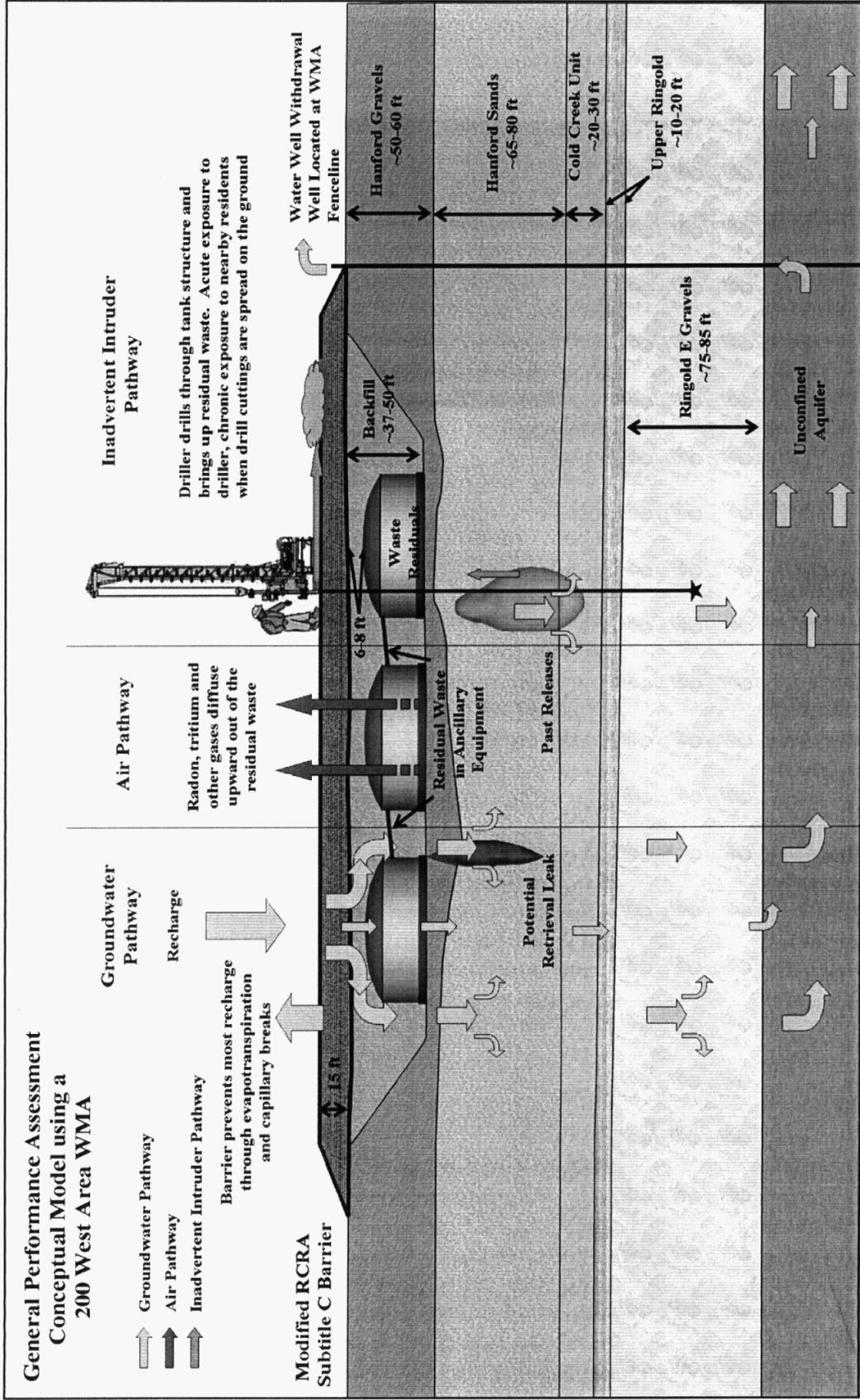
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Figure 1-2. The Hanford Site and its Location in Washington State.

E9705115.2

3
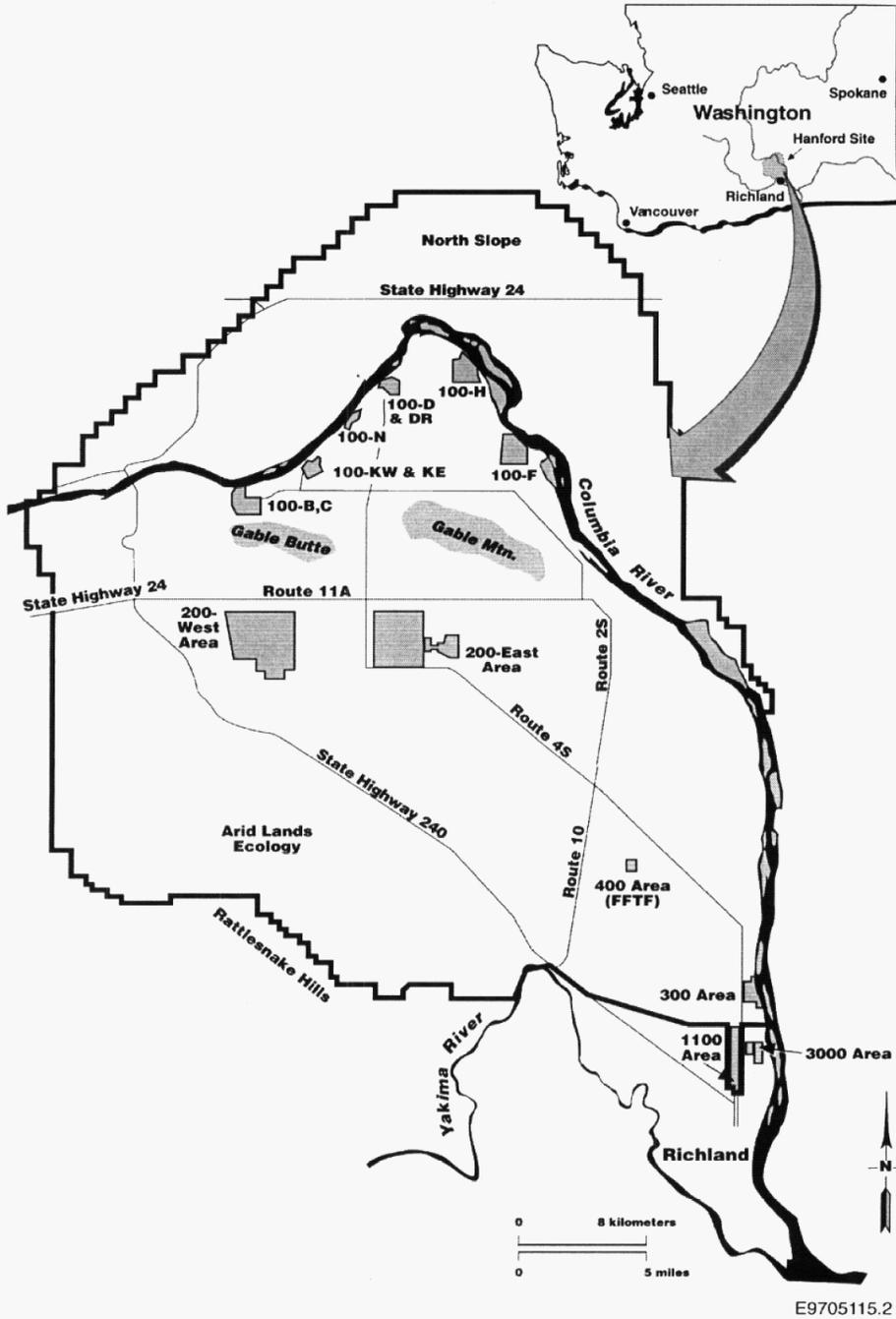
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the Plutonium-Uranium Extraction PUREX separations plant with 21 additional underground tanks. Beginning in the 1990s, DOE's focus shifted to cleaning up the legacy wastes that reside onsite.

To supplement the original underground tank system, which consists of single-wall steel and concrete tanks, known as single-shell tanks (SSTs), double-shell tanks were constructed starting in the late 1960s. Many of the SSTs have leaked, with an estimate of up to 500,000 gallons of wastes lost to the soil and vadose zone, *Tank Farm Vadose Zone Contaminant Volume Estimates* (Field and Jones 2005). As of 2002, all retrievable liquids had been removed from the SSTs, and by 2006, wastes from seven SSTs (C-103, C-106, C-201, C-202, C-203, C-204, and S-112) had been retrieved such that residual wastes in these tanks meets the goals of the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989) (also known as the Tri-Party Agreement) signed by DOE, the Environmental Protection Agency, and the Washington State Department of Ecology.

The Washington State Department of Ecology (Ecology) has determined that wastes from four SST farm waste management areas (WMAs) (WMA B-BX-BY, WMA S-SX, WMA T, and WMA TX-TY) have impacted the groundwater, "Requirements for a Corrective Action Program to Address Releases to the Environment at Eight (8) Single-Shell Tank Farms" letter from Mike Wilson (Program Manager, Nuclear Waste Program, Washington State Department of Ecology) to Jackson Kinzer (Program Manager, U.S. Department of Energy) (Wilson 1998). Some of the highest concentrations of technetium-99, a significant contaminant in tank wastes, are found in groundwater near the eastern edges of the SX and the T tank farms. The source of technetium-99 in groundwater is uncertain because many of the tank farms are surrounded by cribs, which received large amounts of waste, over 100 million gallons of which was direct discharge of supernates from tanks, *Tank Wastes Discharged Directly to the Soil at the Hanford Site* (Waite 1991).

1.3 STRUCTURE OF DOCUMENT

The document is structured to first provide an introduction and background information in Section 1.0. Section 2.0 describes the history of the TFVZ Project, including significant accomplishments since the project was established in 1998. Section 3.0 presents a summary of the nineteen data needs identified in Jones et al. (1998) and their current status. Section 4.0 provides an update of new needs recently identified along with previous high-priority needs identified in Jones et al. (1998) that require additional work.

When Jones et al. (1998) was published, there were few quantitative assessments of groundwater impacts from past tank waste releases that had been performed. Since that time, the TFVZ Project has characterized the major leaks that have been identified and risk analyses have been performed. The *Initial Single-Shell Tank Performance Assessment for the Hanford Site* (SST PA) (DOE-ORP 2006) summarizes the cumulative impacts of past leaks from all SSTs. The insights from the initial SST PA greatly influenced this update of the data needs. The needs in Section 4.0 of this document are organized following the input structure to a performance assessment: inventory, waste form release, recharge (including the effects of surface barriers), geohydrology, geochemistry, and modeling.

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2.0   TANK FARM VADOSE ZONE PROJECT

The goal of the TFVZ Project as described in *Tank Farm Vadose Remediation System Vadose Zone Program Plan* (DOE 1998) is to develop sufficient understanding to support decisions on remediating past releases from tank farms. As the time to remediate and close the entire tank farms approaches, the goal of the TFVZ Project has evolved to characterize and analyze the long-term environmental and human health impacts from tank waste releases from the tank farms and their associated facilities, implement interim measures to mitigate the impacts of these past releases, and plan appropriate final remedies. Thus, the definitions of data gaps and analyses in this document differ somewhat from those in Jones et al (1998), but remain focused on reporting data gaps and needs that are important to estimating future risks in performance assessments.

2.1 EVOLUTION OF THE TANK FARM VADOSE ZONE PROJECT

In the mid-1990s, concerns were raised that tank waste constituents, particularly cesium-137, had traveled deeper in the vadose zone than was predicted with then existing conceptual and numerical models. An external panel of experts provided peer review on TFVZ contamination issues, *Tank Farm Vadose Contamination Issue Expert Panel Status Report* (DOE 1997) and the U.S. Government Accounting Office issued a report, *Understanding of Waste Migration at Hanford is Inadequate for Key Decisions* (GAO 1998).

In response to the concerns over contaminant migration, specifically cesium-137, the TFVZ Project and the Groundwater/Vadose Zone Integration Project (now known as the Groundwater Remediation Project) were established. With input from stakeholders and regulators, the program plan (DOE-RL 1998) was issued. This program plan documented Phase 1 activities, which are now largely complete. The technical goals outlined in the plan were to:

- Provide vadose zone information and impacts to Tank Waste Remediation System (TWRS, now the Office of River Protection or ORP) decision makers

- Determine the nature and extent of vadose zone contamination in the tank farms through new field studies, laboratory analyses and experiments, and historical data assimilation

- Validate models used in providing information

- Develop the database needed for tank farm risk models

- Perform interim corrective actions that will lessen the impacts of tank leak contaminants in the vadose zone.

The Groundwater/Vadose Zone Integration Project (Integration Project) was established to assure that cleanup actions and decisions at Hanford are protective of the Columbia River. The TFVZ Project was and remains a core member of the Integration Project (now known as the Groundwater Remediation Project). One important goal of the Integration Project was to bring

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science to bear on resolution of key Hanford Site environmental issues. The Integration Project included a Science and Technology Project with strong participation from national laboratories and universities. The science and technology needs and activities to fill the gaps were documented in a science and technology roadmap *Groundwater/Vadose Zone Integration Project Science and Technology Summary Description* (DOE 1999b and DOE 2000a) and Groundwater Protection Program, Science and Technology Summary Description (Freshley et al. 2002). The roadmap was used for planning science and technology research funded by DOE Richland Operations Office (RL) to address subsurface problems at the Hanford Site.

DOE (1999b) was used to influence a fiscal year (FY) 1999 call for proposals issued by the DOE Environmental Management Science Program (EMSP) that focused on vadose zone science issues. Many of these issues were associated with the long-term migration behavior of high-level tank waste residuals in the vadose zone. The EMSP established 31 projects ($25 Million in work scope over three years) directed at vadose zone problems. The projects were led by both national laboratory and university principal investigators. The EMSP also provided funding to the Integration Project to facilitate interaction with the principal investigators and to incorporate their results into activities and milestones at the Hanford Site. The Integration Project was able to influence and guide, but not to direct the vadose zone EMSP projects. Guidance and linkage were provided through a series of three focused workshops which paired EMSP investigators with Hanford Site remediation contractors. In addition to hosting the workshops, the Integration Project provided sediment samples to EMSP investigators and facilitated access to the Hanford Site to conduct research. Uncontaminated sediment and groundwater samples were obtained from compliance-driven monitoring wells while contaminated samples were obtained from several different tank farms (S-SX, B-BX-BY) and past practices crib sites. This approach was used to obtain chemical speciation measurements of chromium and cesium-137 (S-SX tank farm), and uranium (B-BX-BY and TX tank farms). The results of these investigations were summarized in the following Field Investigation Reports (FIR), which were published by the TFVZ Project:

- *Field Investigation Report for Waste Management Area S-SX* (Knepp 2002a)

- *Field Investigation Report for Waste Management Area B-BX-BY* (Knepp 2002b)

- *Field Investigation Report for Waste Management Areas T and TX-TY* (Myers 2005).

Beginning in 2004, the DOE Richland Operations Office (RL) transferred responsibility for funding the scientific investigation of tank-farm sediments to ORP from the Integration Project Science and Technology Project. Currently, the TFVZ Project provides funding directly for scientific studies focused on key tank-farm vadose zone issues.

Table 2-1 displays the activities and the reports that have been generated by the TFVZ Project for Phase 1 since Jones et al. (1998). The project has researched Hanford Site records (including operations reports) that dealt with tank farm operations, summarizing the findings in a series of subsurface conditions descriptions reports (Wood et al. 1999, Wood et al. 2000, Wood et al. 2001, Wood et al. 2003, and Wood and Jones 2003). For each tank-farm complex, known as WMAs, a site-specific work plan was written (Knepp and Rogers 2000, Rogers and Knepp 2000

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Table 2-1. Status of the Project (Phase 1). (2 pages)

Item	Waste Management Area			
	A-AX, C, and U	B-BX-BY	S-SX	T and TX-TY
Document previously obtained data and information	Subsurface Conditions Description Report for the C & A-AX WMAs (Wood 2003a) Subsurface Conditions Description Report for the U WMA (Wood 2003b)	Subsurface Conditions Description Report for the B & BX & BY WMAs (Wood 2000)	Subsurface Conditions Description Report for the S-SX WMA (Wood 1999)	Subsurface Conditions Description Report for the T & TX-TY WMAs (Wood 2001)
	A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination (Jones et al. 1998)			
Determine what new information is needed and document how to obtain that data and information	Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for SST Waste Management Areas (DOE 2000b)			
	Site Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMAs A-AX, C, and U (Crumpler 2005)	Site Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA B-BX-BY (Rogers and Knepp 2000)	Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX, (Knepp and Rogers 2000)	Site Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMAs T and TX-TY (Crumpler 2002)
Obtain the data and information	In progress	Complete, except for laboratory analyses of direct push that are in progress.	Complete	Complete; Direct Push documented in Brown 2007.
Document data and analyses	In progress	Field Investigation Report for WMA B-BX-BY (Knepp 2002b)	Field Investigation Report for WMA S-SX (Knepp 2002a)	Field Investigation Report for WMAs T and TX-TY (Myers 2005)
Document the current data, information, and knowledge	RCRA Facility Investigation Report (In progress)			
Implement measures to lessen environmental impacts	Implemented (tested water lines, installed berms and gutters, as well as installed caps for boreholes) In Progress (interim surface barriers, T-106 barrier is being designed for installation in the summer of 2007)			

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Table 2-1. Status of the Project (Phase 1). (2 pages)

Item	Waste Management Area			
	A-AX, C, and U	B-BX-BY	S-SX	T and TX-TY
Perform a Corrective Measures Study on possible interim corrective measures to further minimize impacts			In progress	
Notes:				
CMS = corrective measures study				
RCRA = Resource Conservation and Recovery Act of 1976				
RFI = RCRA facility investigation (report)				
SST = single-shell tank				
WMA = waste management area				

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Crumpler 2002, and Crumpler 2005) and approved by Ecology. The work (whether field or laboratory) was implemented and summarized in field investigation reports (Knepp 2002a, Knepp 2002b, and Myers 2005). Each field investigation report also contains a risk assessment based on known subsurface contaminants, a description of the interim measures implemented, and recommendations for further actions.

2.2 ACCOMPLISHMENTS

The TFVZ Project emphasizes data collection to improve conceptual models of tank farm vadose zone contamination and future impacts. The emphasis is on collecting sufficient information to update the conceptual models, starting with mining existing data. Sediment and pore water samples were collected from the vadose zone based on the current understanding, including input from gross and spectral gamma radiation measurements. A tiered approach was used to evaluate samples in the laboratory and scientific input was incorporated into the process. Specific accomplishments in the process of characterization, field work, laboratory investigations, modeling, and implementation of interim measures are described in the remainder of this section.

2.2.1 Pre-Characterization Activities

Hanford tank farms pose unique challenges for the processes needed to carry out characterization and remediation. The TFVZ Project determined that to be successful, emphasis had to be placed on performing characterization to improve understanding of the subsurface conditions and updating the conceptual model (Jones et al. 1998). Inside the tank farms, there are many sources of contamination and infrastructure that make characterization and remediation difficult. Some of the contaminated sediments extend to 250 feet below ground surface (bgs). Pre-characterization activities were performed to understand past history of operations and contamination occurrences through as many lines of evidence as could be discovered, then to assimilate as much of the information as possible to support field characterization and remediation decisions. The project recognized that the situation would evolve with time as additional data are collected, so the process has remained flexible to support the decisions that will be made.

Before field characterization was initiated, a detailed examination of past characterization in each tank farm was performed, resulting in subsurface condition description reports (Wood et al. 1999, 2000, 2001, 2003a, and Wood and Jones 2003). By reviewing reports from the various processing facilities, detailed descriptions of the components of waste processing streams and of off-normal conditions were discovered that were relevant to the design of field characterization activities (e.g., Field and Jones 2005 and *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site* [Lambert 2005]).

One of the key resources available to the TFVZ Project was the long-term record of gamma radiation measurements in the sediments in the tank farms. When an SST was suspected of leaking, wells were drilled to obtain sediment samples and monitor subsurface contamination using geophysical measurements. Since the wells do not extend to groundwater, they are commonly called drywells. From approximately 1975 to 1995, detectors that measured only the

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total amount of gamma radiation (or gross gamma) were used. A series of reports on the analyses of these measurements were issued, as shown in Table 2-2.

Table 2-2. Gross Gamma Analysis Reports.

Farm	Document Identification	Year	Farm	Document Identification	Year
A	Randall and Price (2001)	2001	S	Randall et al. (1999)	1999
AX	Price (2001)	2001	SX	Randall and Price (1999a)	1999
B	Randall et al. (2000)	2000	T	Randall et al. (2000a)	2000
BX	Randall (1999b)	1999	TX	Randall et al. (2000b)	2000
BY	Randall and Price (1999c)	1999	TY	Randall and Price (1999d)	1999
C	Price and Randall (2001b)	2001	U	Price and Randall (2001a)	2001

In the late 1990s, spectral gamma detectors were deployed in drywells to measure not only the amount of radiation, but also its energy distribution. The energy distribution allows determination of the specific radionuclides that emitted each radiation energy level. A report, which discussed the spectral gamma measurements versus time, was issued for drywells surrounding each SST. The individual tank reports for each tank farm were further summarized as tank farm roll ups. Table 2-3 displays the summary reports for the tank farms that form the initial, or baseline, effort. This spectral gamma effort continues with measurements focused on narrower sets of drywells and on wells outside of the tank farms (see the web pages at http://www.hanford.gov/cp/gpp/data/gpl.cfm).

Table 2-3. Analysis of Drywell Spectral Gamma Logs.

Farm	Document Number	Year	Farm	Document Number	Year
A	GJO-98-64-TAR; GJO-HAN-23	1999	S	GJO-97-31-TAR; GJO-HAN-17	1998
AX	GJO-97-14-TAR; GJO-HAN-12	1997	SX	DOE/ID/12584-268;GJO-HAN-4	1996
B	GJO-99-113-TAR;GJO-HAN-28	1999	T	GJO-99-101-TAR;GJO-HAN-27	1999
BX	GJO-98-40-TAR; GJO-HAN-19	1998	TX	GJO-97-11-TAR; GJO-HAN-13	1997
BY	TAR not issued; GJO-HAN-6	1997	TY	GJO-97-30-TAR; GJO-HAN-16	1998
C	TAR not issued; GJO-HAN-18	1998	U	GJO-97-1-TAR; GJO-HAN-8	1997

References are listed under GJO-HAN-xx

Combining the historical gross gamma and the modern spectral gamma logs along with other information allowed the TFVZ Project to identify the most likely impacted areas of the vadose zone beneath the SST farms for characterization. The combined information was used to determine placement of new characterization boreholes and other subsurface measurements (e.g., geophysics).

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2.2.2 Field Characterization

Field data collection is a critical part of the TFVZ Project. Field characterization has resulted in many significant accomplishments in the last ten years, including those in the following areas:

- Safety
- SX-108 slant borehole
- Relogging of laterals in A and SX tank farms
- Innovative sampling techniques
- Surface geophysical exploration

2.2.2.1 Safety. Drilling and field characterization are inherently dangerous. Drilling for the TFVZ Project is done in the presence of highly radioactive material. Yet the safety record for field characterization has been excellent with no recordable injuries, four first aid cases, and no significant radiation exposures. This rate is far below industry standards and is the result of careful planning and execution.

2.2.2.2 SX-108 Slant Borehole.

A major part of the first phase of the TFVZ Project was the retrieval of vadose zone samples and their subsequent analyses. Most of these samples were gathered through having boreholes penetrate the most contaminated parts of the tank farms:

- Extending the 41-09-39 drywell (near SX-109) to determine the extent of the release from tank SX-108

- Placing a slant borehole under tank SX-108, probably the most caustic leak

- Drilling a well near tank SX-115, finding the highest groundwater technetium concentrations

- Installing a borehole in the middle of the uranium plume from tank BX-102 to determine its vertical extent

- Placing a borehole near tank B-110 to determine the cause of unusual gamma radiation measurements thought to be bremsstrahlung from Sr-90 (Sr-90 was indeed found)

- Drilling three boreholes in TX farm to investigate suspected uranium plumes

- Constructing 2 boreholes near tank T-106, a source of the largest tank leak, to explore movement since the last borehole was located near this tank in 1994.

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Of these, the slant borehole beneath tank SX-108 has attracted the most attention.

One of the largest documented tank leaks is from tank SX-108. One of the key gaps identified in the initial data gaps document (Jones et al. 1998) was the possibility of such waste significantly altering the physical and chemical properties of the sediments. The TFVZ Project investigated directional drilling technologies where the direction of the borehole could change during drilling. However, the industry techniques for such drilling would introduce significant amounts of water into the subsurface, potentially accelerating the movement of already released contaminants. A different method was investigated to drive a casing at an angle and collect contaminated sediment samples. The method was intended to collect samples ahead of the driven casing that were minimally impacted by drag-down effects of drilling operations. After design and demonstration in clean areas outside of tank farms, the slant borehole under tank SX-108 was initiated.

The surface location of the tank SX-108 slant borehole was established based on the intended target zone beneath the tank, the surface and subsurface infrastructure of the farm, and the restrictions on how close to the base of the tank the borehole would be allowed to pass. Ground-penetrating radar was used to map and confirm the locations of subsurface utilities. The surface location was selected based on a three-dimensional map of the subsurface.

The SX-108 slant borehole was advanced at an angle 30 degrees from vertical, passing approximately 3 m (10 ft) from the base of tank SX-108. Ten samples were called out in the work plan for this effort (Rogers and Knepp 2000). The number of intervals sampled was increased to 17 to ensure that critical zones of interest were not overlooked. The analytical scheme was changed to take advantage of the information collected during preceding characterization efforts and to make most efficient use of laboratory resources. One of the 17 samples was lost from the sampler during operations, the rest were successfully recovered. The borehole was advanced to a vertical depth of 43.9 m (144 ft) and 52.2 m (171.2 ft) slant distance (*SX-108 Slant Borehole Completion Report* [Gardner and Reynolds 2000]). The last sample collected was from the fine-grained sediments of the undifferentiated Hanford formation/Plio-Pleistocene unit silty sands. The borehole was logged with down-hole geophysical equipment and decommissioned. Because the driven casing could not be successfully extracted, the final decommissioning was completed according to a variance granted by Ecology.

The analytical protocol developed in conjunction with Ecology was significantly altered from that developed during planning of this work. The revised protocol was designed to be the same as that applied to two previous boreholes in the SX tank farm. Based on lessons learned from those boreholes, many of the laboratory analyses that would have been conducted during the second or third phases were performed during the initial phase.

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Figure 2-1. SX-108 Slant Borehole Drilling
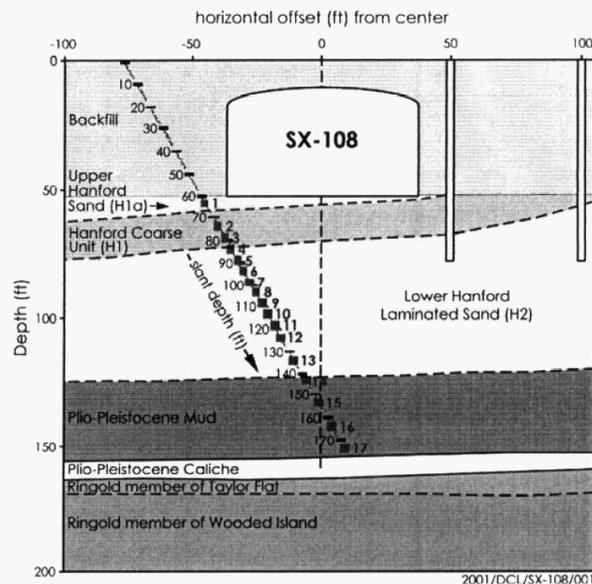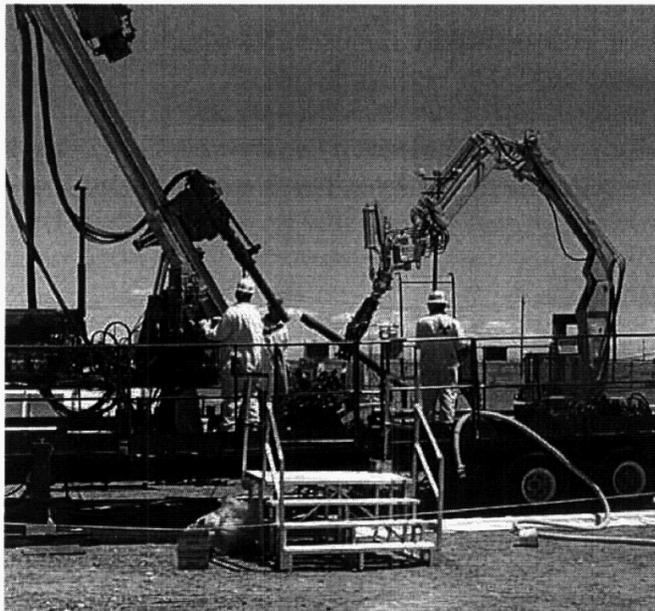
2.2.2.3 Laterals in A and SX Tank Farms. Starting in the late 1950s, horizontal tubes were placed under tanks that had sufficient heat from nuclear decay to boil liquids in tanks (referred to as self-boiling tanks) within the A and SX tank farms. These laterals were instrumented with radiation detectors to detect leaks and monitor contaminant movement. Monitoring the laterals was discontinued in the late 1980s.

The TFVZ Project accessed the laterals and determined that they could be used. They were logged with small diameter radiation detection equipment that could be threaded into the laterals without entering the caissons normally used to access the laterals. The laterals under tanks A-103, A-104, A-105, SX-107, SX-108, SX-110, SX-111, SX-112, and SX-115 were gamma logged as shown in *Gamma Surveys of the SST Laterals for A and SX Tank Farms* (Randall and Price 2006).

2.2.2.4 Innovative Sampling Techniques. Safe sampling of highly radioactive sediment samples retrieved from the vadose zone required development of novel equipment and techniques. For example, the first sampling campaign in the SX tank farm was done in and below an existing borehole. Techniques to extend the borehole without remobilizing contamination and to obtain samples through the existing borehole (side-wall sampling) were developed. Bringing highly contaminated samples to the surface required the development of new sampling methods such as the use of lead over-packed (shielded) split-spoon liners, reconfigured split-spoon samplers to facilitate direct shipment to the laboratory or easy manipulation in the field, and shielded secondary containment, including portable glove boxes and green houses, walk-in fume hoods, and extended handle wrenches/tools to break open the split spoons and remove the shielded liners containing the sediment.

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Boreholes are expensive to install in the contaminated vadose zone beneath tank farms, although costs have been reduced as experience has been gained with time. The direct push technology (where a rod is pushed through the sediment) was evaluated and used, but was unable to penetrate the compacted sediments at the bottom of tank farms. A new direct-push technology based on a hydraulic hammer was developed by the TFVZ Project that was able to access the subsurface to greater depths (up to nearly 120 feet). A photograph of the hydraulic hammer equipment is shown in Figure 2-2. It can be deployed to push vertically or at angles of 30, 45, or 60 degrees from vertical. This technology has been and is being successfully deployed in the C, B, BX, T, TY, and U tank farms.

Figure 2-2. Hydraulically Driven Direct Push Sampler

2.2.2.5 Subsurface Geophysical Exploration. As part of the Groundwater/Vadose Zone Integration Science and Technology Project, vadose zone transport field studies, a geophysical method known as high resolution resistivity (HRR) was deployed at the Hanford Site (*Vadose Zone Transport Field Study: Final Report* [Ward et al. 2006]). During the cited vadose zone field studies in 2000 and 2001, the HRR method was used to detect and track the movement of high salt plumes during injection experiments. The HRR method measures the electrical resistance between many different points (most on the surface, but some subsurface). These resistance values can be inverted (as is done in computer assisted tomography) to show the electrical resistance of a particular volume of sediment. The key species that influence the vadose zone resistivity in the field are the dominant dissolved salts in pore water (usually sodium and nitrate from the neutralization of highly concentrated nitric acid wastes with sodium hydroxide). Thus, the actual concentration of the dominant salts can then be inferred.

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Following successful deployment for the vadose zone transport field studies, HRR was deployed elsewhere on the Hanford Site. It was evaluated at the Mock Tank Site for tank-leak detection and was deployed in the S tank farm (*Surface Geophysical Exploration of the S Tank Farm at the Hanford Site* [Rucker et al. 2006a]) during retrieval operations and for additional testing with tank-leak stimulant injections (See Figure 2-3). In parallel with evaluation of the technology for tank leak detection, Fluor Hanford, Incorporated (FHI), the DOE prime contractor at the Hanford Site for areas outside of the tank farms on the Central Plateau, implemented HRR to survey a past-practice waste site known as the BC cribs and trenches. The three-dimensional subsurface plumes were characterized by FHI in *Plume Delineation in the BC Cribs and Trenches Area* (Rucker and Sweeney 2004). The HRR methodology as applied to exploration for and delineation of existing plumes, rather than leak detection, is known as Surface Geophysical Exploration (SGE) as described in *An Assessment of Surface Geophysical Exploration as a Characterization Tool in Hanford Tank Farms* (Myers 2006). SGE has been used at C, T, and U farms (Levitt et al. 2007, Rucker 2006b, and Rucker 2006c) and will be deployed at all of the remaining SST farms.

Figure 2-3. Surface Map of Plumes under S Farm Determined by Surface Geophysics.
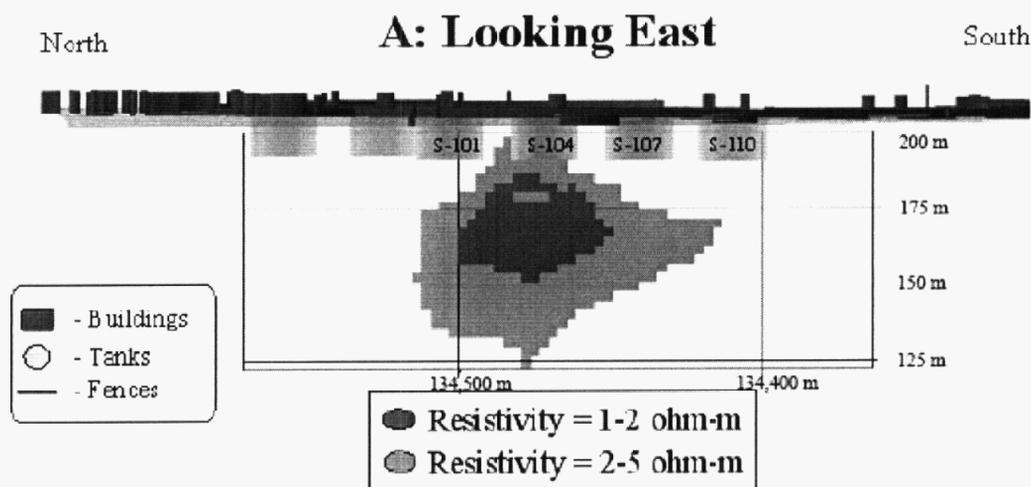
2.2.3 Laboratory

The contaminated vadose zone sediment samples collected by the TFVZ Project were shipped to the Pacific Northwest National Laboratory (PNNL) where measurements were performed to determine contaminant concentrations. Normally, about 20 intact (split spoon) samples were retrieved from each borehole. A hydraulic hammer direct-push campaign usually involved between 20 and 40 pushes, but only one sediment sample is gathered from each push.

Some of the samples collected to date were relatively uncontaminated; others contained levels of radiation that required handling precautions. Thus, laboratory analyses were selected carefully to optimize the data obtained and protect the workers/analysts. With the approval of Ecology, a

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three tier approach for laboratory analyses was developed. The first tier is done on each sample to provide the following:

- A quantitative measure of the hazard of the sample (based on gamma and high energy beta radiation dose rates)

- Quantitative measure of spectral gamma content

- Water extractable quantities of key tank waste contaminants such as technetium, nitrate, chromium, pH, and electrical conductivity

- The moisture content (needed to guide future characterization)

- A visual observation of the sediments (to determine if interesting physical or chemical processes have occurred).

Depending on the tank farm and vadose zone plume being investigated, additional analyses were included in the first tier to focus on additional key contaminants.

Based on the results of the first tier analyses, a second tier of analyses is selected. The second-tier analyses are used to characterize the major sediment constituents (common alkali and alkaline earth cations, aluminum, silicon, iron, and common anions such as halides, sulfate, phosphate, carbonate) and tank waste constituents (most of the RCRA metals and long-lived radionuclides, actinides with half lives greater than several hundred years, and fission products with half lives greater than 10 years). In addition, second tier analyses can include the determination of mineralogy of the sediments, hydrological properties such as matric potential, which indicates whether the sediments are "dry" or "wet" (i.e., capable of draining water in the natural field state), and mobility of the contaminants.

A third (final) tier of analysis is performed on a hand full of sediment samples selected to understand the underlying chemical and physical processes for contaminant transport. These analyses range from determining the speciation of contaminants (e.g., chromium (Cr) oxidation state as Cr^{+3} or Cr^{+6}) to determine the location of particular contaminants on or inside mineral structures, to determining the release or migration kinetics of specific contaminants from the sediments during current or future interactions with percolating water. Often, the analyses in this third tier are performed in DOE Office of Science (DOE SC) facilities. Through the Groundwater/Vadose Zone Integration Project, the TFVZ Project has accessed some DOE SC investigators and facilities to study aspects of the sediments that have been collected. This effort has been known as "wrap-around science" because it is used to compliment baseline characterization of the samples. The sediments are complex because they have been subjected to a complex set of chemicals under extreme (very high salinity, very highly caustic) conditions and elevated temperature conditions for up to 60 years. The DOE SC facilities used to investigate Hanford sediments include the large particle accelerators at the Synchrotron Radiation Laboratory, the Advanced Photon Source at Argonne National Laboratory, and large magnetic spectrometers at the Environmental and Molecular Sciences Laboratory. The results of the wrap-around science effort have significantly aided the effort to improve our understanding of the chemical, physical and hydrologic processes that control the fate of key contaminants in the natural and stressed subsurface environment.

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The baseline characterization results as well as key results from the wrap-around science activities were incorporated directly into the FIRs that have been published. Some of the highlights include:

- Interactions of highly caustic tank waste with sediments
- Cesium mobility
- Uranium mobility
- Fate of technetium through the bismuth phosphate precipitation process
- Release rates from tank waste residuals

2.2.3.1 Interactions of Highly Caustic Tank Waste with Sediments. At the initiation of the TFVZ Project, the conceptual model for tank wastes was that as leaks occurred, they greatly altered the physical and chemical properties of sediments in the vadose zone. Some minor changes in chemical and mineralogical properties of near-tank sediments have been seen based on characterization of the past leaks. Besides the presence of contaminants, pH of the soil was observed to have increased from its natural value of ~7.5 to 8 to as high as ~9.5 to 10 (see Appendix B in each of the FIRs). In addition, water soluble magnesium and calcium generally present on sediment cation exchange sites have been displaced downward having been replaced by sodium present in very high concentrations in the tank liquids that leaked (Appendix D in Knepp 2002a).

To date, the closest sample taken near an SST at the Hanford Site has been sediment cores taken from the SX-108 slant borehole, as reported in Knepp (2002a). One core in that borehole was obtained 2 ft below the base of the tank and 8 ft horizontally from the sidewall of the tank and another sediment core was obtained 14.5 ft below the base of the tank and directly under the tank sidewall. Fourteen additional cores were obtained from deeper in the vadose zone as the slant hole penetrated all the way to locations directly under the center of SX-108. The core sample 14.5 ft below the tank bottom but directly under the sidewall did show slight indications of caustic fluid dissolution attack on individual sediment grains and faint signs of some mineral alteration to new solids called zeolites. This sediment was dry (likely from the high heat from the tank driving water away). The water extract of this sample had a pH of 9.6, and was moderately laden with salts from the tank liquids. Sediment water extracts from samples 21 ft deeper and closer to a projection of the tank's center contained 80 times more salts but normal pH values. The sediments closest to the tank bottom and the sediment 14.5 ft below the tank bottom but right below the tank side wall that showed that mineral alteration contained slightly lower concentrations of the highly sorptive radionuclide cesium-137 than the sediments 21 ft deeper and farther under the tank bottom. The contaminants with the greatest mobility, technetium-99, chromium(VI), and nitrate were found 40 ft beneath SX-108 in cores 9 and 10 (see Figure 2-1) within sediments that showed no signs of caustic attack (Appendix B of Knepp 2002a). The conclusion is that the zone of caustic attack around the SX-108 leak was limited to a zone with a radius of 15 to 20 ft (Knepp 2002a).

In the characterization work performed to date, the caustic tank waste solutions was not observed to significantly impact the physical and hydrologic properties of the sediments in contact with tank wastes. The grain dissolution that occurred did not form large void spaces and mineral precipitation did not plug existing pores and cause large changes in porosity and hydraulic

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conductivity (water flow rates). However, slight changes in porosity, hydraulic conductivity, and formation of new precipitates, such as highly sorptive zeolites, could have had small, but measurable effects on fluid flow direction and contaminant migration in the localized zone impacted by the highly caustic leaked fluids (Appendix B of Knepp 2002a).

2.2.3.2 Cesium-137 Mobility. As described in Section 1.0, a driver for the TFVZ Project and the Groundwater/Vadose Zone Integration Project was to address the issue of cesium-137 being deeper in the vadose zone beneath the SX tank farm than conceptual models at the time could explain. Based on extensive laboratory analyses and modeling an accurate and mechanistically based cesium adsorption model was developed that explained the processes involved and determined the parameters needed to quantify cesium migration through sediments (see Appendix D of Knepp 2002a, Zachara et al. 2000, Zachara et al. 2002, Liu et al. 2003a, Liu et al. 2003b, Liu et al. 2004a, McKinley et al. 2001, and McKinley et al. 2004).

The key finding was that the large amount of sodium that is in tank waste was concentrated by self boiling to concentrations up to four times higher than previously thought and resulted in mass concentrations that saturated available sorption sites in Hanford sediments when the SX-108 leak occurred. Sodium is very similar in its chemical properties to cesium and in large quantities, competed for the available sorption sites. The fission process also created four isotopes of cesium (133, 134, 135, and 137) that when also concentrated by self boiling, helped to saturate the sorption sites in the sediments closest to the tank leak. Cesium-137 occurred in high concentrations in tank waste and when present in fluids that leaked from self boiling tanks, migrated until the cesium atoms encountered sorption sites not already saturated with cesium or sodium, generally to greater distances than previously predicted. As the leaked fluid migrated away from SX-108 in the vadose zone, they were diluted by direct ion-exchange removal onto the native sediments and by mixing with the natural vadose zone water. The cesium concentrations also diminished by sorption onto both cesium preferred sites and general cation exchange sites on the sediments, and by dilution with the vadose zone water. Most of the cesium that currently exists in subsurface sediments beneath leaked SSTs is sorbed and immobilized by strong ion exchange to and diffusion within micaceous minerals. The cesium adsorption model accounts for varying sodium and cesium concentrations and can correctly predict the past and future migration of cesium in the vadose zone.

2.2.3.3 Uranium Mobility. Another focus of study has been on understanding the fate and transport of uranium. At the present time, the general conceptual model for uranium transport at Hanford is incomplete. Work is continuing to improve mechanistic understanding and predictions.

The behavior of uranium varies between tank farms and waste sites in the 200 Area Central Plateau and in the 300 Area. Uranium interactions with Hanford sediments have been found to vary significantly with chemical composition of the waste stream that was disposed. Leaching experiments and detailed solid phase characterization studies on the contaminated sediments show that uranium retardation occurs as a result of both discrete uranium precipitate phases and adsorption onto common sediment minerals.

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The chemical composition of solutions used to leach the contaminated sediments has a strong effect on the amount and rate of uranium release from the contaminated sediments. It has been well documented that pH, carbonate/bicarbonate content, and the concentrations of sorbents are key variables that control the fate of uranium. The presence of natural or waste-induced calcium carbonate and ferric oxides in Hanford sediments interact strongly with dissolved uranium to retard its migration in the percolating pore waters when the pH of the solutions are acidic (below 7). If the solution pH is above neutral and carbonate/bicarbonate concentrations are moderately high (but below concentrations where calcite is actively precipitating), uranium is relatively mobile. Elevated temperature and the presence of phosphate and sulfate ions (both present at high concentrations in the bismuth phosphate type waste streams) can further complicate the fate of uranium beneath the SSTs.

Uranium existing in vadose zone sediments impacted by tank leaks can sustain pore-water concentrations above drinking water standards for long periods of time. This was documented in Appendix D of the B-BX-BY FIR (Knepp 2002b). The uranium in solution may be readsorbed, co-precipitated, or continue to move with little retardation. The sediments impacted by the BX-102 overfill continue to be studied for long-term uranium leaching and transport.

2.2.3.4 Fate of Technetium in the Bismuth Phosphate Precipitation Process. Early plutonium recovery at Hanford was based on the bismuth-phosphate process, which relied on precipitation. This process had a number of drawbacks. First, the slightly depleted uranium was not directly recovered, but was routed to the SSTs for interim storage until recovery methods could be developed. Second, the chemical precipitation process produced large quantities of waste and had no viable process for recycling any process chemicals. It is estimated that the bismuth-phosphate process generated approximately 80 % of the waste volume in underground storage tanks. Finally, the bismuth-phosphate process had to be run in "batch mode." It was known that approximately 10 % of the total beta activity was carried along with the initially precipitated plutonium product. Approximately 1 % of the total beta activity was carried along with the second precipitated plutonium product. The third precipitated plutonium product had essentially all of the total beta activity removed. Therefore, approximately 90 % of the total beta activity was sent to the SSTs with the first "high-uranium" bismuth-phosphate waste stream (i.e., metal waste), approximately 9 % with the second waste stream (i.e., first cycle), and the final 1 % went with the third waste stream (i.e., second cycle).

Sometime during Hanford chemical process history, an assumption was made that "total fission products" could be substituted for "total beta activity." It was assumed during the bismuth-phosphate process operations that essentially all of the "total beta activity" that was tracked with the plutonium product was zirconium/niobium-94. This assumption persisted through the development of the Hanford Defined Waste Model, initial Best-Basis Inventory estimates, and the initial version of *Hanford Soil Inventory Model* (Simpson et al. 2001). This led to errors in projected bismuth-phosphate waste compositions remaining in the SSTs and the waste streams that were transferred to cribs and trenches, which allowed wastes to migrate through the soil column.

The problem associated with the assumption regarding total fission products came into focus during review of analytical results from soil samples collected from beneath the B-38 trench

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which had received large volumes of bismuth-phosphate process first cycle waste. Initially, significant quantities of technetium-99 were expected to accompany nitrate in deep vadose zone sediment samples. However, almost no technetium-99 was found in vadose zone sediment samples containing large quantities of nitrate. This observation led to a reevaluation of historical records associated with the bismuth-phosphate process and additional laboratory studies. The first step in the bismuth-phosphate process was simulated in laboratory-scale simulation tests of the bismuth-phosphate process using selected radioactive tracers. The laboratory simulations confirmed the current interpretation that essentially all of the fission products that drive risk at the Hanford Site (including technetium-99) traveled with the metal waste stream in the bismuth-phosphate process as reported in *Laboratory-Scale Bismuth Phosphate Extraction Process Simulation to Track Fate of Fission Products* (Serne et al. 2007). Since completion of the laboratory work (Serne et al. 2007), both the Best-Basis Inventory (http://twins.pnl.gov/twins3/twins.htm) and *Hanford Soil Inventory Model* (Corbin et al. 2005) estimates have been corrected.

2.2.3.5 Release Rates from Tank Waste Residuals. To support the Single-Shell Tank Performance Assessment, the TFVZ Project measured the release of constituents from residual waste sludge obtained from tanks C-106, C-203, and C-204 after their retrieval. Each of these is described as a sludge tank, which is a tank having waste characterized as being dominated by metal oxides rather than salts. The contaminant release behavior from sludge is very different than release from salt waste.

The total concentrations of the primary contaminants of concern (technetium-99, iodine-129, chromium, and uranium) were found to be relatively low in the C-106 residual sludge as reported in *Hanford Tank 241-C-106: Residual Waste Contaminant Release Model and Supporting Data* (Deutsch et al. 2005b). In addition, the water-leachable release rates were low. Such low values are attributed to the flushes with oxalic acid that were used to retrieve the waste out of C-106. At the end of these flushes, very little water soluble material remained.

The total concentrations of technetium-99 in C-203 and C-204 sludge are lower than the concentrations found in tank C-106 (Deutsch et al. 2005a, Krupka 2006, and Cantrell et al. 2006). The uranium concentrations in C-203 and C-204 sludge materials are 300 to 1000 times higher than the uranium concentrations in the residual sludge from C-106, perhaps reflecting the efficiency of oxalic acid at dissolving and removing uranium. Discrete uranium minerals, including čejkaite, were found in the C-203 and C-204 sludge materials.

Quantitative release models for technetium-99 were developed based on the laboratory testing of C-203 and C-204 sludge materials. These models are based on the concentrations and solubility of technetium-bearing solids in contact with pore water migrating through the sludge materials. There are two stages of technetium release to solution, an initial fast release of mobile technetium-99 from an undetermined salt, followed by slow release of the remaining inventory.

The model for release of uranium from C-203 and C-204 sludge materials is based on the concentrations and solubility of uranium- and sodium-bearing minerals in contact with pore water migrating through the sludge materials. There are three stages of uranium release to solution, 1) an initial low release of uranium due to the "common ion" effect during dissolution

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of sodium nitrate salts, 2) larger release of uranium from čejkaite [$Na_4(UO_2)(CO_3)_3$] after the sodium-nitrate salts are dissolved, and 3) low release of uranium from an undetermined uranium-bearing mineral, perhaps clarkeite, a slightly soluble sodium uranyl hydroxyl-oxide [$Na(UO_2)O(OH)H_2O)_{0-1}$]. The stages of uranium release do not coincide with the stages of technetium release.

2.2.4 Analysis

Groundwater impacts from tank wastes migrating through the vadose zone and from possible future releases are analyzed with computer models using the data collected through literature searches, field work, and laboratory measurements. Important advances have been made in different aspects of these analyses:

- Conceptual model updates
- Temperature-dependent contaminant transport
- SST leak volumes
- Inventory estimate for SST Leaks
- Contaminant distributions for the T-106 tank leak.

2.2.4.1 Conceptual Model Updates. Tank waste is characterized by extreme chemical and physical properties, which may impact waste migration through the vadose zone when leaks have occurred. For example, the leaked waste from tank SX-108 may have reached temperatures greater than 300 °F, specific gravity greater than 1.5, and pH possibly as high as 14 or above. Modeling the complexities of tank leaks is difficult because of the coupled processes that have to be described mathematically and parameters for complex models that must be measured or estimated with technically defensible processes.

To evaluate the impacts of tank leaks, the TFVZ Project separated the conceptual model for leaks into two phases. The first phase occurred during the initial tank leak when the extreme tank waste properties overwhelmed the natural system. Compared to the long-term migration of tank wastes through the vadose zone, this phase was typically short duration. As was the case for cesium-137 migration in the SX-108 tank leak, the initial phase resulted in significant penetration of tank wastes through the vadose zone. The second phase was of longer duration, when mixing of the finite-volume tank waste fluids with vadose zone fluids and dilution have returned the vadose zone to a state where the natural system exerts the greatest control on most of the key processes.

The first phase of the conceptual model was addressed by the TFVZ Project by conducting field and laboratory characterization of the current distribution of contamination and evaluating how the contamination was emplaced through science and technology investigations. The second phase of the conceptual model was evaluated through characterization of current conditions and analyses of future impacts. Evaluation of the second phase of the conceptual model was based on the assumption the natural system has reasserted control.

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2.2.4.2 Temperature Dependent Contaminant Transport. Because of heat generated by radioactive decay, the temperatures in some of the tanks exceeded the boiling point of water. These tanks served as sources for heating the sediments around the tanks. A key question that arose was whether the conceptual model for current and future migration of tank wastes needed to consider temperature effects. The temperature effects were studied for a cross section incorporating tanks SX-107, SX-108, and SX-109 (Appendix D.7.1 of Knepp 2002a). The results of this study demonstrated that temperature-dependent modeling is absolutely necessary for high-heat tanks during the early stages of the leak. However, if the modeling begins with current conditions (approximately year 2000), using the existing plumes and temperature regime as boundary conditions, the differences in estimated fluxes entering groundwater using temperature-dependent and isothermal calculations were demonstrated to be insignificant.

2.2.4.3 Single-Shell Tank Leak Volumes. In the early 1990's, a systematic evaluation of the integrity of the SSTs was performed. Leak volume estimates derived from this process were based largely on in-tank liquid level measurements and tended to provide conservatively high leak volumes. Tank leak volume estimates based on these evaluations are documented in monthly Tank Waste Summary Reports (HNF-EP-0182). Some of these estimates appear to be inconsistent with more current vadose zone characterization data. As a result, more current evaluations to estimate the volume and inventory of SST leaks were conducted by the Vadose Zone program. These evaluations considered liquid level measurements, characterization of waste streams going into the tanks, and geophysical radiation logging measurements outside of the tanks. SST leak volume estimates based on vadose zone program evaluations are summarized in Field and Jones (2005). Some of the estimates were larger, some smaller, and most were the same as the SST leak volume estimates in HNF-EP-0182. The greatest differences, due to inconsistencies in large liquid level decreases and little or no evidence of a large leak based on geophysical radiation logging data, were for tanks A-105, C-101, and U-101. This volume estimates require further review as well as the need to establish the uncertainties associated with both the volume and composition estimates. Tank leak volume and UPR estimates and the resulting waste compositions will be reassessed and updated in accordance with a protocol document developed with Ecology (Schepens 2006).

2.2.4.4 Inventory Estimate for Single-Shell Tank Leaks. Based on the SST leak volume estimates from Field and Jones (2005), improved waste stream transfer records, and chemical compositions of various waste types the inventories of released contaminants in each tank leak event were updated (Corbin et al. 2005). This document not only details the releases inside the tank farm, but also all of the releases to the soil in the cribs, trenches, and ponds (non-SST disposal facilities), and the larger spills and unplanned releases in the Central Plateau.

2.2.4.5 Contaminant Distributions for the T-106 Tank Leak. Borehole C4104 was drilled in 2003 to assess the migration of contaminants from the 1973 tank leak at T-106. The C4104 borehole was drilled to provide sediment from the vadose zone as close as possible to borehole 299-W10-196 that was installed in 1993. C4104 is situated approximately 13 ft to the east of

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299-W10-196 and farther away from Tank T-106. The cable tool drilling and split spoon sampling used for C4104 met refusal at approximately 127 ft below ground surface. This was shallower than was reached at 299-W10-196 (approximately 180 ft bgs).

The analysis of the T-106 tank leak compared the vertical distributions and concentrations of various constituents per gram of dry sediment for both boreholes. No attempts were made to obtain samples of the pore water within the sediments at 299-W10-196 in 1993; thus, the only comparisons that can be made are for the total concentration of constituents in the sediments of each borehole. The activities of short-lived radionuclides found in borehole 299-W10-196 were decay corrected to 2003 when borehole C4104 was emplaced so that the comparisons represent the present day conditions (assuming that significant migration of radionuclides has not occurred in borehole 299-W10-196 over the last ten years).

Nitrate is one of the most mobile and highest concentration contaminants present in tank fluids and is not present in the Hanford natural environment at high concentrations. Thus nitrate is a very good indicator of tank waste migration in the vadose zone. Data collected for nitrate in sediments from borehole C4104 suggest that the maximum concentration in 2003 might be approximately 6 ft deeper than at 299-W10-196, so there is evidence of vertical migration of mobile nitrate in the ten years between drilling of the boreholes. The concentrations of nitrate found in the sediments vary, with the peak concentration of 4,400 µg/g found in 299-W10-196 and 2,600 µg/g found in C4104. This may represent dispersion and/or lateral migration of the nitrate with time.

Another mobile constituent present in tank fluids is technetium-99. Comparison of the technetium-99 profiles between the depths of 95 to 105 ft bgs show that contamination in the Cold Creek lower subunit in borehole 299-W10-196 in 1993 is not present in borehole C4104 at similar depths in 2004. Unfortunately, the sampling and measurement frequency in 1993 for technetium-99 in borehole 299-W10-196 was too coarse to adequately complete a profile of the vadose zone plume. Accounting for the data missing from borehole 299-W10-196, the masses of technetium-99 in the two boreholes appear to be quite similar. The conclusion is that the shallow portion of the technetium profile does appear to have descended six to ten ft over the ten-year span between the measurements. Whether the deeper portion of the profile has migrated a similar distance cannot be assessed.

A third constituent in the T-106 leak fluids that can be analyzed to make statements about contaminant migration is cobalt-60. After decay correcting the two borehole data sets to a common time, the data suggest that cobalt-60 has migrated deeper into the sediment profile within the Ringold Taylor Flat member when compared to the profile in 1993. In the 299-W10-196 borehole, the deepest peak of cobalt-60 was found at 111 ft bgs in 1993, whereas in borehole C4104 in 2003, the deepest cobalt-60 peak was found at approximately 113 ft bgs. The cobalt-60 activities for both borehole profiles, after decay correction to 2003, are in close agreement. This suggests that the total mass of cobalt-60 has not changed and that the leading edge of the plume has redistributed only a few feet deeper into the profile in the past ten years. Additional details and comparisons of less mobile contaminants are found in *Characterization of Vadose Zone Sediments below the T Tank Farm: Boreholes C4104, C4105, 299-W10-196, and RCRA Borehole 299-W11-39* (Serne et al. 2004b).

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2.2.5 Implementation of Interim Measures

Although final closure of the SST farms is years away, interim measures can be taken to mitigate contaminant movement. Three such actions have occurred (see chapter 5 in each of the following Field Investigation Reports [Knepp 2002a, Knepp 2002b, and Myers 2005]):

- Construction of berms and gutters to control surface water run on to tank farm surfaces
- Test and remove or cap off waterlines extending into tank farms and areas of vadose zone contamination
- Cap open boreholes

Currently, an interim barrier is being designed for installation over the plume from the T-106 tank release.

The tank farms were constructed in small valleys in the Central Plateau so that the waste created during chemical reprocessing of fuels would flow downhill from the processing plants to the storage tanks. However, that design also allows surface water (particularly water from rapid snowmelt) to drain onto tank farm surfaces via overland flow (surface water run on). There have been several instances during Hanford Site operations where tank farms have flooded following rapid snowmelt events. This was thought to be a driver for vadose zone contamination in the tank farms to migrate downward toward the water table. The TFVZ Project designed and constructed berms around the SST farms to divert surface water away from the farms and into gutters and drains, both previously existing and newly constructed. These berms and gutters were successfully tested during the 2004-2005 winter, which was very wet and resulted in generation of surface water and overland flow.

In addition to consideration of surface-water run on, the TFVZ Project evaluated the impact of leaking water lines within the tank farms. Throughout Hanford Site operations, water was used for a variety of purposes inside the tank farms. As active operations of the SST farms have ceased and the focus placed on waste management and remediation, the need for water inside the SST farms has decreased. As part of interim measures completed by the TFVZ Project, all waterlines inside SST farm fence lines were tested for leaks. Water lines, where testing demonstrated that integrity was compromised and that the lines were no longer in service, were capped before they enter the tank farms.

There are numerous boreholes (also known as drywells) inside the tank farms used for vadose zone monitoring. At the time they were constructed, each drywell was capped. However, many of the caps were misplaced and some of the drywells became open conduits to the subsurface. The TFVZ Project installed waterproof caps on all of the drywells to minimize this pathway.

The above interim measures do not address moisture influx from precipitation (rain or snow) that lands directly on a tank farm. An interim barrier is being designed for installation over the plume from the T-106 tank release. This barrier, made from a mixture of polyurea/polyurethane sprayed over a felt substrate, will collect water and then divert it out of the tank farms. This barrier system, including moisture measurement arrays, will be constructed by September 2007.

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2.3 Relationship to Other Activities

The TFVZ Project is integrated and interfaces with a number of organizations to gather and analyze data, use the data in risk assessments, and then mitigate long-term impacts. The key interfaces include:

- Other tank farm organizations
- DOE's Office of River Protection
- DOE's Richland Operations Office
- Pacific Northwest National Laboratory
- Other Hanford Site contractors
- Washington State Department of Ecology
- Other regulatory agencies

2.3.1 Other Tank Farm Organizations

The TFVZ Project closely interacts with many other tank farm organizations. Some, such as the Tank Farm Closure Project, are responsible for the tank-farm facilities in which the TFVZ Project performs field measurements and collect sediment samples. Engineering Process Control Group of CH2M HILL Hanford Group, Inc. provides information, such as inventory data, to the TFVZ Project, while other organizations are impacted by the conclusions of the project. Other tank farm organizations provide service functions, such as safety, quality assurance, and procurement. All field activities are planned and implemented following procedures and policies of the corresponding facilities, supported by organizations serving cross-cutting functions (e.g. safety, quality assurance, and procurement).

Assessments of long-term risk require large amounts of data, much of which comes from organizations other than the TFVZ Project. For example, results from the Hanford Tank Waste Operations Simulator (HTWOS, a computer program and database), which is the responsibility of the Process Engineering Group, provides the reference inventories for Hanford's long-term risk assessments.

The results from the TFVZ Project (particularly those contained in assessments of long-term risk) have important impacts on the Tank Farm Closure Operations and other organizations. For example, DOE Order 435.1, *Radioactive Waste Management*, requires that performance assessments set requirements on what waste can be accepted in disposal facilities (including facilities closed as landfills, the present plan for tank farms). Thus, organizations responsible for retrieval, disposal, and closure are impacted by the results from assessments of long-term risk.

2.3.2 U.S. DOE Office of River Protection

CH2M HILL Hanford Group (of which the Tank Farm Vadose Zone Project is a part) is the prime contractor to the DOE Office of River Protection (ORP) for the operation of the Hanford Site Tank Farms. Thus, ORP sets the overall requirements for project activities. In addition, DOE orders (particularly DOE Order 435.1, *Radioactive Waste Management*) provide that the

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field manager of ORP has approval authority over many of the documents produced by the Tank-Farm contractor.

As a participant of the *Hanford Federal Facility Agreement and Consent Order* (HFFACO), or the Tri-Party Agreement, ORP must concur with milestone documents sent to the Washington State Department of Ecology. In addition, ORP is the formal conduit of documents sent to other government entities (e.g., the Nuclear Regulatory Commission) and for interactions with Native American Tribes.

2.3.3 U.S. DOE Richland Operations Office

The DOE Richland Operation Office (RL) is the other field office at the Hanford Site charged with site cleanup. Because of agreements with ORP, RL performs certain functions for the ORP. For example, RL has the lead for legal matters and the Resource, Conservation, and Recovery Act of 1976 permits. The TFVZ Project works with RL, as requested by ORP, in such areas.

2.3.4 Pacific Northwest National Laboratory

Various PNNL organizations are funded directly by the TFVZ Project to perform data collection, scientific investigations, model development, and computer simulations. Such work follows tank farm requirements as specified in procurement documents. In general, the work is reported in PNNL documents and in peer-reviewed journal articles.

PNNL is also funded by Fluor Hanford, Inc. (FHI) to provide support for technical integration and assessment, remediation and closure science, remediation decision support, and groundwater monitoring. PNNL also provides support to FHI for remedial investigation/feasibility studies for the 300 Area uranium plume and support to other operable units under investigation for remediation, which aids the basic understanding of moisture flow and contaminant transport in Hanford's vadose zone.

2.3.5 Fluor Hanford, Inc.

The TFVZ Project is only one of several projects collecting data on the Hanford Site's Central Plateau. As part of the data collection for the TFVZ Project, access to non-tank farm sites is needed, and the project works closely with FHI, which is responsible for soil waste sites adjacent to tank farms and for groundwater remediation. In addition, DOE assigned the responsibility for an integration project involving all Hanford contractors dealing with soil and groundwater investigations and remediation directly to FHI. To ensure coordination of the various field activities, integrated project teams have been formed.

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2.3.6 Washington State Department of Ecology

The U.S. Environmental Protection Agency (EPA) has delegated responsibility for the implementation of most parts of the Resource Conservation and Recovery Act (RCRA) to the Washington State Department of Ecology (Ecology). Ecology also implements the similar hazardous waste laws of Washington State. It often supports the Washington State Department of Health (Health) in implementing air regulations at the Hanford Site and regulations involving radioactive materials.

Ecology is the lead agency for the M-45 series of milestones in the Hanford Federal Facility Agreement and Consent Order (HFFACO). Included in these milestones (specially the M45-50 series) are assessments of long-term impacts from vadose zone contaminants released from SSTs. Ecology reviews the FIRs produced by the TFVZ Project. Milestones M45-55, -58, and -60 give review and approval authority to Ecology for the RCRA Facility Investigation (RFI) Report, the Corrective Measures Study (CMS), and the RFI/CMS Work Plan.

Section 2.5 of Appendix I ("Single-Shell Tank System Waste Retrieval and Closure Process") of HFFACO states that both DOE and Ecology must approve the SST WMA– specific performance assessments. This approach is used to "provide a single source of information that DOE can use to satisfy potentially duplicative functional and/or documentation requirements."

2.3.7 Other Regulatory Agencies

The TFVZ Project also interacts with other regulatory bodies:

- U.S. Environmental Protection Agency
- U.S. Nuclear Regulatory Commission
- Washington State Department of Health.

2.3.7.1 U.S. Environmental Protection Agency. The EPA has regulatory responsibility for cleanup at the Hanford Site. However, according to the HFFACO, the Washington State Department of Ecology has the lead authority for most activities related to of the Hanford Site Tank Farms.

2.3.7.2 U.S. Nuclear Regulatory Commission.

The U.S. Nuclear Regulatory Commission (NRC) functions as a consultant to DOE on various nuclear waste issues. As described in Appendix H ("Single-Shell Tank Waste Retrieval Criteria Procedure") of the HFFACO; DOE and Ecology are to set a tank waste retrieval goal and "notify the NRC as required for compliance with the Nuclear Waste Policy Act." In addition, DOE must "Establish an interface with the NRC, and reach formal agreement on the retrieval and closure actions for single shell tanks with respect to allowable waste residuals in the tank and soil column." As part of this consultation, the NRC is reviewing the *Single-Shell Tank Performance Assessment* (SST PA) (DOE-ORP 2006).

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2.3.7.3 Washington State Department of Health.

The Washington State Department of Health (Health) is responsible for enforcing Federal and State of Washington laws and regulations on protection of air resources. The main interaction of the TFVZ Project with Health is through data collection activities that involve potential impacts on air resources.

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3.0 UPDATE OF FY 1999 DATA AND ANALYSIS GAPS

In Jones et al. (1998), the nineteen (19) identified data and analysis needs were organized into categories:

- Inventory (Sections 3.1 through 3.6)
- Geohydrology (Sections 3.7 through 3.10)
- Geochemistry (Sections 3.11 through 3.12)
- Recharge (Sections 3.13 and 3.14)
- Modeling (Sections 3.15 through 3.19)

For each category, the data or analysis need was described, including the impact of the data on radionuclide migration, the current level of knowledge, the importance ranking, the feasibility of collecting more information (data needs only), the path forward, and limitations of the derived information.

Impact levels were assigned using expert judgment as direct, indirect, low, or unclear. An impact was defined as direct if the data or analytical result quantified a condition or process that strongly influences eventual radionuclide contamination levels in the unconfined aquifer. An impact was defined as intermediate if the data or analytical result would quantify a condition or process that moderately influences eventual radionuclide contamination levels in the unconfined aquifer. An impact was defined as low if the data or analytical result would quantify a condition or process with minimal effect on eventual radionuclide contamination levels in the unconfined aquifer. Finally, an impact was defined as unclear if the effect of the process, condition, or analytical result on radionuclide migration was not known, but may be significant or provide a means to better understand the current and future distribution of radionuclides.

Knowledge levels in Jones et al. (1998) were defined as acceptable, medium, low, and variable. The knowledge level was defined as acceptable if site-specific, quantifiable data were available to provide input into a radionuclide migration model and additional data would only marginally improve understanding. The knowledge level was defined as medium if some site-specific, quantifiable data or relevant literature values were available. Such data could be used in radionuclide migration models and represent reasonably conservative assumptions. Use of these estimates would lead to conservatively high estimates of groundwater contamination. Additional data were expected to clearly improve both quantification of the condition or process and confidence in the values used in a radionuclide migration model. The knowledge level was defined as low if no site-specific information was available and no general literature values could be used with confidence to represent the process or parameter in a radionuclide migration model. If the parameter or process was considered vital to the evaluation of radionuclide migration, additional data collection to develop values was recommended. The knowledge level was defined as variable if some components of the data gap were acceptable, while others were medium and low. An example would be where data exists for one tank farm WMA but not others.

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Considering both the determination of impact and knowledge level, the data or analysis needs were ranked for prioritization of work scope. Not all combinations of impact and knowledge level occurred, so only the following combinations were addressed (See Table 3-1).

- If the impact was defined as direct and the knowledge level low, a ranking of 1A was assigned and the activity was defined as high-priority work scope.

- If the impact was defined as unclear and the knowledge level low, a ranking of 1B was assigned and the activity was also assigned as high-priority work scope.

- If the impact was defined indirect and the knowledge level low, a ranking of 2 was assigned. If additional funding were available after resources are allocated to higher priority items, Jones et al. (1998) recommended that priority 2 items be addressed.

- If the impact was defined as low and the knowledge level acceptable, medium, or low, a ranking of 4 was assigned. A ranking of 4 was also assigned if the impact was defined as direct or intermediate and the knowledge level was defined as acceptable. In any of items ranked as 4, the recommendation was that no additional resources be spent, but these items were included for completeness (Jones et al. 1998).

- If the knowledge level was variable, the ranking was chosen based on the subsets of knowledge and the associated impacts of each subset.

- For other cases, a ranking of 3 was assigned. Jones et al. (1998) recommended that resources be spent on these needs to improve confidence in waste management decisions as necessary.

Table 3-1. Rankings based on Knowledge Level and Impact Level

Impact level	Knowledge level			
	Acceptable	Medium	Low	Variable
Direct	4	3	1A	(a)
Indirect	4	3	2	(a)
Low	4	4	4	(a)
Unclear	4	3	IB	(a)
(a) Ranking was chosen based on the subsets of knowledge and the associated impacts of each subset				

Updated data and analysis needs presented by Jones et al. (1998), including the current (2007) status, are tabulated in Table 3-2. Several of the needs were subdivided in this update. The need "Waste chemistry effects on Radionuclide mobility" was separated into "Waste chemistry effects on uranium(VI) mobility in the vadose zone" and "Waste chemistry effects on radionuclide mobility in the vadose zone (except U(VI))." The need "Recharge effects of processing operations" was separated into "Recharge effects from tank-farm infrastructure (past events)" and "Recharge effects from tank-farm infrastructure (future events)." In the table, the information is the same as that presented by Jones et al. (1998) except that a column was added to document the "revised ranking" based on whether work had been performed to address the gap or the drivers for the gap had changes.

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations
Radionuclide concentrations in vadose zone (known large past releases – Phase I) (Section 3.1)	Data	Indirect	Acceptable (at end of FY07)	Variable	1A	4	Will be revisited as new information becomes available.	
Spectral gamma logging data (SGL) (inventory) (Section 3.2)	Data	Indirect	Acceptable	High	3	4	Closed for past leaks, SGL is part of Retrieval Program	Does not monitor long-lived mobile radionuclides. Data are from vertical point source.
Convert gamma logging data to CoC distributions (inventory) (Section 3.3)	Analysis	Indirect	Acceptable	Low.	2 or 3	4	Complete. May be revisited when SGE results are interpreted.	Need computer simulations that model the complex history of past leaks.

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations
Past leak volumes (Section 3.4)	Data	Direct	Acceptable	Limited	1A	2	Update as necessary. Work with Washington Department of Ecology on values.	
Composition of past leaked tank waste (Section 3.5)	Data	Direct	Acceptable	Limited	1A	4	Update as necessary.	
Correlation of estimated versus measured inventory (Section 3.6)	Analysis	Direct	Medium	High, using SGE	1A	3	Perform SGE measurements and compare to previous estimates.	No direct measurement of Tc-99 inventory.
Geohydrology of vadose zone formations (Section 3.7)	Data	Direct	Acceptable	High	3 or 4	4	Will be revisited as new Hanford Site work is completed.	
Geohydrologic properties of clastic dikes (Section 3.8)	Data	Indirect	Acceptable	Low	3 or 4	4	Closed	

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations
Geohydrologic properties of disturbed local region around poorly cased boreholes (Section 3.9)	Data	Indirect	Medium	Medium	4	3	Historical gamma logging indicates enhanced contaminant transport through unsealed boreholes. Seal if necessary. Impacts occur at a local scale.	
Change in hydraulic properties for contaminated soils (Section 3.10)	Data	Indirect	Acceptable	Medium	1B	4	Collected soils from most highly contaminated vadose zone plumes. Observed no significant changes in mineralogy/structure that would alter hydraulic properties. Will be revisited as new Hanford Site work is completed.	Hydraulic property testing was not performed.
Waste chemistry effects on uranium(VI) mobility in the vadose zone (Section 3.11)	Data and Analysis	Direct	Low	High	Mobile radionuclides 4; sorbed radionuclides 2 or 3	1A	Continue leaching studies for sediments at BX-102, TX-104, and other tank farms (e.g. WMA U) to determine the processes controlling uranium geochemistry at each location with the overall goal to determine a "unifying" conceptual model for	Mechanistic studies can be difficult and costly. Currently assume distribution coefficient (Kd).

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations
							U(VI).	
Waste chemistry effects on radionuclide mobility in the vadose zone (except U(VI)) (Section 3.12)	Data and Analysis	Low for mobile CoCs, medium or low for sorbed CoCs	Acceptable	Variable	Mobile radionuclides 4; sorbed radionuclides 2 or 3	4	Will be revisited as new work is completed. Variable depending on CoC. Knowledge level acceptable for mobile radionuclides and cesium-137. Path forward is to continue mechanistic studies and reactive transport modeling for uranium and other CoCs as required. Include discussion of organics in expanded text.	Mechanistic studies can be difficult and costly. Currently assume distribution coefficient (Kd).
Recharge effects from tank-farm infrastructure (Past events – Recharge effects of processing operations) (Section 3.13)	Data	Unclear	Low	Low	2 to 4	1B	Impacts from past operations have been evaluated; corrective measures have been deployed where appropriate. Will be revisited as additional information becomes available.	Specifics are difficult to quantify from past pipeline leaks, snowmelt, and other events.

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations
Recharge effects from tank-farm infrastructure (Future events - Recharge effects of processing operations) (Section 3.14)	Data	Indirect	Acceptable	Low	2 to 4	4	Interim measures have been incorporated. Umbrella effects have been evaluated. Continue reviewing ongoing work and revisit as additional information becomes available.	
Current distribution of past tank waste discharges (Initial distribution of tank waste to soil) (Section 3.15)	Data and analysis	Unclear	Low to Medium	High	1A or 2	1B	Data from spectral gamma logging and characterization boreholes. Analyses in FIRs show less sensitivity to this issue than previously thought. SGE being applied to locate contamination and develop three-dimensional plume distributions and guide location of additional boreholes or direct pushes.	Limited data on leak volumes, leak rates, waste chemistry, and number of leaks for specific tanks.

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations
Projection of contaminant migration (modeling approach) (Section 3.16)	Analysis	Direct	Acceptable	Use available data	1A	4	Modeling approach will be revisited as new Hanford Site work is completed. Modeling will be used to identify where additional data are needed and provide feedback to data collection activities.	Natural system heterogeneity and database uncertainty.
Temperature distribution in contaminated soils (Section 3.17)	Data	Indirect	Acceptable	High	1B	4	Closed. Data were collected and impacts analyzed in S-SX FIR, which had the greatest thermal impacts.	Historical temperature data are limited.
Thermal effects on radionuclide-soil reactions (Section 3.18)	Data and Analysis	Indirect	Acceptable	Medium	2 to 4	4	Closed. Sampled and analyzed mineralogy of soils in hot zone as part of the S-SX FIR. SX FIR analysis by S&T Project showed no significant impact in future migration.	
Thermal effects on physical transport rates (Section 3.19)	Data and Analysis	Indirect	Acceptable	Medium	2 to 4	4	Closed. Modeling analysis by S&T project documented in S-SX FIR showed that thermal effects do not impact future migration.	

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Table 3-2. Jones et al. (1998) Data Gaps and Needs (7 pages).

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Original Ranking	Revised Ranking	Status and Path Forward	Limitations

Notes:

CoC	=	contaminant of concern
FIR	=	field investigation report
SGE	=	surface geophysical exploration
SGL	=	spectral gamma logging
S&T	=	Science and Technology
WMA	=	waste management area

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3.1 Radionuclide Concentrations in the Vadose Zone

Description: Sediment concentrations of radionuclides from the largest past leaks as a function of spatial location. This was the goal of the Phase 1 characterization performed by the tank farm vadose zone (TFVZ) Project.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data.

Impact: The previous impact in Jones et al. (1998) was identified as direct.

The current impact is defined as indirect. Simulations performed for the field investigation reports (FIRs) (Knepp 2002a, Knepp 2002b, and Myers 2005) show that groundwater impacts are primarily determined by the total inventory of leaked contaminants. The simulations demonstrate that spatial distributions and lateral flow influence arrival times, but have less impact on peak groundwater contaminant concentrations than does the total inventory.

Knowledge Level: The previous knowledge level for this gap was determined to be low. This has been a major focus of the TFVZ Project phase 1 characterization effort, which will be completed in FY 2007.

The knowledge level will be acceptable, following the completion of the TFVZ Project Phase 1 Characterization Project in 2007. The current knowledge level is based on extensive review of historical documents and spectral gamma logging data from all available drywells in all SST farms. This information is supplemented with soil characterization data from a limited number of borehole samples. While there are some limitations, current information is adequate for developing groundwater impact estimates. Considerable information has been summarized in the field investigation reports for each of the tank farms investigated as part of Phase 1.

Feasibility of Collecting Additional Data: Jones et al. (1998) documented the feasibility of collecting additional data to resolve this data gap as high.

The feasibility of collecting data in the future to support Phase II is defined as variable. Surface geophysical exploration can be used to provide measurements of nitrate concentrations from past leaks. From such measurements and known nitrate/technetium ratios for leak fluids, technetium concentrations may be estimated. Non-mobile contaminants can be extrapolated from cesium-137 activity. The likelihood for obtaining an extensive number of sediment samples deep in the vadose zone is low because of limitations on drilling in the SST farms. The likelihood of obtaining sediment samples at shallow depths (less than 100 feet bgs) is much higher because of the newly developed hydraulic hammer direct push technology.

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The previous priority ranking was 1A; currently it is ranked 4 because Phase I is nearly complete.

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Path Forward: The Phase I effort is nearly completed. Information from successive characterization efforts will be used to refine estimates.

Limitations: None.

3.2 SPECTRAL GAMMA LOGGING DATA

Description: The baseline spectral gamma logging data provided extensive data that contributed to the development of the TFVZ Project. However, relogging drywells essentially provides no new information because almost all gamma activity comes from cesium-137, which is generally immobile. Spectral gamma logging of all new wells is expected to continue.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data.

Impact: Jones et al. (1998) identified the impact as intermediate.

Currently, the impact is identified as indirect. Spectral gamma logging provides information on cesium-137 and other radionuclides emitting intense gamma radiation. However, such contaminants are not themselves important for groundwater impact because most are not mobile and don't impact groundwater. The information from monitoring these constituents in the vadose zone can be used to infer information about mobile contaminants and in rare instances to monitor migration of gamma-emitting isotopes into or out of the sediments surrounding the casing interrogated by the technique.

Knowledge Level: The knowledge level at the time of Jones et al. (1998) was identified as medium. Since that time, spectral gamma logging has been performed on drywells inside the tank farms and reported in summary reports for each farm.

The knowledge level is determined to be adequate. Any new wells will be characterized with the spectral gamma-logging technology.

Feasibility of Collecting Additional Data: The feasibility of collecting additional data to resolve this data gap is high. The technique has been documented in procedures and is well understood. The same definition was used in Jones et al. (1998).

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The priority ranking in Jones et al. (1998) was 3, the current ranking is 4.

Path Forward: This effort is effectively completed for existing drywells in the SST tank farms. However, this technology is expected to have wide application in all planned direct-push boreholes. The Tank Waste Retrieval Project is continuing to use this technique to support leak detection monitoring for potential leaks during waste retrieval.

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Limitations: Spectral gamma logging does not monitor contaminants important for groundwater impacts (i.e. mobile, long-lived contaminants).

3.3 CONVERT GAMMA LOGGING DATA INTO CoC DISTRIBUTIONS

Description: The expectation was that the extensive measurements of cesium-137 would lead to a correlation to the spatial distribution of mobile, long-lived contaminants important for groundwater impacts.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Analysis.

Impact: The previous impact was defined as intermediate/low in Jones et al. (1998).

Currently, the impact is defined as indirect. In limited cases where there was adequate data density, spectral gamma logging data have been used to project total cesium-137 activities and extrapolated to provide comprehensive inventory data. However, there generally isn't sufficient density of characterization data to support this type of analysis.

Knowledge Level: Previously, this data gap was defined as low-knowledge level.

Currently, the knowledge level is defined as acceptable because available data have been evaluated. Sediment sampling in Phase I has repeatedly shown that there is some correlation between the spatial distribution of cesium-137 (which becomes immobile) and the distribution of mobile contaminants.

Feasibility of Collecting Additional Data: Jones et al. (1998) recommended using available data. Data collected in Phase I have shown that there is a weak correlation between cesium-137 and mobile contaminants, so the feasibility and value of collecting additional data are low.

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The previous priority ranking in Jones et al. (1998) was defined as 2 or 3. Subsequent data collection and analysis in Phase I have reduced the priority ranking to 4.

Path Forward: Complete. May be revisited when new information, such as SGE results, becomes available.

Limitations: There are only limited sets of data that include both mobile radionuclides and cesium-137 activities.

3.4 PAST LEAK VOLUMES

Description: Single-shell tank (SST) leak volumes are important because they provide direct input for developing tank leak inventories and it has been shown that risk calculated in performance assessments is proportional to inventory. Leaks from a number of SSTs, approximately two dozen, are well documented (e.g., the T-106 leak in 1973). There are a number of other tanks that are labeled as "assumed leakers".

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data/Analysis.

Impact: The impact defined by Jones et al. (1998) and currently is direct. Past tank leak volumes as well as the compositions of the leaked waste directly impact contaminant inventories that reside in the vadose zone.

Knowledge Level: The previous knowledge level was defined in Jones et al. (1998) as medium/low. The historical records have been critically reviewed and central tendency volume estimates were summarized in Field and Jones 2005. However, because of inconsistent data large uncertainties remain for some tanks (e.g., A-105, C-101, and U-101).

Feasibility of Collecting Additional Data: Jones et al. (1998) recommended use of available data, because the feasibility of collecting new data beyond what already exists is limited. The leaks occurred in the past, usually over 40 years ago. New techniques such as SGE coupled with analyses of sediment samples obtained with direct push technologies may provide new information that can be used to improve leak volume estimates.

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The previous priority ranking defined in Jones et al. (1998) was 1A. Work done in Phase I and documented in Field and Jones (2005), has reduced the current priority. However, given the remaining uncertainties and ongoing assessments, the current priority is given as 2.

Path Forward: At the request of Ecology, estimates in Field and Jones (2005) are being reassessed beginning with the C Tank Farm. Estimates will also be reassessed as additional data are obtained. Work with the Washington State Department of Ecology on methodology to estimate leak volumes.

Limitations: None.

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3.5 COMPOSITION OF PAST LEAKED TANK WASTE

Description: A number of the SSTs are documented to have leaked. The compositions of fluids lost during the tank leak events are variable because of the complex chemical processing of irradiated nuclear fuels used at the Hanford Site and the complex waste transfer operations over the operating lifetimes of the tanks.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data.

Impact: The previous impact defined in Jones et al. (1998) and currently is direct. Simulations documented in the tank farm FIRs and the initial SST PA show that the size, position, and composition of past leaks will be the most significant source of groundwater impacts in the future.

Knowledge Level: The previous knowledge level defined in Jones et al. (1998) was medium/low. Currently, the knowledge level is defined as acceptable. For the largest leaks, operational records have been reviewed to determine waste compositions. In some cases (e.g. bismuth phosphate processing), laboratory recreations of the processing have been performed to test assumptions (Serne et al. 2007). The highest uncertainties are associated with small leak volumes, but large uncertainties on small volumes have little impact on the overall inventory estimates. Recent leak composition estimates are documented in Corbin et al. (2005).

Feasibility of Collecting Additional Data: Jones et al. (1998) recommended using available data. The feasibility of collecting additional data is limited because the leaks occurred in the past, usually over 40 years ago. If additional field data become available or new historical records are found, the current information will be reassessed.

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The previous priority ranking in Jones et al. (1998) was defined as 1A. Based on the Phase I work documented by Corbin et al. (2005), the priority ranking is currently 4.

Path Forward: Update as new information is identified.

Limitations: None.

3.6 CORRELATION OF ESTIMATED VERSUS MEASURED INVENTORY

Description: Inventories for past leaked events are estimated by using the estimated leak volume and the expected composition of the leaking fluid (based on operating records).

Origin: Existing data gap from Jones et al. (1998).

Information Type: Analysis.

Impact: The impact previously defined in Jones et al. (1998) and currently is direct. Inventories of past leaks directly affect estimates of groundwater impacts.

Knowledge Level: The previous knowledge level in Jones et al. (1998) was defined as medium to low; currently, it is defined as medium. For the largest leak events, these estimates of inventory have compared well with cesium-137 measurements (where available in sufficient detail) and relative proportions of measured mobile contaminants (technetium-99 and nitrate) in collected vadose zone soils contaminated by a given leak event.

Feasibility of Collecting Additional Data: Previously, Jones et al. (1998) recommended using available data. However, because of recent advances with surface geophysical exploration (SGE), the feasibility of collecting data has increased. Current efforts are directed towards quantification of nitrate past release inventory derived from SGE data. If successful, this technique may provide more quantitative estimates of plume volumes. Such information can be correlated with independently developed leak inventory estimates.

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The previous priority ranking defined in Jones et al. (1998) was 1A. This was a major area of emphasis for Phase I; however the priority ranking has been reduced to 3.

Path Forward: Work is underway to develop the methodology and tools to be able to use SGE to estimate nitrate inventories and compare to estimates based on leak volume and nitrate composition in the leaked fluid.

Limitations: No direct measurement of leaked technetium-99 inventory.

3.7 GEOHYDROLOGY OF VADOSE ZONE FORMATIONS

Description: The geology of the sediments determine the hydraulic properties used in the risk assessment. Underlying the Hanford tank farms are sandy, gravelly, and consolidated layers, with thin silty layers also present.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data.

Impact: The previous impact defined in Jones et al. (1998) was direct and intermediate. Because of extensive vadose zone characterization and field experiments, the impact of vadose zone geohydrology is recognized to be direct. Lithostratigraphy for various geologic units and their hydraulic characteristics are controlling factors in flow and contaminant migration.

Knowledge level: Jones et al. (1998) defined the knowledge level as known/medium.

Based on extensive vadose zone characterization data obtained as part of borehole drilling in S-SX (Knepp 2002a), B-BX (Knepp 2002b), and T-TX-TY (Myers 2005) tank farms conducted over the past 5 years and documented in the Field Investigation Reports (Knepp 2002a, Knepp

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2002b, and Myers 2005), the overall geology and stratigraphic controls in 200 East and West Areas are well known; the knowledge level is now defined as acceptable.

Feasibility of Collecting Additional Data: The feasibility of collecting additional data as part of RCRA borehole drilling in the vicinity of tank farms to resolve this data gap is high.

Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: The previous priority ranking was defined by Jones et al. (1998) as 3 or 4. Currently, the priority ranking is defined as 4.

Path forward: While the available geologic information is adequate in characterizing the large-scale stratigraphy in the 200 Areas, much less information is known on small-scale features (paleosols and fine-textured features). The fine-textured lenses embedded in an otherwise coarse Hanford formation can enhance lateral migration of contaminants while slowing down the vertical movement.

Limitations: Borehole drilling operations generally miss the fine-scale paleosols. However, neutron moisture logs have been shown to be useful indicators of small-scale stratigraphy (Ward et al. 2006) at the Sisson and Lu site and transferred to the BC cribs and trenches in the 200 East Area (*Vadose Zone Contaminant Fate-and-Transport Analysis for the 216-B-26 Trench*, Ward et al. 2005). Fine-textured sediments generate higher neutron counts (and higher moisture content), while coarse-textured sediments generate lower neutron counts (and lower moisture content). Therefore, rather than depending only on geologic logs as the primary source of information, neutron counts, whenever available, can be used as a surrogate to characterize fine-scale features.

3.8 GEOHYDROLOGIC PROPERTIES OF CLASTIC DIKES

Description: Clastic dikes are linear features that are included in some conceptual models as preferential pathways for contaminants. Commonly distinguishing attributes are different sediment mineralogy and particle size distributions. If the clastic dike materials differ from surrounding soils, a preferential pathway is plausible.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data.

Impact: Jones et al. (1998) defined the impact as intermediate/low. Based on work conducted during Phase I and through field experiments by the Integration Project science and technology activity as well as the Environmental Management Science Program (EMSP), the impact is now defined as indirect. The presence of clastic dikes in unsaturated media appears unlikely to contribute much to the transport of the bulk quantity of leaked wastes and to long-term risk relative to higher peak concentrations for long-lived mobile radionuclides in groundwater (Knepp 2002a and Murray et al. 2003).

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Knowledge level: The previous knowledge level was defined by Jones et al. (1998) as low. Currently, knowledge level is defined as acceptable. The FIR modeling (Knepp 2002a), analyzing the impact of clastic dikes on contaminant breakthrough curves in groundwater, were unavailable during preparation of Jones et al. (1998). As reported in Knepp (2002a), compared to simulations that considered no dikes, results of clastic dike simulations suggest a minimal impact. These simulation results are used as a basis for a change in the definition of knowledge level from low to acceptable. In general, clastic-dike sediments represent properties of fine sediments such as fine sand, silt, and clay. Thus, the hydraulic properties of clastic dikes can be considered essentially as a subset of the porous matrix properties for the Hanford sediments, based on laboratory measurements of clastic dike samples. As a result, in many cases, the clastic dikes may actually act as a barrier to flow rather than as fast flow channels under unsaturated flow conditions. This is suggested by some recent results from an EMSP investigation (Murray et al. 2003) for dikes that are primarily filled with fine-grained material. The Remediation and Closure Science Project performed infiltration experiments at the same site on Army Loop Road that was investigated by the EMSP project (Ward et al. 2006). Ward et al reached the same conclusion, although they found the flow through the dike depended on the overall flux and corresponding moisture contents.

Feasibility of Collecting Additional Data: The feasibility of collecting additional data to resolve this data gap is low.

Document Support: PA/closure plan, CMS, Work Plan.

Original Priority Ranking: 3 or 4.

Priority Ranking: The previous priority ranking defined by Jones et al. (1998) was 3 or 4; currently, it is defined as 4.

Path forward: This data gap is considered closed. Since Jones et al. (1998), an EMSP project evaluating the topic has been completed (Murray et al. 2003).

Limitations: Clastic dike properties vary across the Hanford Site. A number of reports have been published on hydraulic properties for clastic dike sediments and experiments that have been conducted, but they sample only a fraction of the clastic dikes thought to exist at the Hanford Site.

3.9 GEOHYDROLOGIC PROPERTIES OF DISTURBED LOCAL REGIONS AROUND POORLY CASED BOREHOLES

Description: Contaminant transport is usually modeled assuming that transport properties are uniform over discrete portions of a region. The presence of poorly cased (sealed) boreholes could provide a faster pathway for contaminants and has been documented at the Hanford Site (e.g., at the 216-U-1 and U-2 crib documented in *U1/U2 Uranium Plume Characterization, Remedial Action Review and Recommendation for Future Action* (Baker et al. 1988)).

Origin: Existing data gap from Jones et al (1998).

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Information Type: Data.

Impact: Jones et al. (1998) previously defined the impact as intermediate/low. Currently, the impact is defined as indirect. Analyses performed for Phase I have shown that this preferential pathway has relatively small impact. Few tank-farm boreholes extend all the way to groundwater. In addition, poorly cased boreholes present a small fraction of the available area. However, in some cases (e.g., a borehole near tank B-101), there is evidence of the borehole being a conduit. Gamma radiation logging of all boreholes in the SST farms shows that this is a rare occurrence.

Knowledge Level: The previous knowledge level documented in Jones et al. (1998) was low/medium. Current knowledge level is defined as medium.

Feasibility of Collecting Additional Data: Jones et al. (1998) defined the feasibility of collecting additional data to resolve this gap as low. Currently, it is defined as medium. It would be difficult to perform field experiments in tank farms, although a field experiment could be performed outside the farms.

Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: Jones et al. (1998) defined the priority ranking for this gap as 1A. Currently, the priority ranking is 3 because the impact is considered to be low.

Path Forward: Decommission or seal boreholes as necessary.

3.10 CHANGE IN HYDRAULIC PROPERTIES FOR CONTAMINATED SOILS

Description: Some tank waste had pH values above 14. There is a concern that the leakage of such waste could create such extreme chemical environments that sediment properties would change.

Origin: Existing data gap from Jones et al. (1998).

Information Type: Data.

Impact: The previous impact defined by Jones et al. (1998) for this data gap was unclear, but potentially high. Currently, the impact is defined as indirect. For large-scale vadose zone flow and transport modeling documented in the FIRs and the initial SST PA over long time frames, lithostratigraphy for various geologic units and their hydraulic characteristics are the primary controlling factors in flow and contaminant migration. Any potential changes in hydraulic properties at a local scale play a secondary role.

Knowledge Level: The knowledge level previously was defined in Jones et al. (1998) as low. Currently, it is defined as acceptable. Since publication of Jones et al. (1998), sediment samples taken just below tank SX-108 (with the slant hole sampling) show minimal changes with respect to sediments' physical, hydrologic, and mineralogical properties. The SX-108 tank leak was expected to cause some of the more extreme changes in sediment properties. However, effects

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of tank waste chemistry (high pH) for SX-108 were localized to a small region. These results, which were not available during preparation of Jones et al. (1998), are used as a basis for the change in the definition of knowledge level from low to acceptable. Also as discussed above, any potential impact due to change in hydraulic properties is expected to be small for long-term, large-scale vadose zone flow and transport models.

Feasibility of Collecting Additional Data: The feasibility of collecting existing data to resolve this gap was previously defined by Jones et al. (1998) as high. Currently, it is medium because some of the site characterization work for high impact tank leak sites such as T-106 and SX-108 sites is complete. Samples may be recovered as part of the remediation of the large pipeline leak in C tank farm as part of Phase 2 efforts.

Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: 4.

Path forward: Sediment samples have been collected from the most highly contaminated vadose zone plumes (i.e., SX tank farm). Analysis of the samples detected no significant changes in mineralogy/structure that would alter hydraulic properties. This issue will be revisited as Phase II work is planned, particularly when samples from characterization of the C pipeline leak are recovered.

Limitations: Because of their high radioactivity, hydraulic property testing was not performed on the SX tank farm sediments.

3.11 WASTE CHEMISTRY EFFECTS ON URANIUM(VI) MOBILITY IN THE VADOSE ZONE

Description: Tank wastes have highly varied and extreme composition (far from equilibrium with natural subsurface conditions), such as high pH, that influence subsurface uranium(VI) migration by promoting chemical reactions with the native subsurface sediments. All tank wastes had large amounts of sodium and nitrate, and most had large amounts of phosphate, sulfate and carbonate. The leakage of these wastes created chemical and mineralogical changes in the sediments beneath the leaking tanks affecting contaminant mobility. For uranium(VI) the presence of dissolved inorganic carbon (carbonate and bicarbonate), phosphate, and pH had large effects on uranium(VI) migration through formation of strong, anionic aqueous complexes with uranium(VI) that influenced adsorption, solubility, and mineral precipitation. Among the aqueous complexes, those with carbonate: $UO_2(CO_3)_2^{2-}$, $UO_2(CO_3)_3^{4-}$, and $CaUO_2(CO_3)_2^0$ are the most prevalent in Hanford pore waters.

Origin: Existing data gap from Jones et al. (1998). The original data gap was split into this one for uranium and a second gap for other contaminants (Section 3.12).

Information Type: Data and analysis.

Impact: Previously, the impact was defined by Jones et al. (1998) as medium or low for sorbed radionuclides. Currently, it is defined as direct for uranium(VI) in the Hanford vadose zone.

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Waste chemistry has significantly impacted the subsurface mobility of dissolved uranium(VI) [uranyl; UO_2^{2+}]. While laboratory and field studies indicate that uranium interactions with vadose zone sediments are sensitive to the chemistry and temperature of the released waste fluids, a generalized understanding of these interactions that could allow defensible predictions of future mobility does not exist. For example, the fate of the uranium that entered the vadose zone from the BX-102 overfill appears especially enigmatic. Uranium appears to have migrated laterally distances of 25 m (~80 ft) and to depths 30 m (~100 feet) below the tank bottom quickly during the overfill event itself. But subsequent to the overfill event, a significant amount of the uranium has precipitated as sodium uranyl silicates within deep fractures in mineral grains, thus limiting the amount of uranium available for transport (see Appendix D of Knepp 2002b; Liu et al. 2004b, Catalano et al. 2006, and McKinley et al. 2006). At borehole C3832 near tank TX-104, uranium appears to be quite mobile in the vadose zone within the Hanford formation; but, upon reaching the Cold Creek lower subunit that is enriched with caliche, a moderately strong binding of uranium(VI) is found. More details are found in Appendix D of Myers (2005). Solid-phase characterization of uranium(VI)-rich sediments from the vadose zone near the BX-102 overfill and the TX-104 leak suggests that the geochemical reactions responsible for uranium retardation are strikingly different between these two sites. These differences are tentatively attributed to differences in waste chemistry, but additional research is needed to establish clear cause-effect relationships. Ongoing research on uranium(VI) mobility in 300 Area vadose zone and aquifer sediments (not tank related) has also demonstrated that waste composition can have long-term effects on uranium(VI) mobility by influencing the chemical nature and physical location of sorbed uranium [e.g., see "Kinetic desorption and sorption of U(VI) during reactive transport in a contaminated Hanford sediment," Qafoku et al. (2005), "Fluorescence spectroscopy of U(VI)-silicates and U(VI)-contaminated Hanford sediments," Wang et al. (2005), and "Changes in uranium speciation through a depth sequence of contaminated Hanford sediments," (Catalano et al. 2006)]. More work is needed to understand the interrelationships between waste stream chemistry and sediment mineralogy on the mobility of uranium at the Hanford Site.

Knowledge Level: Jones et al. (1998) defined the knowledge level as known/medium. Studies of uranium(VI) in the vadose zone at several tank farms and at soil waste sites have indicated that U(VI) adsorption/precipitation properties vary significantly between locations. Therefore, although extensive work has been done, our knowledge level on predicting the future mobility of uranium at any given site remains low. Understanding of the mobility and long-term migration potential of uranium(VI) released from tanks and tank infrastructures is lacking for uranium.

An especially important technical need is to understand how the tank waste chemical composition may impact the mobility of in-ground uranium(VI) in the vadose zone. As discussed in Appendix D of Knepp (2002a), how the uranium has changed from being highly mobile to rather immobile in the vadose zone proximate to tank BX-102 and where the groundwater uranium plume east of the BX tank farm has its source is uncertain.

Feasibility of Collecting Additional Data: The feasibility of collecting additional data for all radionuclides was defined by Jones et al. (1998) as variable. For uranium, it is currently defined as high. Studies are underway to determine the long-term release and mobility of uranium presently sequestered in the vadose zone.

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Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: Jones et al. (1998) defined the priority ranking for sorbed radionuclides as 2 or 3. However, because of the issues around uranium mobility and its long-term fate and transport, the ranking for uranium(VI) is currently defined as 1A.

Path Forward: Iterative "tiered" characterization will be performed on each new borehole in the tank farms. If new contaminants are discovered that were not present in past boreholes, or if the concentration of contaminants are larger than at other boreholes, or if the distribution of any contaminant versus depth appears to be different from past distributions that we understand, then specific attention will be given to improving our understanding of the geochemical attributes of the contaminant. Water, acid, or other reagents will be used to leach contaminants from sediments, as an initial assessment of their speciation and mobility. The characterization information will then be compared to the existing knowledge base to see if the results are consistent with current conceptual models of geochemical reaction and retardation. State-of-the-art spectroscopic and microscopic instrumentation such as microbeam-X-ray fluorescence, diffraction, and X-ray absorption spectroscopy will be used to identify the solid surfaces and crystalline structures with which uranium is associated. More involved experimentation to identify how mineral association controls uranium desorption and dissolution kinetics will continue as a part of the Vadose Zone Characterization Project, EMSP, and science and technology projects. Efforts of this type will continue at BX-102, TX-104, and in the 300 Area and any new location where significant concentrations of uranium are encountered until we determine what processes are controlling uranium geochemistry at each location with the overall goal to determine a "unifying" conceptual model for uranium(VI) fate at Hanford.

Limitations: Mechanistic studies can be difficult and costly. A concerted effort over the past three to four years has been undertaken to identify geochemical reactions controlling dissolved uranium(VI) concentrations in contact with Hanford sediments and to identify the nature and behavior of uranium in contaminated sediments using state-of-the-art instrumental and experimental methods. Results to date have shown that a different reaction series has apparently occurred between uranium and the native sediments at each site, giving rise to sorption complexes of different chemical composition, and thermodynamic and kinetic behavior. Studies continue in hopes of determining some commonalities and basic understanding of the controlling mechanisms. Currently the distribution coefficient (K_d) constructs are assumed to be adequate for determining long-term risks, but for uranium(VI), K_d can vary over a large range depending on waste stream composition and sediment type.

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3.12 WASTE CHEMISTRY EFFECTS ON RADIONUCLIDE MOBILITY IN THE VADOSE ZONE OTHER THAN URANIUM(VI)

Description: Some tank waste had very high pH values. All tank wastes had large amounts of sodium and nitrate, as well as other co-contaminants that could influence radionuclide and contaminant mobility. The leakage of such waste will create changes in the natural sediments beneath the leaking tanks affecting the mobility of contaminants.

Origin: Existing data gap from Jones et al. (1998). The original data gap was split, one for uranium (Section 3.11) and a data gap for other contaminants (this section). Uranium mobility is discussed in Section 3.11.

Information Type: Data and analysis.

Impact: Jones et al. (1998) defined the impact of this gap as low for mobile radionuclides, and medium or low for sorbed radionuclides.

For mobile contaminants such as pertechnetate [$^{99}TcO_4^-$], and nitrate [NO_3^-], the chemical composition of the fluids, which leaked from tanks or were spilled during tank overfilling and transfer line leaks, does not appear to influence the subsequent interactions of the dissolved contaminants with sediments. Based on in-situ K_d measurements calculated from the ratio of water-leachable concentrations to strong acid-leachable concentrations at each of the contaminated boreholes studied there does not appear to be any sensitivity to the chemical composition of the leaked fluids (see FIRs [Knepp 2002a and 2002b] and borehole reports [Serne et al. 2002a,b,c,d,f,g, and 2004a,b]). For most of the slightly interacting contaminants such as chromium(VI) (chromate; CrO_4^{2-}), and cobalt-60, the chemical composition of the waste fluids do have minor effects on the subsequent interactions of these species with the vadose zone sediments. For example, highly caustic fluids from the SX tank farm were capable of dissolving some of the native iron-bearing minerals, which released ferrous ions to solution that were capable of reducing some of the chromium(VI) and allowing it to bind as chromium(III) species to oxidized ferric hydrous oxides that were originally present in the sediments or newly formed ferric hydrous oxides from the oxidation of the dissolved ferrous iron (see Appendix D of Knepp 2002a, Qafoku et al. 2003, and Zachara et al. 2003). This unique geochemical process was found to retard the movement of a portion of the released chromium(VI) over a linear distance of a few tens of meters from the tank bottom. However, from an overall risk standpoint, the partial chromium(VI) retardation was small and most of the chromium(VI) moved deeper into the vadose zone, farther than the pH front. There is a possibility that the heterogeneous reduction of $^{99}TcO_4^-$ to insoluble technetium(IV) could occur in microscopic regions of the unconfined aquifer where low concentrations of iron$^{2+}_{(aq)}$ are generated by dissolution of ferrous-iron containing minerals such as chlorite and basaltic glass (Fredrickson et al. 2004 and Zachara et al. 2007). This reduction would decrease technetium-99 mobility and complicate technetium migration predictions in groundwater.

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The interaction of cesium-137 with vadose zone sediments is also sensitive to the total concentration of cesium (stable and radioactive isotopes) and the total concentration and distribution of competing cations (especially sodium). At the SX tank farm the extremely high concentration and high temperature of the liquid that leaked [16 M and self-boiling] and high total cesium [millimolar] allowed cesium-137 to migrate 14 to 18 m (46 to 59 ft) below the tank bottoms where dilution of tank liquors with native pore waters changed the composition such that adsorption reactions again became adequate to retard the cesium-137. Subsequent percolation of recharge water has also removed more of the sodium and other competing cations such that the cesium-137 desorption process becomes less favored with time and the current distribution of cesium-137 below the SX tank farm is quite immobile (see Zachara et al. 2002; Steefel et al. 2003; McKinley et al. 2001 and 2004; Liu et al. 2003a,b and 2004b; Flury et al. 2002; Chen et al. 2005; Zhao et al. 2004; and Appendix B of Knepp 2002a).

At the T tank farm some mobile cobalt-60 exists within the Hanford formation H2 and Cold Creek Formation upper and lower subunits and yields an in-situ K_d value of 0.06 to 0.3 mL/g. The divalent cobalt^{2+} ion should be strongly adsorbed and immobile in Hanford sediment. The cause of the low K_d for the cobalt has not been identified, but complexation with some organic (e.g., EDTA) ligand may yield an overall net negative charge on the complex may be the reason (Zachara et al. 1995a,b).

Knowledge Level: The knowledge level was defined by Jones et al. (1998) as known or medium. Currently, it is defined as acceptable for contaminants of concern (CoCs) such as technetium-99, nitrate, cesium-137, strontium-90, actinides, cobalt-60, and lanthanide fission products. Detectable concentrations of iodine-129 have not been found in most of the sediments and pore waters obtained to date. However, in the few instances where very low concentrations of iodine-129 could be measured, it appears to be mobile as would be predicted for the anionic iodide species.

The effects of tank fluid chemical composition on the subsequent geochemical interactions of contaminants with vadose zone sediments has been characterized where measurements have been performed (see Section 3.11). The chemical composition of the tank fluids (both its high ionic strength and caustic nature) have been investigated in recent years using a combination of Hanford and EMSP funding.

The high ionic strength of leaked tank waste impacted the adsorption of cationic contaminants through competition reactions that have/are becoming better understood through research. The effects of high base in the tank waste have been studied extensively in the laboratory and have been found to cause the formation of highly adsorbing/sequestering secondary minerals of zeolitic- or clay-like nature. These secondary minerals originated from dissolution of the Hanford sediments' primary minerals such as quartz, feldspars and basaltic glassy phases, and fine-grained detrital phases including smectite and chlorite. These secondary minerals had higher sorption tendencies for contaminants than the primary minerals and thus improved the retardation capabilities of the vadose zone sediments as suggested by work by Um et al. (2005), and Chorover et al. (2004). Current understanding is that the alteration zone formed by the caustic fluid interactions with the vadose zone sediments was limited (at most tens of meters) around the tank bottoms of leaks studied to date. In fact, identification of measurable amounts of the zeolitic secondary products in the field has been quite elusive (the section of Appendix D in

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S-SX FIR Knepp 2002a by McKinley et al), and some studies indicate that the products of high base reaction may not have a significant effect on contaminant retardation (Liu et al. 2003b; Ainsworth et al. 2005). It is known that some of secondary minerals observed to form as products of high base reaction are not thermodynamically stable in the near neutral pH environments more representative of natural Hanford conditions. Thus the enhanced sorptive qualities of the secondary minerals may be transient and not significant over the long-time periods of interest to tank closure risk analyses.

Feasibility of Collecting Additional Data: Both Jones et al (1998) and the current feasibility of collecting additional data to resolve this gap are variable.

Most chemical compositions of tank waste at the time of leaks or overfills have been estimated from spent fuel reprocessing process knowledge as opposed to actual measurements at the time of the fluid escape. Pore fluids from the vadose zone have been characterized to define the end-state chemical composition resulting from waste-sediment interaction and subsequent mixing with recharge waters. These measured pore-water compositions have allowed the formulation of qualitative conceptual geochemical models of the reaction paths involved in waste-sediment reaction that have not been experimentally investigated or verified. All the available field measurements are after 30 to 50 years of tank leak fluid interaction with the vadose zone environment. The closest sediment samples have been obtained 5 ft from the tank bottom and more commonly 10 to 15 ft from the sides of the tanks. The highly caustic fluid pH values that are estimated to have been present in the tanks have not been found in the vadose zone. Thus the zone of interaction where the pH exceeds 10 is either short (≤ 5 feet) or transient (<30 years).

Contaminated sediments from future boreholes can be collected and characterized to determine if the distribution of contaminants in the sediments is as would be predicted based on current knowledge.

Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: Both the previous (Jones et al. 1998) and current priority ranking is 4 for the CoCs that have been observed to date in contaminated vadose zone sediments.

Path Forward: With each borehole, the standard iterative "tiered" characterization will be performed. If new contaminants are discovered that were not present in past boreholes, or if the concentrations of any contaminant are larger than at other boreholes, or if the distribution of any contaminant versus depth appears to be different from the past distributions that we understand, then specific attention will be given to improving understanding of the geochemical attributes of the contaminant. Using water, acid or other reagents to leach the contaminants from the sediments, the speciation and mobility of contaminants will be studied. The characterization information can then be compared to the existing geochemical knowledge base to see if the results fit the current knowledge base or not. State-of-the-art solid phase instrumentation such as microbeam-X-ray fluorescence, X-ray diffraction and X-ray absorption spectroscopy will also be used to directly measure the association of contaminants with the other common sediment-bearing elements, actual contaminant mineralogy, and contaminant valence state and nearest neighbor crystalline structures. More involved experimentation to identify how mineral

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association controls key contaminant desorption and dissolution kinetics will continue as a part of the Vadose Zone Characterization Project, EMSP, and Remediation and Closure Science projects. Efforts of this type will continue at past SST sites and any new location where significant concentrations of key contaminants are encountered until we determine what processes are controlling each contaminant's geochemistry at each location with the overall goal to determine a "unifying" conceptual model for each key contaminant's fate at Hanford.

As stated, the knowledge level is sufficient for mobile radionuclides such as technetium-99, chromium(VI), nitrate, and immobile cesium-137 to allow defensible, long-term predictions of future transport. Less information is available for iodine-129 and strontium-90, while virtually no information is available from other contaminants such as europium. The path forward will be to initiate mechanistic studies and reactive transport modeling for newly identified CoCs that have not been studied in detail, or that show atypical distributions versus depth, or atypical water versus acid extract data.

Limitations: Mechanistic studies can be difficult and costly. Currently the distribution coefficient (K_d) constructs are assumed to be adequate for determining long-term risks. It is well known, however, that the K_d for constituents such as strontium-90 and others may change markedly with waste and pore water concentration, and with sediment texture and mineralogy, and that there may be ranges where the K_d models do not apply. Furthermore, K_d may vary significantly with contaminant concentration, all other factors being equal. The K_d construct may also be inappropriate if precipitation/dissolution reactions or kinetic processes are involved. Thus, it is important to determine if the K_d approach can be applied and the appropriate ranges of K_d values to be used in risk assessments to represent the waste regimes and sediments being modeled.

3.13 RECHARGE EFFECTS FROM TANK-FARM INFRASTRUCTURE (PAST EVENTS)

Description: Tank farm infrastructure can affect the amount of moisture that enters the sediments. Recharge effects from tank farm operations arise from multiple aspects of those operations:

- Water/transfer line leaks
- Surface conditions (for example, gravel surfaces)
- Underground structures near the surface that could trap water
- Thermal effects from the tank waste
- Water run-on from non-farm sources
- Lateral subsurface flow from non-farm sources
- Above ground structures (e.g., roofs and foundations) that concentrate moisture

Effects from the tank farm surface (either gravels or a final surface barrier) are treated in other data gaps and needs. This data gap addresses the remaining effects.

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Origin: Existing data gap from Jones et al. (1998). Data gap has been split into past events (this gap) and future events (Section 3.14).

Information Type: Data.

Impact: Jones et al. (1998) defined the impact as direct to low. Currently, the impact is defined as unclear. Moisture can be added into the system from leaks from water lines, transfer lines, spills, or tank leaks. The amount of water introduced by the last three are thought to be rather small (usually less 10,000 gallons) and have small effects in the risk assessments as shown in FIRs Knepp (2002a and 2002b) and tank closure risk assessments Mann and Connelly (2003) and Connelly (2004). However, large amounts of water (>100,000 gallons) over a long period of time (years) have leaked from water lines (e.g., the water line south of the SX tank farm). Such moisture drivers play a major part in contaminants reaching groundwater (Knepp 2002a). During 2001 to 2003, all unneeded water lines were capped off and all needed waterlines were hydraulically tested.

The effect of large underground structures (e.g., the tanks) in diverting moisture flow in the subsurface has been evaluated and incorporated into performance assessment models. However, such structures can also be moisture traps, leading to higher moisture contents above the tanks. Such higher moisture content could lead to higher than normal evaporation rates.

The heat generated by the decay of radioactive waste warms the soil. Temperature measurements in boreholes near the tanks currently show temperatures as high as 140 °F, whereas the soil a few feet below the ground is normally about 55 °F. These higher temperatures will increase evaporation and hence decrease the rate estimated for recharge.

Above ground structures (such as the 242 S evaporator, huts over lateral access ports) are located inside or just adjacent to tank farms. The roofs of these structures will likely shed precipitation in such a way that it concentrates the water in small areas, such as a roof drip line. The result will be a net increase in the overall recharge rate.

The tank farms were construction at elevations lower than the processing plants to facilitate liquid transfer from the plants to the tank farms. Surface water (flows from rain storms or snow melting) occurred as overland flow and collected (sometimes as ponds) at the tank farms. During 2001 to 2003, berms and gutters were installed in and around tank farms to eliminate this condition.

Cribs (structures receiving large volumes of liquid discharges) are located near most tank farms. Measurements at the BC cribs have shown that moisture can move laterally long distances (several hundred feet) away from the vertical line of discharge.

Knowledge level: Both the knowledge level defined by Jones et al. (1998) and current knowledge levels are low. Knowledge of the impacts of current and future recharge is acceptable as the sources (waterline leaks and run-on) are controlled, if not eliminated. Also the effects of most past waste leaks are either small or explicitly included in the risk analyses. However, knowledge of past waterline leaks, run-on events, and possible flow from near-by cribs is poor or unknown at present.

Feasibility of Collecting Additional Data: Jones et al (1998) defined the feasibility of collecting additional data to resolve this gap as variable. Currently, it is defined as low. There is no indication that records were kept that provide quantitative estimates of past waterline leaks or run-on events.

Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: Jones et al. (1998) defined the priority ranking as 2 to 4. Performance assessment analyses and tank farm characterization have determined that this is an important driver for contamination in the vadose zone and the priority ranking has been raised to 1B.

Path Forward: Continue opportunistic review of literature (including photos) of past events. Monitor integrity of pipelines that are not capped and the performance of berms and gutters installed to control surface-water run-on.

Limitations: Past recharge events (storms or water line leaks) are poorly documented or quantified. Indirect inferences must be used.

3.14 RECHARGE EFFECTS FROM TANK-FARM INFRASTRUCTURE (FUTURE EFFECTS)

Description: Tank farm infrastructure can increase the amount of moisture that enters the vadose zone. For future events, the primary impacts are expected to be:

- underground structures near the surface that can trap water
- thermal effects from the tank waste
- above ground structures (for example, roofs, foundations) that concentrate moisture

Origin: Existing data gap from Jones et al. (1998). The current data gap has been split into past events (Section 3.13) and future events (this data gap).

Information Type: Data.

Impact: Jones et al. (1998) defined the impact as direct to low. Currently it is defined as indirect. The effect of large underground structures (e.g., the tanks) in diverting moisture flow in the subsurface is well understood and is readily incorporated into simulation models. However, such structures can also be moisture traps, leading to higher moisture contents above the tanks. Such higher moisture content could lead to higher than normal evaporation rates.

The heat generated by the decay of radioactive waste warms the soil. Temperature measurements in boreholes near the tanks currently show temperatures as high as 140 °F, whereas the soil a few feet below the ground is normally about 55 °F. These higher temperatures will increase evaporation and hence decrease the rate estimated for recharge. However, detailed modeling in the S-SX FIR (Knepp 2002a) determined that such effects are small for future transport.

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Above ground structures (such as the 242 S evaporator and huts over lateral access ports) are located inside or just adjacent to tank farms. The roofs of these structures will likely shed precipitation in such a way that it concentrates the water in small areas, such as a roof drip line. The result will be a net increase in the overall recharge rate.

Knowledge level: The knowledge level defined by Jones et al. (1998) was low. Currently, it is defined as acceptable. Effects of current and future recharge are acceptable as the sources (waterline leaks and run-on) are being controlled, if not eliminated.

Feasibility of Collecting Additional Data: Jones et al. (1998) defined the feasibility of collecting additional data to resolve this gap as variable. Currently, it is defined as low. Details are very site specific and it will be difficult to generalize conditions to significantly improve the data base.

Document Support: PA/closure plan, CMS, Work Plan.

Priority Ranking: Previously, Jones et al. (1998) defined the priority ranking as 2 to 4. Currently, it is defined as 4.

Path Forward: Continue opportunistic review of literature (including photos) of past events. Monitor integrity of pipelines not capped off and of berms/gutters installed to control run-on to farm.

Limitations: None.

3.15 CURRENT DISTRIBUTION OF PAST TANK WASTE DISCHARGES

Description: A large volume (up to 500,000 gallons) of radioactive and hazardous waste may have leaked from underground tanks and associated infrastructure.

Origin: Existing data gap from Jones et al (1998).

Information Type: Data and analysis.

Impact: Jones et al. (1998) defined the impact as direct/intermediate. Currently, it is defined as unclear because performance assessment analyses have shown less sensitivity to this parameter than was previously thought.

Knowledge Level: In both Jones et al. (1998) and currently, the knowledge level is defined as low to medium. Characterizing vadose zone contaminants has been the emphasis of the TFVZ Project, but drilling in each tank farm has been limited to a few wells. Qualitative estimates of contaminant plumes were developed from spectral gamma logging data. Geostatistical modeling was successful in developing plume data in a limited number of cases where adequate data sets were available. Application of high-resolution resistivity measurements (through SGE, see Section 2.2.2.5) may be useful in delineating contaminant plumes. In addition, recent advances in direct-push technology have allowed better

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characterization of spatial distributions of contaminants to the depths that the technology can penetrate.

Feasibility of Collecting Additional Data: Jones et al. (1998) recommended using available data. However, recent advances in subsurface geophysics have changed the feasibility of collecting additional data to high. The application of high resolution resistivity methods such as SGE may provide significant new data that can be used to develop waste plumes. Activities are underway to quantify the response of the electrical geophysical methods to subsurface contaminants.

Document Support: CMS, Work Plan, RFI, PA/closure plan.

Priority Ranking: The previous priority ranking was defined in Jones et al. (1998) as 1A or 2. Currently, it is defined as 1B.

Path Forward: Pursue high-resolution resistivity methodology in SST farms.

Limitations: Limited data on leak volumes, leak rates, waste chemistry, and number of leaks for specific tanks.

3.16 PROJECTION OF CONTAMINANT MIGRATION (MODELING APPROACH)

Description: Reliance must be placed on modeling analyses to estimate future contaminant migration from the disposal facility or vadose zone to the accessible environment. Both the conceptual models and their numerical representations must quantify future environmental impacts that are sufficiently reliable to make tank closure decisions.

The vadose zone flow and transport simulations documented in the field investigation reports for the S-SX, B-BX-BY, and T-TX-TY WMAs (Knepp 2002a,b and Myers 2005), the initial SST PA, and closure risk assessments for both past leaks and retrieval leaks use the current distribution of vadose zone contamination as an initial condition, rather than modeling the leak events themselves.

Origin: Existing need from Jones et al. (1998).

Information Type: Analysis.

Impact: Both the definition in Jones et al. (1998) and currently are that this gap has direct impact.

Knowledge level: Jones et al. (1998) defined the knowledge level as medium/low. Currently, it is defined as acceptable. The modeling approach has been used to model contaminant migration from tank waste sources in the S-SX, B-BX-BY, and T-TX-TY WMAs (Knepp 2002a,b and Myers 2005), the initial SST PA (DOE-ORP 2006), and in closure risk assessments. The conceptual model for future contaminant migration away from closed SST waste management areas is based on three principle migration pathways: groundwater, air, and intruder. Of these air and intruder pathways involve simple processes (e.g., diffusion of volatized contaminants

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through soil or structures and exhumation/distribution of contaminants in soil, respectively). These pathways are evaluated using simple analytic solutions and algebraic calculations (for air and intruder, respectively). Given, the simplicity of the migration processes and the generally benign environment impacts projected by the numerical applications, the models are widely accepted.

The modeling approach is based on release of tank waste constituents in the vadose zone upon contact with infiltrating water and migration through the vadose zone to the underlying unconfined aquifer and down gradient towards the Columbia River. Flow and transport through the vadose zone is evaluated in two dimensions. Field characterization data collected by the TFVZ Project and other projects have supported basic modeling assumptions. For example, anisotropic fluid migration in the vadose zone has been characterized by field experiments (Yeh et al. 2005 and Ward et al. 2006), field characterization studies of past tank leak contamination (Myers 2005), and the technetium-99 plume underlying the BC cribs and trenches.

Feasibility of Collecting Additional Data: Both Jones et al. (1998) and this document recommend use of available data. The modeling approaches for all three pathways are adequate for evaluating all scenarios currently being considered. Alternative conceptual models of large scale features and processes affecting contaminant migration (e.g., clastic dikes) can be represented in the modeling approach.

Document Support: Performance assessments.

Priority Ranking: The previous priority ranking by Jones et al. (1998) was 1B. Currently, the ranking is 4, based on work completed in Phase I characterization and the initial SST PA.

Status and Path Forward: The modeling approach was used for completion of the SST performance assessment and will be used in future analyses. Modeling will be used to identify where additional data are needed and provide feedback to data collection activities.

Limitations: The modeling approach is limited to simulations of the disposal environment. Natural and engineered system heterogeneities that exist on a small scale cannot realistically be modeled because of an insufficient database and computing limitations.

3.17 TEMPERATURE DISTRIBUTION IN CONTAMINATED SOILS

Description: Depending on the radioactivity initially present in the leaking fluid and the leak volume, heat transferred to the soil column varied spatially and temporally. Local hot spots were generated at every tank waste loss location.

Origin: Existing need from Jones et al. (1998).

Information Type: Data.

Impact: Jones et al. (1998) defined the impact of this data gap as low. Currently, it is defined as indirect, but the impact is discussed in thermal effects data gaps section (Section 3.18).

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Knowledge level: The previous knowledge level defined by Jones et al. (1998) was low. Currently, it is defined as acceptable. A modeling analysis was completed to estimate the temperature history at the tank SX-108 leak site and existing temperature distributions around tank SX-108 and is reported in Appendix D of Knepp (2002a). The model results were checked against available temperature data and were found to reasonably match the observations. Few temperature measurements are available from the subsurface soils contaminated by tank waste losses at the time of leakage when maximum values would be expected. Subsequent temperature measurements have been taken periodically at existing drywells and in recent characterization boreholes. Remnant elevated temperatures remain at locations where large highly concentrated losses occurred (e.g., near tank SX-108). Limited thermal profiles can be generated over the vadose zone portion covered by drywell distribution whenever data is collected but the need for such information is minimal. Evaluations of thermal effects on contaminant migration were completed in the field investigation report for the S-SX WMA (Knepp 2002a). From these analyses it was concluded that the heat energy applied to the subsurface by tank waste inside the tank or discharged to the soil column caused minimal changes in contaminant migration rates or estimated peak groundwater concentrations. These analyses are summarized in Section 3.19.

Feasibility of Collecting Additional Data: Both the Jones et al. (1998) and current definition of the feasibility of collecting additional data to resolve this gap are defined as high. Temperature measurements can be taken from all available drywells.

Document Support: Performance assessments.

Priority Ranking: The previous priority ranking by Jones et al. (1998) was 1B. Currently, the ranking is 4, based on work completed in Phase I characterization and the initial SST PA.

Status and Path Forward: This data gap is considered to be closed. Any future updates will rely on modeling analysis that has been performed.

Limitations: Few early historical temperature measurements were taken.

3.18 THERMAL EFFECTS ON RADIONUCLIDE-SOIL REACTIONS

Description: Temperature gradients are known to impact the rate of moisture movement. Some tanks heated surrounding sediments and could also facilitate changes in vadose zone mineralogy and radionuclide sorption processes.

Origin: Existing need from Jones et al. (1998).

Type of Information: Data and analysis.

Impact: The previous impact in Jones et al. (1998) was defined as unclear. Currently, it is defined as indirect. Coupled flow and transport modeling of the SX-108 leak demonstrated that temperature profiles primarily affected vadose zone flow rather than geochemical reactions and only for a short period of time (e.g., no more than a couple of decades near tank SX-108 after the leak occurred). Changes in chemical behavior observed in the vadose zone at SX-108 are readily explained by tank fluid chemistry effects (e.g., extended migration of cesium-137 in the vadose

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zone was facilitated by extreme sodium concentrations in tank SX-108 fluid that successfully suppressed cesium-137 sorption on soils relative to sorption in the presence of ambient vadose zone water).

Knowledge level: The previous knowledge level defined by Jones et al. (1998) was low. Currently, it is acceptable because of work performed as part of the S-SX field investigation report. Modeling analyses (Appendix D, Sections D.7.1 and 7.1.2 of Knepp 2002a) indicate that temperature impacts dissipate with radioactive decay over time such that the temperature differences in perturbed versus undisturbed soils become small from this time forward. With regard to radionuclide interactions, both higher temperatures and tank waste chemistry must be considered as acting simultaneously. Characterization of highly contaminated soils underlying tank SX-108 show minimal changes to soil mineralogy with the possible exception of the formation of sodium zeolite phases (Appendix D Section D.2 of Knepp 2002a). Tank waste contaminants also appeared to be largely below the sediments that appeared to be most affected by interactions with tank waste. Leaching experiments with retrieved soils contaminated by tank waste have shown current contaminant behavior to be consistent with ambient temperature results. If higher temperature effects occurred earlier, extreme changes in constituent mobility have not been observed. Alternative contaminant behavior inferred from current contaminant distribution in the vadose zone (e.g., cesium-137 near tank SX-108) is more plausibly related to tank fluid chemistry effects (e.g., temporarily enhanced cesium-137 mobility because of competitive sodium sorption saturating all available surface sorption sites in the near-tank region).

Feasibility of Collecting Additional Data: The feasibility of collecting additional data to resolve this gap is medium. Leaching, sorption and desorption studies can be simulated in the lab by conducting experiments at varying temperatures.

Document Support: Performance assessments.

Priority Ranking: Jones et al. (1998) defined the priority ranking as 2 to 4. Currently, it is defined as 4 and the data gap is considered closed.

Status and Path Forward: This data gap is closed.

Limitations: None.

3.19 THERMAL EFFECTS ON PHYSICAL TRANSPORT RATES

Description: Temperature gradients are known to impact the rate of moisture movement. Some tanks have heated surrounding sediments.

Origin: Existing need from Jones et al. (1998).

Information Type: Data and analysis.

Impact: Jones et al. (1998) defined the impact as unclear; currently, it is defined as low. Coupled flow and transport modeling of the SX-108 leak indicates that dynamic temperature

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profiles in the vadose zone underlying tanks in some cases have had significant transient effects on fluid and vapor flow, but long-term contaminant migration and peak groundwater concentrations are relatively unperturbed (see discussion below). Also, because major heat losses to the soil are not likely to occur again (waste retrieval and radioactive decay are eliminating the plausible heat sources), no significant thermal perturbations to the vadose zone and effects on future contaminant migration are expected.

Knowledge level: Previously, the knowledge level defined by Jones et al. (1998) was defined as low. Currently, it is defined as acceptable. Two modeling analyses were completed in the S-SX field investigation report (Appendix D, Sections D.7.1 and D.7.2 of Knepp 2002a) that simulated the effects of heat energy on fluid and contaminant migration in the subsurface. Contaminant migration histories under non-isothermal conditions were compared to those under isothermal conditions.

In the analysis (Knepp 2002a), the assumed energy source was the waste stored in tanks SX-107, SX-108, and SX-109 and was assumed to provide the heat source. In the second analysis (Knepp 2002a), only heat from waste in tank SX-108 was considered. In each analysis, both liquid containing a soluble species and vapor flow were modeled. The analysis progressed from 1965 forward. Initially, in the subsurface near the tanks, temperatures exceeded boiling, which created a dry zone where fluid vaporized and moved away from the tanks toward the cooler region. The soluble contaminants precipitated out of solution in the dry zone. At the edge of the dry zone, temperatures dropped below boiling, the vapor condensed, and the liquid was drawn back toward the tank because of capillary forces, creating a liquid vapor counter flow zone. Salts also precipitated in this counter flow zone as liquid migrated towards the dry zone, vaporized and condensed. This process effectively dissipated heat in the subsurface. Over time (about ten years), heat dissipation and radioactive decay caused the region in which temperatures exceeded boiling to shrink until no region above boiling temperatures remained. As heat continued to dissipate in the subsurface, larger volumes of the vadose zone increased in temperature to the point that the entire vadose zone under the tanks was impacted. Once the entire vadose zone rewetted, vapor flow became inconsequential and recharge resumed, but at a slightly greater rate relative to those calculated for isothermal ambient temperature conditions due to the increased moisture gradients.

Despite the significant transient history of fluid flow in the vadose zone imposed by thermal energies, contaminant migration histories and peak groundwater concentrations were not affected. In the thermal modeling analyses, contaminants in the leaking tank fluids were tracked along with the fluid distributions. Outside the vadose zone impacted by boiling temperatures, the contaminant mass flux under non-isothermal conditions was predicted to lag behind that estimated for isothermal conditions. Because contaminants lost from fluid in the dry zone during vaporization could not migrate until liquids reformed in the dry zone after temperatures dropped below the boiling point, contaminant migration was delayed relative to an assumption of isothermal conditions below boiling. Conversely, once full vadose zone recharge was reestablished, migration of mobile contaminants was enhanced in the non-isothermal case, but only slightly. Mobile contaminant breakthrough curves for technetium-99 were derived for both model scenarios in Knepp (2002a). The technetium-99 mass was predicted to arrive at its current depth in the vadose zone and assumed to migrate from year 2000 forward. The peak arrival

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times and peak values were less than 10 % different with non-isothermal peaks arriving slightly earlier at slightly lower concentrations.

Feasibility of Collecting Additional Data: Jones et al. (1998) defined the feasibility of collecting additional data as unclear. Currently, the feasibility of collecting additional data to resolve this gap is defined as medium. Small-scale laboratory flow and transport experiments could be completed at various temperatures to measure property changes.

Document Support: Performance assessments.

Priority Ranking: The previous priority ranking by Jones et al. (1998) was 1B. Currently, the ranking is 4, based on work completed in Phase I characterization and the initial SST PA.

Status and Path forward: Currently, this data gap is considered closed.

Limitations: None.

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4.0   FY 2007 DATA GAPS AND NEEDS

4.1   INTRODUCTION

This chapter presents data gaps and needs identified by the TFVZ Project during FY 2006. The data gaps and needs are arranged in groups that reflect components of the tank farm vadose zone conceptual model:

- Section 4.2   Inventory
- Section 4.3   Release
- Section 4.4   Recharge
- Section 4.5   Geohydrology
- Section 4.6   Geochemistry
- Section 4.7   Modeling

Within each group or component of the conceptual model, the new data gaps and needs are ordered by priority. To provide a complete list in one place, the data gaps previously identified in Jones et al. (1998) and updated in Table 3-2 are included in Table 4-1, if their priority is 1 or 2.

For the revised list of data gaps and needs, priorities were assigned based on the impact of the gap/need on groundwater impacts and the associated knowledge level. The criteria for priority ranking are very similar to that used as in Jones et al. (1998).

Impacts are defined as direct, indirect, low, and unclear. An impact is direct if the data or analytical result quantifies a condition or process that strongly influences eventual radionuclide contamination levels in the vadose zone or groundwater. An impact is indirect if it doesn't quantify a condition or process that influences radionuclide fate and transport in the vadose zone and groundwater. An impact is unclear if the effect of the process, condition, or analytical result on radionuclide migration is not known, but may be significant or provide a means to better understand the current and future distribution of radionuclides.

Knowledge levels are defined as low, medium, and acceptable. In Jones et al. 1998, a knowledge level of variable was used. In the current effort, the data gap or need was subdivided until the knowledge level was identified as low, medium, or acceptable. A knowledge level is low if no site-specific information is available and no general literature values can be used with confidence to represent the process or parameter in a radionuclide migration model. If the parameter or process is considered vital to the evaluation of radionuclide migration, additional data collection to develop usable values is recommended. Knowledge level is medium if some site-specific, quantifiable data or relevant literature values are available. A medium knowledge level is assumed to lead to a database that is sufficient to provide estimated values that can be used in radionuclide migration models to perform a reasonably conservative risk assessment. Use of these medium knowledge level estimates is expected to lead to conservatively high

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estimates of groundwater contamination. Additional data are expected to clearly improve both quantification of the condition or process and confidence in the values used in a radionuclide migration model. A knowledge level is acceptable if site-specific, quantifiable data are available to provide input into a radionuclide migration model and additional data are expected to only marginally improve understanding.

Considering both the determination of impact and knowledge level, the data or analysis needs are ranked for prioritization (Table 4-1). Not all impact-knowledge level combinations occurred, so there are fewer entries in the table than possible combinations.

- If the impact is direct and the knowledge level low, a ranking of 1A was assigned and the activity is defined as highest-priority.
- If the impact is unclear and the knowledge level low, a ranking of 1B was assigned and the activity is also assigned as high-priority.
- If the impact is indirect and the knowledge level low, a ranking of 2 was assigned.
- If the knowledge level is medium, a ranking of 3 was assigned.
- If the impact is low and the knowledge level acceptable, medium, or low, a ranking of 4 was assigned. A ranking of 4 is also assigned if the impact is direct or indirect and the knowledge level is acceptable.

Table 4-1. Definition of Priority Ranking.

Priority Ranking	Impact	Knowledge Level
1A	Direct	Low
1B	Unclear	Low
2	Indirect	Low
3	Any	Medium
4	Low	Any
	Any	Acceptable

The gaps and needs are summarized in Table 4-2 as well as the assigned priority for each gap/need. Also in Table 4-2 are summaries of the path forward and any limitations noted.

For each data gap or need, the following information and/or descriptions is provided:

- The gap/need and whether it has been added since the original analysis in Jones et al. (1998)
- The type of information associated with the gap/need (data or analysis)
- How the data gap/needs affect the calculated impacts (directly, indirectly, or unclear)
- The knowledge level of the data gap/need (low, medium, or acceptable)
- How feasible data collection is for the data gap/need (low, medium, high)

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- In which document or set of documents that the data gap or need will be used
- Priority ranking 1-4
- The status and path forward for the data gap/need
- Any limitations associated with the data gap/need

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Inventory								
Tank residual inventories (NEW) (Section 4.2.1)	Data and analysis	Direct	Low	High (Regulatory requirement)	RDR, Appendix H	1A	Prior to retrieval, residual inventories will be taken from HTWOS output. After retrieval, measured data will be used.	Retrieval methodology is highly uncertain.
Detection and Measurement of Tank Leaks during Retrieval (New) Section 4.2.2)	Data	Direct	Low	High	RDR, TWRWP, Leak Volume Report, PA/closure plan, Appendix H	1A. Scope outside TFVZ Project (LDMM)	HHR is now accepted as a means of tank leak detection in S Farm. Application of HHR to other farms is pending.	Additional testing and analysis are needed to determine the effectiveness of technologies.
Retrieval leak inventories (NEW) (Section 4.2.3)	Analysis	Direct	Low	Medium	RDR, TWRWP, Leak Volume Report, PA/closure plan, Appendix H	1A. Scope outside TFVZ Project (LDMM)	Potential retrieval leak inventories are calculated using HTWOS output and various leak volume. The initial SST PA treated retrieval leaks as sensitivity cases. Tests indicate significant potential for HRR. In-farm testing at S-102 provided a statistically valid minimum leak loss value.	Retrieval methodology is highly uncertain.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Infrastructure inventories (NEW) (Section 4.2.4)	Analysis and limited data	Unclear	Low	Low to Medium	PA/closure plan, CMS, RDR	1B	Preliminary infrastructure inventories are under development. Impacts from direct exposure may need to be considered.	Retrieval strategies are in determinant for MUSTs.
Current distribution of past tank waste discharges (From Jones et al. 1998) (Section 4.2.5)	Data and analysis	Unclear	Low to Medium	High	RFI, CMS, Work Plan, PA/closure plan	1B	Data from spectral gamma logging and characterization boreholes. Analyses in FIRs show less sensitivity to this issue than previously thought. SGE being applied to locate contamination and develop three-dimensional plume distributions and guide location of additional boreholes or direct pushes	Limited data on leak volumes, leak rates, waste chemistry, and number of leaks for specific tanks.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Near-surface soil concentrations-inventories (NEW) (Section 4.2.6)	Data	Unclear	Low to medium	High	CMS, Work Plan, RFI,TWRWP, PA/closure plan	1B	Limited data bases exist. Work is underway to extrapolate what we know into inventory data. Characterization will be identified through CMS process. Hydraulic hammer direct push technology makes characterization more efficient and cost effective. Impacts from direct exposure may need to be considered.	Limited historical records exist.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
				Release				
Tank waste residual release models (NEW) (Section 4.3.1)	Analysis and Data	Direct	Low	High (Samples are regulatorily required.)	PA/closure plan, Appendix H	1A	Limited sampling/analysis has been performed. From this limited data set, the water leaching of key CoCs has been found to be variable and tank specific. The path forward is to expand sampling and analysis.	The current data base is sparse. The goal of binning post-retrieval sludge into categories based on leaching behavior may be difficult given the varied history of many tanks.
Tank grout characteristics (NEW) (Section 4.3.2)	Data	Unclear	Low for aged grout, medium for young grout	High for chemical characteristics Medium for physical characteristics	PA/closure plan, Appendix H	1B	Tank grout characteristics (NEW)	Extrapolation from short to long-term data. Difficulties of measuring hydraulic properties of high-quality grouts.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Recharge/ Surface Barriers								
Recharge through gravel surfaces (NEW) (Section 4.4.1)	Data	Direct	Low	Medium	PA/closure plan, CMS, Work Plan	1A	Path forward is to measure recharge under tank farm gravel surfaces (e.g., chlorine-36 and chloride data, TDR, etc.).	Past efforts using flux meters in the tank farms have not been proven useful
Surface barrier performance after design life (NEW) (Section 4.4.2)	Data and Analysis	Direct	Low	Medium	PA/closure plan, CMS, Work Plan	1A	IDF Recharge Data Package (Fayer 2004) and related other reports present status. Path forward: continue collecting recharge data and reinvestigate given concerns.	Projection of long-term behavior is an extrapolation of current data and understandings
Timing of initial barrier placement (NEW) (Section 4.4.3)	Analysis	Direct	Low	N/A	PA/closure plan, CMS, Work Plan	1A	Timing of initial barrier placement not defined. Path forward is to perform sensitivity studies on the impact of barrier placement timing.	Management decision
Recharge effects from tank-farm infrastructure (Past events) (Section 4.4.4)	Data	Unclear	Low	Low	PA/closure plan, CMS, Work Plan	1B	Impacts from past operations have been evaluated; corrective measures have been deployed where appropriate. Will be revisited as additional information becomes available.	Specifics are difficult to quantify from past pipeline leaks, snowmelt, and other events.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Surface barrier performance during design life (NEW) (Section 4.4.5)	Data	Indirect	Medium	High	PA/closure plan, CMS, Work Plan	3	IDF Recharge Data Package (Fayer 2004) presents status. Path forward: incorporate data from planned instrumented field-scale barriers such as the B-57 and U Plant barriers.	Projection of long-term behavior is problematic.
Impacts of episodic events on long-term recharge estimates (NEW) (Section 4.4.6)	Data and Analysis	Direct	Acceptable	High for short-term (decades)	PA/closure plan, CMS, Work Plan	4	IDF Recharge Data Package (Fayer 2004) presents status. Path forward: continue reviewing ongoing work and revisit as additional information becomes available.	Events that contribute to recharge are episodic and infrequent and thus make long-term recharge rates difficult to estimate.
Geohydrology								
Contaminant contribution to vadose zone and groundwater from nearby non-tank farms sources (NEW) (Section 4.5.1)	Analysis and Data	Direct	Low to medium	High	PA/closure plan, CMS, Work Plan	1A	ORP and RL have contractors integrate efforts on source and groundwater contamination. Path forward to include stable and radioactive isotope signatures.	Solution requires contributions across projects and DOE offices (ORP and RL).

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Short-term temporal and spatial variation in groundwater contaminant concentrations (NEW) (Section 4.5.2)	Data and Analysis	Unclear	Low	High	PA/closure plan, CMS, Work Plan	1B	Measurements show vertical and short-term temporal changes. Current models don't account for these variations. Determine the importance of variations. Path forward to be done by Hanford Groundwater Remediation and Closure Assessment Project. (Requires history search, combined with modeling to assess the causes and implications of these events.)	Monitoring is accomplished on a quarterly, semi-annual, or annual frequency at limited spatial locations. Temporal changes potentially come and go without being recognized. Difficulty of making small-scale elevation measurements in wells.
Hydraulic properties for facility containment system (NEW) (Section 4.5.3)	Data and Analysis	Unclear	Low	High	PA/closure plan, CMS, Work Plan	1B	Knowledge of the current state of tank system materials hydraulic properties is incomplete, e.g. unsaturated hydraulic properties not measured. Path forward: determine material properties and model explicitly.	Tanks currently in use; breach of containment is unacceptable.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Vapor flow under low recharge (NEW) (Section 4.5.4)	Analysis	Unclear	Low	Low	PA/closure plan, CMS, Work Plan	1B	Review past work at other sites (Beatty, Nevada; Ward Valley, California; Australia) as analogs to evaluate importance of potential vapor flow under low infiltration.	Data sparse on Hanford sediment properties (e.g., unsaturated hydraulic conductivity) for low moisture contents under arid recharge conditions.
Hydraulic properties at low saturation (NEW) (Section 4.5.5)	Data	Unclear	Low	Medium	PA/closure plan, CMS, Work Plan	1B	Review past Hanford work on soil hydraulic properties (e.g., ultracentrifuge measurements) and at other sites to extend existing database on relatively wet and intermediate water contents. Make use of EMSP results.	Data sparse on Hanford sediment properties (e.g., unsaturated hydraulic conductivity) for low moisture contents under arid recharge conditions.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Contaminant dispersion in groundwater (NEW) (Section 4.5.6)	Analysis	Indirect	Low	Medium	PA/closure plan, CMS, Work Plan	2 (Scope outside of TFVZ Project)	Status: Groundwater models assume dispersion values. Path forward: Use site monitoring results in model calibration and to perform history matching.	Limited release events for data interpretation to develop estimates. Difficulty of separating groundwater plumes at Hanford. Changing flow directions over time.
Anisotropy and lateral flow in the vadose zone (NEW) (Section 4.5.7)	Data and Analysis	Unclear	Medium	Medium	PA/closure plan, CMS, Work Plan	3	Theories have been developed and applied, but Hanford data sets are limited Apply methods developed from Sisson and Lu data sets to other sites. Continue ORNL experiments. Evaluate SGE data sets and impacts of fluid properties.	Lack of opportunities for field experiments similar to those performed at the Sisson and Lu Site.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Small-scale stratigraphy (NEW) (Section 4.5.8)	Data and Analysis	Indirect	Medium	Low	PA/closure plan, CMS, Work Plan	3	Large-scale geology is well documented. This data need pertains to microstratigraphy (other than clastic dikes) impact on lateral spreading. Path Forward: As new information becomes available add to database.	Based on coarse spatial examinations, geologic descriptions from boreholes (particularly older ones) often miss the fine layers that control the lateral migration of fluids. Recognition of these layers requires that near continuous core be collected during sampling episodes.
Upscaling hydraulic properties (NEW) (Section 4.5.9)	Analysis	Direct	Medium	Medium	PA/closure plan, CMS, Work Plan	3	Limited work has been done on stochastic and other (e.g. pedotransfer) functions upscaling methods. Compare results with field data and continue to refine methodology as necessary.	Limited number of field sites and data sets to test methodology. Borehole geophysics can be used to extend existing relationships to similar geologic media.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Preferential flow pathways (NEW) (Section 4.5.10)	Data and Analysis	Indirect	Acceptable	Medium to low	PA/closure plan, CMS, Work Plan	4	Long-term simulations for risk assessment suggest little change in peak concentrations with and without preferential pathways (i.e., clastic dikes, unsealed boreholes, and other mechanisms). Continue reviewing ongoing work on preferential pathways under unsaturated flow.	
Geochemistry								
Waste Chemistry Effects on Uranium(VI) Mobility in the Vadose Zone (Section 4.6.1)	Data and Analysis	Direct	Low	High	PA/closure plan, CMS, Work Plan	1A	Continue leaching studies for sediments at BX-102, TX-104, and other tank farms (e.g. WMA U) to determine the processes controlling uranium geochemistry at each location with the overall goal to determine a "unifying" conceptual model for U(VI). Tank residuals in C farm are highly enriched in U and vadose zone impacts after leaching will need to be addressed.	Uranium chemistry is complicated. Incorporating more complicated geochemical modeling (other than K_d approach) in risk assessment computer codes will increase running times.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Chemical interactions between concrete shell and tank residue (NEW) (Section 4.6.2)	Data and analysis	Unclear	Low	Medium	PA/closure plan, CMS, Work Plan	1B	Limited knowledge of interactions between tank residual materials and structural concrete. Path forward is to evaluate previous work and continue performing leaching experiments on appropriate analog concrete materials or actual tank structural concrete if available. Emphasis on transport of released material through concrete shell.	Obtaining adequate analogs for aged concrete materials or actual tank structural concrete.
Chemical interactions between tank fill and residue (NEW) (Section 4.6.3)	Data and Analysis	Unclear	Low	Medium	PA/closure plan, CMS, Work Plan	1B	Nonexistent for aged fill material and limited information from Savannah River for young fill. Path forward is to evaluate previous work and continue conducting experiments on appropriate fill materials. Interface between fill material and concrete shell.	Obtaining adequate analogs for aged fill materials, including diatomaceous materials previously used as fill materials.

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Chemical interactions between tank liner and waste (NEW) (Section 4.6.4)	Analysis	Unclear	Medium	Use available data	PA/closure plan, CMS, Work Plan	3	Knowledge on liner corrosion is available in Hanford and general literature. Path forward is to assess the impact of existing knowledge and apply as appropriate.	Gathering existing knowledge into a useable form.
Impact of natural soil organic content on contaminant transport (NEW) (Section 4.6.5)	Data and Analysis	Low	Acceptable	Medium	PA/closure plan, CMS, Work Plan	4	Work on IDF PA shows that low soil organic content will not affect fate and transport. Documented in expanded text.	Natural organic matter is low in Hanford sediments and difficult to analyze.
Modeling								
Expand database for history matching of simulations (NEW) (Section 4.7.1)	Data	Indirect, but of high impact	Low to medium	Medium	PA	2	Limited (Sisson/Lu, BC Cribs, T-106, C pipeline). Perform key experiments (e.g. HRR) for events that have a known leak history and continue to collect SGE data. Measurements must be performed to capture time evolution of plumes.	Most events have a poorly known source history and plume evolution. Quality of surface HRR in tank farms is unknown. Limited data sets that capture time dimension

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Parameter variability effects on risk estimates (NEW) (Section 4.7.2)	Analysis	Direct	Medium	Variable	PA	3	Currently, have performed sensitivity analyses. Path forward is to expand quantitative sensitivity analyses and use them to quantify variability in risk impacts.	Difficult to assign parameter uncertainty. Assignment of minimum and maximum values has been done in the initial SST PA.
History matching vadose zone numerical models/codes (NEW) (Section 4.7.3)	Analysis	Indirect	Medium	Medium	PA	3	Limited data base exists (Need 4.7.1 will expand the data base). Perform comparison runs against existing field data (e.g. Sisson/Lu experiments, T-106, BC cribs and trenches, and C pipeline).	History matching opportunities are limited because of slow contaminant migration processes and limited knowledge of sources and current contaminant distributions.
Near surface contamination risk assessment (NEW) (Section 4.7.4)	Analysis	Indirect	Medium to Low	Medium to Low	PA	3	Assessments (human health and ecological) are planned. Efforts are being coordinated with the 200 Area ecological assessment.	

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Table 4-2. Data Gaps and Needs, Ordered by Subject Area and Priority Ranking. (15 pages)

Title	Information Type	Impact	Knowledge Level	Data Collection Feasible?	Document Support	Ranking	Status and Path Forward	Limitations
Notes:								
CoC	=	contaminant of concern						
CMS	=	corrective measures study						
DOE	=	U.S. Department of Energy						
Ecology	=	Washington State Department of Ecology						
EMSP	=	Environmental Management Science Project						
FIR	=	field investigation report						
HRR	=	high resolution resistivity						
HTWOS	=	Hanford Tank Waste Operations Simulator						
IDF	=	Integrated Disposal Facility						
LDMM	=	leak detection, monitoring, and mitigation						
MUST	=	miscellaneous underground storage tank						
ORNL	=	Oak Ridge National Laboratory						
ORP	=	DOE Office of River Protection						
PA	=	performance assessment						
RCRA	=	*Resource Conservation and Recovery Act of 1976*						
RDR	=	Retrieval Data Report						
RFI	=	RCRA Facility Investigation (report)						
RL	=	DOE Richland Operations Office						
SGE	=	surface geophysical exploration						
SST	=	single-shell tank						
SST PA	=	Initial Single-Shell Tank Performance Assessment (DOE-ORP 2006)						
TFVZ	=	tank farm vadose zone						
TWRWP	=	Tank Waste Retrieval Work Plan						
WMA	=	waste management area						

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4.2 INVENTORY

Groundwater, air, and inadvertent intruder impacts predicted in risk assessments depend linearly on the inventory of key contaminants. Calculations indicate that for the groundwater pathway the key contaminants are technetium-99, iodine-129, nitrate, hexavalent chromium, and uranium isotopes from past leaks. There are contributions from other sources (intentional discharges to waste sites and potential retrieval leaks) that also contribute to future groundwater contamination and impacts (although at lower impact levels). Key contaminants that result in predicted impacts via the air pathway are tritium and radon, while the key contaminants for the inadvertent intruder pathway are the actinides.

4.2.1 Tank Residual Inventories

Description: Not all of the waste will be retrieved from tanks. Of the seven tanks currently retrieved, there is still ~0.3 to 1.5 % of the tank capacity left in the tank.

Origin: New data gap, because of expanded scope of the TFVZ Project.

Information Type: Data. Tank residual inventory estimates are needed for tanks not yet retrieved.

Impact: Direct. Volume and composition of waste materials left in the tank at the end of retrieval drive groundwater impacts beyond approximately 3,000 years.

Knowledge Level: Low. Only seven of 149 SSTs have been retrieved (C-103, C-106, C-201, C-202, C-203, C-204, and S-112). Various retrieval efforts are still under development. Until tanks are retrieved and residual waste is characterized, estimates of residual waste inventory are derived from the Hanford Tank Waste Operations Simulator (HTWOS RPP 2003).

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high, after individual tanks are retrieved. Under the *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology 1998), the residual waste in each tank are to be sampled and characterized.

Document Support: PA/Closure plan, RDR, TPA Appendix H reports.

Priority Ranking: 1A. The scope of this task is outside of the TFVZ Project. For retrieved tanks where measurements of actual tank waste are performed, the scope is assigned to the Tank Waste Retrieval Project. For tanks that have not been retrieved, where computer models are used, the scope belongs to Engineering Process Group, which is responsible for HTWOS.

Path Forward: The recommended path forward is to continue to collect samples of tank waste residues when each tank is retrieved and submit the samples for laboratory analyses. Tanks will be grouped according to "residual waste type" to manage the scope of laboratory analyses to be performed. The data quality objectives report on residual samples (Banning 2005) documents this process.

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Limitations: The methodologies that will be used for tank waste retrieval methodology are highly uncertain. Sampling of tank residual waste is technically difficult and the information for performance assessment modeling may not be available until far in the future. Because this process cannot be accelerated, no action is required.

4.2.2 Detection and Measurement of Tank Leaks during Retrieval

Description: The process for gathering environmental and risk-based information to be followed in the event of a possible leak has not been defined. Because the data associated with movement (transport) of tank wastes lost during a retrieval incident can provide invaluable insight into the long-term movement and associated risks, a plan to capture those data, should a retrieval incident take place, is essential to assuring that the data are collected in appropriate quantity and quality to conduct the analyses.

Origin: New data gap, because of the expanded scope of the TFVZ Project.

Information Type: Data (high resolution resistivity data for a simulated leak at tank S-102) and analysis.

Impact: Groundwater impacts from potential retrieval leaks are proportional to leaked inventory. Inventory will be determined by a combination of the leak volume and composition of the leak (see Section 4.2.3). Therefore, the impact of this gap will be direct.

Knowledge level: The current knowledge level for this data gap is low. The need for and uses of the data to be acquired should a retrieval leak occur are well established. However, collection of these data is not a standard part of planned activities. The activities surrounding a leak event are likely to be directed at the immediate concerns of protecting the health and safety of on-site workers, but an in-place plan would allow collection of the data that would lead to long-term validity of risk analyses.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high as shown by the S-102 demonstration.

Document Support: Retrieval Data Report (RDR), Tank Waste Retrieval Work Plan (TWRWP), Leak Volume Report, Performance Assessment (PA)/closure plan, and TPA Appendix H reports.

Priority Ranking: 1A.

Path Forward: High resolution resistivity (HRR) is now accepted as a means for tank leak detection in S farm. Application of HRR as a leak detection technology to other farms is pending demonstration in those farms.

Limitations: Additional testing and analysis are needed to determine the effectiveness of prior versions of leak detection systems.

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4.2.3   Retrieval Leak Inventories

Description: During retrieval of waste from underground tanks, there is a potential that there will be loss of contamination to the soil column. Presently, potential retrieval inventory estimates are developed from HTWOS model data. Real-time leak inventory estimates will be calculated from leaked fluid composition and leak volume data. The leak volume data may be estimated from the leak detection methodologies described in Section 4.2.2. This gap recognizes the need to analyze data (Section 4.2.2) to determine the total amount released during a retrieval leak.

Origin: New data gap included because of expanded scope.

Information Type: Analysis.

Impact: The impact of this data gap is direct. Current projections of volumes of potential leaks during retrieval are very small compared to leaks that have already occurred.

Knowledge Level: The current knowledge level is low. It is possible to collect samples of fluids associated with "retrieval leaks," should leaks occur. However, because leak volume estimates will likely be highly uncertain, the inventory estimates will also be uncertain. Once leak volumes are well characterized, the uncertainty will decrease.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. Prior to initiation of tank waste retrieval, inventory estimates will come from HTWOS model predictions. During retrieval, inventory for retrieval leaks can be generated from vadose zone samples collected with the direct push technology.

Document Support: RDR, TWRWP, Leak Volume Report, PA/closure plan, and TPA Appendix H reports.

Priority Ranking: 1A. The Tank Waste Retrieval Project is responsible for estimating retrieval leak inventories.

Path Forward: Prior to retrieval, potential retrieval leak estimates will be a byproduct of HTWOS modeling runs and estimated leak volumes. After retrieval, the Tank Waste Retrieval Project will supply estimates.

Limitations: The retrieval methodology that will be used, other than "modified sluicing", is highly uncertain.

4.2.4   Infrastructure Inventories

Description: Residual inventories of contaminants within the tank-farm infrastructure (e.g., pipelines, small tanks) at the time of planned closure are currently assumed to be minor (compared to residual waste planned to be left in the tanks). However, the inventory associated with tank-farm infrastructure has not been extensively characterized. Inventory estimates are based largely on historical records. The extent of clean-up of ancillary equipment is currently

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unknown; however, if ancillary equipment is demonstrated to contribute significantly to risk, it is reasonable to assume that additional characterization and remediation will be required.

Origin: New data gap, because of the expanded scope of the TFVZ Project.

Information Type: Analysis.

Impact: The impact of this data gap is currently defined as unclear. Using current assumptions for infrastructure inventories, calculations indicate that infrastructure sources are less important than past leaks for groundwater impacts. However, this is based on the assumption that small tanks are cleaned to the same extent as larger tanks. If small tanks are not retrieved, a new analysis needs to be performed.

Knowledge Level: Although specific information is generally low, some operations records are available. Therefore, the knowledge level is low to medium.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. The initial approach will involve modeling likely inventories based on historical records. Sampling and analysis activities may be delayed until remediation occurs.

Document Support: PA/closure plan, Corrective Measures Study (CMS), and RDR.

Priority Ranking: 1B.

Path Forward: Initial inventory estimates have been developed for plugged pipelines in SST farms. Some inventory data are available for residuals in various smaller tanks such as the vaults, Miscellaneous Underground Storage Tanks (MUST), and catch tanks. As closure plans are developed for the smaller tanks, better estimates of residual waste to be left in those tanks will become available.

Limitations: Retrieval strategies are indeterminate for MUST and other tank farm infrastructure.

4.2.5 Current Distribution of Past Tank Waste Discharges

Description: A large volume (up to 1,000,000 gallons) of radioactive and hazardous waste may have leaked from underground tanks and associated infrastructure.

Origin: Existing data gap from Jones et al (1998).

Information Type: Data and analysis.

Impact: The impact is currently defined as unclear. Performance assessment calculations demonstrate that past leaks are the largest contributor within the tank farms for future groundwater impacts.

Knowledge Level: Knowledge level is low to medium. Characterizing vadose zone contaminants has been the emphasis of the TFVZ Project, but drilling in each tank farm has been

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limited to a few wells. Qualitative estimates of contamination plumes were developed from spectral gamma logging data. Geostatistical modeling was successful in developing plume data in a limited number of cases where adequate data sets are available. Application of HRR measurements (through SGE, see Section 2.2.2.5) may be useful in delineating contamination plumes. In addition, recent advances in direct-push technology have allowed better characterization of spatial distributions of contaminants to the depths that the technology can penetrate.

Feasibility of Collecting Data: The feasibility of collecting additional data to resolve this gap is high. The application of high resolution resistivity methods may provide significant new data that can be used to develop waste plume distribution and inventory estimates.

Document Support: CMS, Work Plan, RFI, and PA/closure plan.

Priority Ranking: 1B.

Path Forward: The path forward includes pursuing the high resolution resistivity and direct push methodologies to characterize the vadose zone subsurface proximate to SST farms.

Limitations: Limited data exist on leak volumes, leak rates, waste chemistry, and number of leaks for specific tanks.

4.2.6 Near-Surface Soil Concentrations - Inventories

Description: Inventory within the top 15 to 25 feet, which resulted from surface spills and piping leaks.

Origin: New data gap, added because of expanded scope of the TFVZ Project.

Type of Information: Historical records and field data (concentrations of key contaminants in sediment samples).

Impact: The impact of this data gap is unclear. The amount of near-surface soil remediation has not yet been defined. Local near surface areas of high contamination could affect local biota depending on the accessibility and subsequent exposure of biota to existing contamination. If high impact is plausible, near-surface contamination may require remediation.

Knowledge Level: The knowledge level is low to medium. Historical records identify a number of near-surface waste loss events. In addition, spectral gamma logging data has been used to identify some "hot-spots." The spectral gamma data provide dense coverage in some areas of the tank farms, but large areas of the tank farm surfaces have not been monitored with this method. The recently developed hydraulic direct push technique (see Section 2.2.2.4) is being used to characterize vadose zone contamination.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high, using the hydraulic direct push technology in conjunction with SGE.

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Document Support: CMS, Work Plan, RFI, and PA/closure plan.

Priority Ranking: 1B.

Path Forward: Additional data collection about the "nature and extent" of near-surface contamination could potentially be obtained using the hydraulic driven direct-push technology or SGE. However, general characterization will require the development of a characterization plan and will likely await decisions of near-surface remediation and tank farm closure as made by the corrective measures study (CMS) process.

Limitations: A limitation to filling this data gap is that relatively few historical operations/characterization records exist. This limitation could be addressed through application of the direct-push technology.

4.3 RELEASE

For waste forms that have long release times compared to the travel time through the vadose zone, release rates become important. For these cases, it is the release rate rather than the total inventory that dominates predicted groundwater impacts.

4.3.1 Tank Waste Residual Release Models

Description: Most tank waste retrieval techniques that will be employed are based, at least partially, on water soluble methods. Thus, the residual wastes are not expected to release contaminants quickly when water contacts the residual waste. Recent experiments in tanks C-106, C-202, and C-203 show that technetium is released slowly from the residual waste (Cantrell et al. 2006).

Origin: New data gap included because of expanded scope of the TFVZ Project.

Information Type: The information type is both data and analysis, consisting of both direct measurement of and reliance on calculations for determination of release rates and source term concentrations in residual waste.

Impact: The impact of this data gap is direct. For waste forms that slowly release their contaminants (as compared to vadose zone travel times), estimates of groundwater contaminant concentrations predicted with performance assessment models are linearly dependent on the contaminant release rate.

Knowledge Level: The knowledge level is low because only a fraction of the tanks have been studied thus far. Based on the tank sludge materials studied to date (from 6 tanks – C-106, C-202, C-203, C-204, AY-102, and BX-101),), the release rates for some of the primary contaminants of concern (technetium-99, iodine-129, and uranium) are less than expected and highly variable between individual tanks. The limiting factors appear to be minerals and solids in the tanks that have sequestered the contaminants, effectively immobilizing a large percentage of their remaining mass. The variability in chemistry and solid phases between the tanks leads to

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significantly different release rates from the residual sludges in different tanks and a limited ability to group the tanks. Grouping tanks may be possible after a larger number of tanks have been studied and trends in contaminant release rates are identified.

The salt cake tanks that have been retrieved have not been sampled, so measurements of release rates from salt cake residual materials cannot be made. Thus, only theoretical constructs are available for predicting the release of contaminants from residual salt cake left in such tanks.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high (Deutsch et al. 2005c). A requirement of the HFFACO is that samples of residual waste be taken after a tank has been retrieved. The clamshell sampling device that is currently used is capable of collecting samples of the residual salt cake and sludge materials.

Document Support: PA/closure plan and TPA Appendix H reports.

Priority Ranking: 1A.

Path Forward: The limited sampling and analysis of residual wastes that has been performed to date for the retrieved sludge tanks shows the need for sampling additional tanks as part of retrieval to determine contaminant release mechanisms and provide realistic release models for performance and risk assessments. The release-model data must also be developed by testing residual waste materials in salt cake tanks. Once a sufficient number of tanks have been sampled, characterized, and tested, it is possible that binning of the tanks can be done based on fewer analyses of the residual waste or knowledge of tank fill and retrieval history.

Limitations: The current database is sparse and sampling and analyses are difficult and costly. The solid phases in the residual wastes following retrieval of a tank are a complicated mixture and determining the associations of contaminants with the solids is an iterative process. The goal of binning post-retrieval waste materials into a few categories based on similar leaching behavior may be difficult given the varied operational history of many of the tanks.

4.3.2 Tank Grout Characteristics

Description: Closed tanks will consist of residual waste enclosed by engineered materials, primarily grouts. The hydraulic and geochemical properties of these grouts will affect the rate of release of contaminants from the residual materials and will likely impact predicted groundwater concentrations.

Grout that will be used to fill closed tanks serves two purposes. First, grout hinders the flow of moisture entering the system (as compared to the flow in porous soil), thus lowering the near-field rate of contaminant transport following release. This reduction of hydraulic conductivity, however, will change with time as the grout ages. Aging causes the structure and mineral assemblage of grout materials to change. These changes can result in either volume expansion or volume contraction, both of which can lead to the development of cracks in the porous media, which may change moisture flow through the grout. Second, grout hinders the release and subsequent movement of contaminants away from their source location. For conceptual models dominated by diffusional release, the effective diffusion coefficient for each

contaminant in each particular grout will determine the release of each contaminant. For conceptual models of contaminant release that are dominated by chemical interactions (such as solubility), the water chemistry surrounding the waste will control the release of contaminants. Water reaching the residual waste will have the chemical characteristics of fresh cement pore water during the early stages of the weathering process, and these chemical characteristics will evolve as the cement ages. Accurate predictions of contaminant release rates are necessary for long-term risk assessments.

Origin: New data gap included because of expanded scope of the TFVZ Project.

Information Type: The information type is data, including both chemical and physical data on fresh and aged grout.

Impact: The impact of this data gap is unclear, likely consisting of a combination of indirect (moisture flow/contaminant release rates in solubility models) and direct (contaminant release rates in diffusional models) impacts.

Knowledge Level: The knowledge level is low to medium. While the knowledge level is medium for young grout, it is low for chemical characteristics, particularly for aged grout. Knowledge of physical characteristics is low for aged grout, but medium for young grout. Current information documented in Deutsch et al. (2006).

Although the chemical characteristics of fresh cement grout have been extensively studied, there is little information on the chemical interaction of leachate from grout materials (both fresh and aged) with the residual wastes present in Hanford tanks. These interactions may inhibit or enhance the mobility of contaminants from the waste, and must be determined to develop reliable contaminant-release rate models for this system.

The physical manner in which grout fill within a tank will age and develop cracks that allow water to infiltrate through the grout and reach the waste is not well known compared to the likely hydraulic properties of the fresh grout.

Feasibility of Collecting Data: The feasibility of collecting data is high for chemical characteristics using actual tank waste and cement simulants. The feasibility of collecting data on physical characteristics is medium. The hydraulic properties of fresh grout can be studied in the laboratory or at field scale; however, simulating the effect of long-term weathering of the grout will be a challenge.

Document Support: PA/closure plan and TPA Appendix H reports.

Priority Ranking: 1B.

Path Forward: Laboratory studies of the chemical interactions between fresh and aged grout with residual waste collected from the tanks will be conducted. These studies will include single- and multiple-contact leaching tests to evaluate short-term and long-term effects on the contaminants of primary concern. Release rate models for key contaminants that drive risk will be developed for use in the long-term performance and risk assessments. Laboratory studies will

also be conducted to evaluate the hydraulic performance of grouts to estimate water infiltration rates for fresh and aged material.

A DOE complex-wide workshop was held at Savannah River in December 2006. A follow-up workshop is scheduled at Hanford this year.

Limitations: Laboratory measurements on the chemical interactions of grout can only be made over relatively short time frames, thus extrapolations from short-term measurements will be required to address the long time periods required for performance and risk assessments. Because of their low permeability, measuring hydraulic properties for high-quality grouts is challenging.

4.4 RECHARGE/SURFACE BARRIERS

Moisture is the primary driver for contaminant release and transport through the vadose zone to the groundwater. There are multiple sources of water in the tank farms (precipitation, water run-on, and water line breaks). Much work has been performed at the Hanford Site to characterize infiltration and recharge (Fayer and Walters 1995; Fayer and Szecsody 2004).

4.4.1 Recharge Through Gravel Surfaces

Description: Past measurements have shown that recharge is enhanced when natural soils are replaced by gravels (crushed rock) and kept vegetation free. The use of gravel to cover tank farm surfaces was implemented early in tank-farm operations to provide radiological shielding from the waste in the tanks, and a stable working surface. Surface contamination was quickly flushed into the subsurface away from workers. Quantitative estimates of infiltration and recharge through gravel covers depend on the amount of fine-grained sediments associated with the gravels.

Origin: This is a new data gap. The importance of recharge through gravels became more obvious with simulations performed for the FIRs (Knepp 2002a, Knepp 2002b, and Myers 2005).

Information Type: Data (infiltration rate as a function of time and location).

Impact: The impact of this data gap is direct. Recharge rates of 100 mm/yr have been assumed in modeling of gravel surfaces in tank farm risk assessments, in contrast to much lower values for vegetated natural soils or man-made barriers (less than 1 mm/yr). Computer simulations in the S/SX and B/BX/BY FIRs showed that estimated future groundwater impacts from past leaks depended strongly on the recharge rate for the gravel surfaces.

Knowledge level: While infiltration and recharge have been studied extensively at the Hanford Site, the knowledge level specific to recharge through gravel surfaces is low. Attempts to directly measure moisture fluxes in the subsurface in tank farms have not yielded usable results for a variety of technical reasons, including installation, calibration, and maintenance. In addition, the surface layers in tank farms have evolved over time.

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Feasibility of Collecting Data: The feasibility of collecting data to resolve recharge through gravel surfaces is medium. Measurements of chloride and chlorine-36 as a function of depth have been used to estimate past recharge rates, but application of these methods to tank farms may be problematic because of rapid recharge and infiltration through tank-farm gravel covers. Additional data collection methods include measurement of particle-size distributions (for those farms where surface layers have remained stable) and the placement of new moisture measuring instruments. A project is currently underway to collect data adjacent to the T-106 tank in preparation of installing an interim barrier over the documented leak from that tank.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1A. As documented in the Hanford Site Composite Analysis (Kincaid et al. 1998) and the initial SST PA (DOE-ORP 2006), past leaks from tank farm facilities have the largest impact on groundwater and a major uncertainty driving the estimation of the impacts is the amount of moisture that passes through the gravel surface.

Path forward: The path forward includes direct measurement of recharge under tank farm gravel surfaces through improved deployment of flux meters as is being done for the T-106 tank leak interim barrier demonstration as well as additional measurements with other methods (e.g. chlorine-36 and chloride, Time Domain Reflectometry, etc.). Tank farm surface particle-size distributions can also be characterized to provide data for the impact of fine materials in gravel for recharge calculations.

Limitations: Past efforts using flux meters in the tank farms have encountered difficulties that have rendered the data unusable. A project is currently underway to collect data adjacent to the T-106 tank in preparation of installing an interim barrier over the plume created from the leak from that tank. This project addresses the technical issues associated with the previous applications of the flux-meter technology.

4.4.2 Surface Barrier Performance after Design Life

Description: Surface barriers are planned to be installed as part of tank farm closure. Although a prototype barrier over the 216-B-57 crib (immediately north of the BY tank farm) has been monitored since it was constructed in 1994 (DOE 1997; Gee, Wing, and Ward 1999) and work has been completed on a barrier design, the barriers specific to tank-farm closure have not yet been designed. The exception is the interim surface barrier being placed on the T-106 tank leak. It is intended to address reduction of moisture movement through the subsurface for a period of years. The design for final surface barriers will include specification of a design life during which the barrier will perform as intended. A key aspect of surface barrier performance will include barrier performance after the design life.

Origin: This is a new data gap included because of expanded scope of the TFVZ Project.

Type of Information: Data and analysis (infiltration rate as a function of time and location).

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Impact: The impact of this data gap is direct. Performance and risk assessments have demonstrated that the amount of vadose zone contamination projected to impact groundwater is proportional to long-term recharge rates.

Changes in the structure and hydraulic properties during the design life of a barrier and beyond are expected. However, some of these changes may alter barrier performance. The changes that could modify performance include alterations of the properties of the silt loam layer, the properties in the vicinity of the silt loam-sand interface (i.e., the capillary break), the reduction of silt loam thickness by erosion, and the change in properties caused by addition of wind-deposited material, predominately dune sand.

Knowledge level: The knowledge level specific to surface barrier performance is low. The current knowledge level is documented in *Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment* (Fayer and Szecsody 2004) and includes lysimeter data for materials similar to those planned for surface barriers. However, this analysis is for conceptual design and changing material properties are determined through theoretical considerations, rather than through evaluation of actual barrier performance.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. Performing direct measurements on barriers that are hundreds of years old is not feasible, but it may be possible to identify and evaluate analogs. Accelerating the simulated aging of barriers may be feasible depending upon the component being evaluated.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1A. The recharge rate after the design life of the surface barrier is a key input to determine the impact from wastes left in the tank farms.

Path forward: The path forward consists of continuing to collect data from lysimeters and the existing prototype barrier and evaluating possible analog sites and accelerated aging studies. Once designs for surface barriers for tank-farm closure are finalized and barriers constructed, specific components of the design can be evaluated. The components that need to be addressed include barrier side-slope impacts, lateral water flow beneath the barrier, potential subsidence of closed tanks, and future scenarios (e.g., climate changes).

Limitations: Regulators are concerned that low estimates of recharge rates used in current Hanford performance and risk assessments are not valid. Projection of long-term behavior, by its nature, is problematic.

4.4.3 Timing of initial barrier placement

Description: DOE has issued Records of Decision requiring that surface barriers be placed over closed tank farms. The timing of barrier placement has not been determined, nor has the need for and plans to install temporary barriers been evaluated. The TFVZ Project is proceeding with installation of a temporary barrier over the T-106 tank leak.

Origin: This is a new data gap, resulting from expanded scope of the TFVZ Project.

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Information Type: Analysis.

Impact: The impact of barrier-placement timing is direct for past and retrieval leaks. Risk assessments documented in the field investigation reports for the B/BX/BY and S/SX tank farms (Knepp 2002a and 2002b) showed that the timing of the installation of barriers can significantly impact the timing and amount of vadose zone contamination from past leaks reaching groundwater.

Knowledge level: The knowledge level is low. Planning for final closure of tank farms has recently been initiated and the detailed schedules for closing individual farms are not defined.

Feasibility of Collecting Data: The feasibility of collecting data does not apply because timing of initial barrier placement is a management decision and not a technical input.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1A.

Path forward: The path forward consists of performing risk assessments using various assumptions of barrier emplacement to provide information to remediation decision makers regarding the sensitivity of groundwater impacts to timing of initial barrier placement.

An interim barrier covering the T-106 release plume is scheduled for construction this year.

Limitations: Timing of initial barrier placement is a management decision and not a technical input.

4.4.4 Recharge Effects from Tank-Farm Infrastructure (Past Events)

Description: Tank farm infrastructure can directly impact the amount of vadose zone moisture beneath tank farms available for transporting contaminants from past leaks. Water from tank farm operations comes from many sources:

- Water and transfer line leaks
- Underground structures near the surface that could trap water
- Above ground structures (e.g., roofs and foundations) that concentrate moisture
- Water run-on from overland flow
- Lateral subsurface flow from outside the tank farms.

Origin: This is an existing data gap from Jones et al. (1998), but has been split into past events (this gap) and future events (Section 4.4.6).

Information Type: Data.

Impact: The impact of this data gap is unclear. Moisture can be added to the system by leaks from water lines, transfer lines, spills, or tank leaks. The amount of water added by transfer

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lines, spills, and tank leaks are thought to be small (usually less 10,000 gallons) compared to the other sources. Even large tank leaks are projected to have small impacts in the risk assessments performed as part of FIRs (Knepp 2002a and 2002b) and tank closure risk assessments (Mann and Connelly 2003 and Connelly 2004). However, large amounts of water (>100,000 gallons) over a long period of time (years) may have leaked from water lines (e.g., the water line south of the SX tank farm). During 2001 to 2003, all unused water lines entering tank farms were capped off and the remaining water lines that are in use were hydraulically tested to ensure integrity.

The role of the large underground waste tanks in diverting and concentrating moisture flow in the subsurface (the so-called umbrella effect) has been evaluated with risk and performance assessment models. Tank-farm structures can also serve as moisture traps in the subsurface, leading to higher moisture contents above the tanks.

Above ground structures (e.g., the 242 S evaporator and huts over lateral access ports) are located inside or adjacent to tank farms. The roofs of these structures shed precipitation and concentrate the water in small areas. The result is a net localized increase in the overall recharge rate.

The tank farms were constructed at elevations lower than the processing plants to facilitate liquid transfer from the plants to the tank farms. Surface water flow from rain storms and snow melt (overland flow) has been documented to collect (and pond) inside the tank farms. During 2001 to 2003, berms and gutters were installed in and around tank farms to eliminate moisture flow onto the SST farms.

Waste discharge cribs are located near most tank farms. Lateral flow from past operations of these cribs has been documented at the 216-U-1 and U-2 crib (Baker et al. 1988), and recent HRR measurements at the BC cribs and trenches (Rucker and Sweeney 2004) have shown that vadose zone moisture can move laterally significant distances.

Knowledge level: The knowledge level for this data gap is low. The impacts of current and future recharge will be minimized because the sources (waterline leaks and run-on) have been controlled or eliminated. However, knowledge of the impacts from past waterline leaks, run-on events, and possible flow from nearby cribs is poorly known at present.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is low. There is no indication that records were kept to enable quantitative estimates of past waterline leaks or run-on events. Measurement of increased moisture (caused by lateral water flow from nearby cribs) may be possible by the use of high resolution resistivity (implemented through SGE) where the water is co-located with salts or contaminants, as demonstrated in the BC cribs and trenches as well as the T tank farm.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B.

Path Forward: The path forward includes continuing opportunistic review of literature (including photos) of past events. The integrity of pipelines that are not capped needs to be

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monitored as well as the performance of berms and gutters installed to control surface-water run-on from overland flow.

Limitations: Past recharge events (storms or water line leaks) are poorly documented or quantified, so indirect inferences must be used.

4.4.5 Surface Barrier Performance During Design Life

Description: Surface barriers are planned to be installed as part of tank farm closure. Although a prototype barrier has been installed at the Hanford Site and work has been done on barrier design, the barriers specific to tank-farm closure have not been designed. Surface barrier design will include specification of a design life during which the barrier will perform as intended. A key aspect of surface barrier performance will include barrier performance during design life.

Origin: *This is a new data gap, included because of expanded scope of the TFVZ Project.*

Information Type: Data.

Impact: The impact of this data gap is indirect. For past tank leaks and future potential retrieval leaks, the current recharge through the gravel surface has been demonstrated to be important. The recharge rate during the surface barrier design life was shown in the initial SST PA to be less important than recharge after the design life of the barrier (DOE-ORP 2006).

Knowledge Level: The knowledge level for this data gap is medium as documented in (Fayer 2004). However, this analysis is for a conceptual design. The detailed design goal for recharge rate is likely to be below 0.5 mm/yr.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high. As designs are finalized, their performance will be evaluated through numerical modeling and instrumentation will be included in the design to evaluate surface barrier performance after emplacement.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 3.

Path forward: The path forward is to continue data collection and analysis from instrumented field-scale barriers (such as the prototype) and from planned field-scale barriers (such as those planned to be emplaced over U Plant cribs and over BC cribs and trenches).

Limitations: Concern has been expressed that low estimates of recharge rates are not valid. Projection of long-term behavior, by its nature, is problematic.

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4.4.6 Impacts of Episodic Events on Long-Term Recharge Estimates

Description: Recharge is driven by episodic events (rain, snow melting, waterline leaking), but is generally represented as an average over many years in computer models. The impacts of episodic events are important both for existing gravel covers and future surface barriers used for tank-farm closure.

Origin: This data gap is new from issues raised by stakeholders.

Information Type: Data and analysis.

Impact: Recharge is the result of a combination of discrete precipitation events that occur episodically, discontinuously, and with various intensities. These precipitation events include rainfall, snowmelt, and run-on from surrounding areas. The importance of episodic events may be more significant for gravel covers where rapid infiltration can drive moisture deeper in the profile than for finer-grained sediments where evapotranspiration can remove water and reduce recharge and deep drainage. Therefore, the impact of episodic recharge on tank-farm risk assessments is direct.

For modeling purposes, an effective long-term average recharge rate is generally used to represent the flux of moisture entering the system. The key question is whether the recharge estimation methods cover sufficient time to capture the entire range of infrequent episodic events and produce credible estimates of the true means for the various soil and tank farm covers that exist at the Hanford Site.

Knowledge level: The current knowledge level for long-term recharge impacted by episodic events is acceptable and is documented in (Fayer 2004). Both short-term (through the use of lysimeters and fluxmeters) and long-term (through the use of natural tracers in the soil) estimates are used to estimate the effective recharge rates for various soil covers. The tracer data averages over hundreds of years and thus provides an effective average for natural soil and vegetation cover at the Hanford Site. No such long-term data exists for conditions of disturbed soil conditions such as tank-farm gravel surfaces or for surface barriers, so short-term measurements must be extrapolated through the use of computer modeling. Although the data and methods have been reviewed both internally and externally, some regulators are not convinced. Short-term measurements (e.g. drainage, pressure head) for gravel covers and surface barrier analogs have been made in lysimeters and used to estimate effective recharge estimates. Such experimentation has included rare storm events (e.g., 500 and 1,000 year storms) as well as more constant stress tests (two and three times current precipitation rates).

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high, but limited to the short term (a few years to decades). Long-term experiments (tens to thousands of years) for new facility components (e.g. surface barriers) are not possible because of the time durations monitoring would require. The prototype surface barrier over the 216-B-57 crib

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(immediately north of the BY tank farm) has been monitored since it was constructed in 1994 and will continue to be monitored for the foreseeable future.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 4.

Path forward: The path forward consists of continuing to review on-going work (such as the performance of the existing prototype barrier and the planned barriers over U Plant cribs and the BC cribs and trenches).

Limitations: Events that contribute to recharge are episodic and infrequent, thus it is difficult to estimate their impact on long-term recharge rates. Establishing a long-term data set to verify that recharge estimates for surface barriers can appropriately represent such episodic events requires interface with multiple programs (e.g., Hanford Surface Barrier on B-57; U Plant covers to-be-built).

4.5   GEOHYDROLOGY

Water flow through the vadose zone provides the driving force to move contaminants from their sources to the groundwater and then to the receptor. Items identified in the current effort (geohydrology) were grouped into three categories: (a) facility containment, (b) vadose zone, and (c) groundwater.

4.5.1   Contaminant Contribution to Groundwater from Nearby Non-Tank Farm Sources

Description: Groundwater monitoring at the Hanford Site is integrated by groundwater interest areas (Hartman, Morasch, and Webber 2006). These groundwater interest areas include groundwater operable units that lie within the interest areas. The Groundwater Remediation Project defined these groundwater interest areas to aid in planning, scheduling, and interpreting groundwater data for *Resource Conservation and Recovery Act* (RCRA) facilities and *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) past-practice sites, as well as *Atomic Energy Act* monitoring. Groundwater monitoring is performed on indicator parameters that once exceeded, trigger assessment of contaminants and characterization. Monitoring has shown that in many cases, groundwater concentrations are many times drinking water standards. However, it is sometimes difficult to determine the source of contamination because in those cases, tank waste was deliberately discharged to ground in close proximity to the tanks.

Origin: This data gap is new, from integration efforts among Central Plateau projects.

Information Type: Analysis and data.

Impact: The impact of this data gap is direct. The analysis of contaminant source influences strategies for remediation and closure of tank farms and nearby cribs and trenches. Proper remediation depends on knowing where the source is located.

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Knowledge Level: The knowledge level is low to medium. There has been little effort to identify specific leaks and discharges as the source of specific groundwater contamination plumes. The Groundwater Remediation Project monitoring attributes groundwater contamination to known or suspected SST leaks as well as past-practice discharge cribs. In some cases, groundwater monitoring points to a specific source (e.g. technetium-99 from the BY cribs [Hartman, Morasch, and Webber 2006]); but in others, it is difficult to determine whether existing groundwater contamination is from a past tank leak or waste discharge to a past-practice discharge site (e.g. uranium in WMA B-BX-BY). Resolving the source is an integration issue between the TFVZ Project and past practice waste site investigations.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high. Detailed analyses of the historical groundwater chemistry data can be performed. Bulk water chemistry and ratio of radioisotopes from groundwater and vadose zone samples can be used to delineate between tank-farm sources and past-practice waste discharges, if the two sources have different isotopic "signatures." Surface geophysical exploration (SGE) can be used to identify deep vadose zone contaminant plumes that may have impacted groundwater if those plumes include salts that produce an electrical signature.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1A.

Path Forward: The path forward consists of developing an integrated groundwater/vadose zone approach to evaluate groundwater data. The integrated effort will perform detailed analyses of historical groundwater chemistry data and evaluate isotope geochemistry to delineate sources. The integrated activities will also evaluate SGE survey results to identify deep vadose zone contaminant plumes that may have impacted groundwater.

Limitations: This data gap crosses the responsibilities of ORP and DOE RL as well as multiple contractors and therefore requires integration of investments.

4.5.2 Short-Term Temporal and Spatial Variation in Groundwater Contaminant Concentrations

Description: Groundwater monitoring at the Hanford Site is integrated by groundwater interest areas (Hartman, Morasch, and Webber 2006). These groundwater interest areas include groundwater operable units. The Groundwater Remediation Project (groundwater project) defined groundwater interest areas to assist in planning, scheduling, and interpreting groundwater data for RCRA facilities and CERCLA past-practice sites, as well as Atomic Energy Act monitoring.

Groundwater monitoring results immediately east of the T tank farm indicate a high-concentration plume of multiple contaminants about 40 feet below the water table in addition to lower, but nearly uniform contaminant concentrations from 40 feet down to 120 feet below the water table. This contaminant distribution cannot be easily explained with our current knowledge of sources and contaminant transport.

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Origin: This data gap is new and arose from recent (2003) collection of groundwater monitoring data as a function of depth below the water table.

Type of Information: Analysis and data.

Impact: The impact of this data gap is unclear. Recent technetium-99 monitoring data near the T WMA point to a lack of understanding of contaminant sources and possible movement from the vadose zone into the water table.

Knowledge Level: The knowledge level for this data gap is low. Present understanding of sources and transport do not explain monitoring results.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high. Various techniques (understanding of source inventories, modeling, reanalysis of groundwater monitoring data, additional monitoring data, added characterization data of vadose zone plumes, and added use of radioisotope ratios) can be combined.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B. (This data gap crosses DOE ORP and DOE RL as well as multiple contractors.)

Path Forward: The path forward is continuation of multi-contractor efforts (with the support of the DOE field offices and regulatory agencies) to develop plans for characterization of the affected groundwater operable units and overlying vadose zone sources.

Limitations: This data gap crosses the responsibilities of DOE-ORP and DOE-RL as well as multiple contractors and therefore requires integration of work scope.

4.5.3 Hydraulic Properties for Facility Containment System

Description: To simulate water infiltration and contaminant transport through the vadose zone under post-closure conditions by advection or diffusion processes, data are needed for hydraulic properties of the various materials and how those properties change over time. It is expected that a closed tank system will consist of an outer concrete shell, the metal liner, and grout fill.

Origin: This is a new data gap, because of the expanded scope of the TFVZ Project.

Information Type: Data and analysis.

Impact: The impact of this data gap is unclear. Release of contaminants to the vadose zone from a tank farm that has been closed will be complex. Efforts are just beginning to define the modeling approach for post-closure conditions, so the importance of hydraulic parameters is not known.

Knowledge Level: The feasibility of collecting additional data to resolve this gap is low. Hydraulic properties of the external concrete shell are unknown and little work has been

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performed for liner materials, especially as they have aged through time in contact with waste. In addition, grout compositions to be used to fill the retrieved tanks have not yet been selected.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high. Samples of concrete shells can be obtained from the domes of the tanks. When grout fill compositions are determined, their hydraulic properties and transport characteristics can be measured. However, finding analogous materials to represent highly aged (>100 years) grout will be difficult.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B.

Path Forward: The path forward consists of determining hydraulic properties of tank shell, liner and fill materials as they become available and performing model simulations.

Limitations: The tanks are currently in use as storage facilities and breach of containment is unacceptable. It may be possible to collect samples if new access ports are drilled to support tank retrieval. Grout fill compositions have not yet been selected.

4.5.4 Vapor Flow Under Low Recharge

Description: Moisture contents in sediments around tanks are expected to be very small (less than 5 weight percent) after surface barriers are installed based on the low recharge rates. At such low moisture contents, vapor flow and transport may be important.

Origin: This data gap is new based on extrapolation of moisture contents associated with lower recharge rates.

Information Type: Analysis.

Impact: The impact of this data gap is unclear. In general, water flux includes both liquid and vapor phases. During the tank farm operational period, the infiltration rate through the gravel-covered surfaces can be as high as 100 mm/yr. Under such conditions, contribution of downward liquid fluxes is considerably larger than that of any potential vapor flux. As part of the tank closure process, an engineered barrier will be placed over a tank farm. The downward liquid flux through an intact barrier can be as low as 0.05 mm/yr. With infiltration through the engineered barrier approaching zero, the contribution of vapor fluxes to the water flux is expected to be significant.

Knowledge level: The knowledge level is low. With an engineered barrier in place, the magnitudes of water fluxes can potentially be close to the uncertainties inherent in measuring or calculating these fluxes, which make it difficult to resolve basic issues such as direction and rate of water movement and controls on unsaturated fluid flow. The direction and rate of water flow are affected not only by hydraulic head (sum of matric potential and gravity) gradients but also by temperature and air pressure gradients. Furthermore, vegetative cover may be one of the primary controls on the magnitude of water flow in the unsaturated zone in an arid setting.

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Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is low. Prior to evaluating the feasibility of collecting additional data, the data collected at the Hanford Site as part of long-term recharge studies and tracer (chlorine-36 and chloride mass balance) measurements will be examined.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B.

Path Forward: The path forward to evaluate the importance of vapor flow includes literature review of long-term paleoclimate controls on water fluxes for thick vadose zones in arid and semi-arid settings (e.g., past work by PNNL and work at other sites including Beatty, Nevada; Ward Valley, California, and Australia) as analogs to evaluate importance of potential vapor flow under low infiltration.

Limitations: Data on Hanford sediment properties (e.g., unsaturated hydraulic conductivity) are sparse for low moisture contents under arid recharge conditions.

4.5.5 Hydraulic Properties at Low Saturation

Description: Moisture contents in sediments are expected to be very small (less than 5 weight percent) after surface barriers are installed based on the low recharge rates. However, unsaturated moisture flow theory and parameters are based on much higher levels of moisture content.

Origin: New. New information is being generated from extrapolation of existing moisture contents to lower recharge rates.

Information Type: Data.

Impact: The impact of hydraulic properties at low saturation on contaminant transport through the vadose zone is unclear. Knowledge of unsaturated hydraulic conductivity (K) and its dependence on water content (θ) is essential in understanding and predicting vadose zone flow and contaminant transport. Due to the difficult nature of experimental characterization of the $K(\theta)$ relationship, hydrologists often rely on measurement of the pressure-water content (or saturation) relationship and predictive models. Most of the theoretical models for predicting $K(\theta)$ invoke use of the capillary bundle model as an idealization of the porous medium and subsequent derivation of Darcy's law on the basis of an equivalent, Hagen-Poiseuille equation for flow through the capillary bundle. The models use a tortuosity term to describe and quantify the non-ideal fluid flow through tortuous flow paths representing sediment grains in porous media, compared with flow through an idealized capillary bundle. Furthermore, these models invoke the capillary pressure-desaturation relationship as a surrogate descriptor of the actual pore radii distribution to calculate flow velocity by the Hagen-Poiseuille equation. In spite of various empiricisms, the resulting models have been found to reasonably predict the $K(\theta)$ relationship, especially for the relatively high moisture regime. In particular, the Brooks-Corey model (Brooks and Corey 1966) and the van Genuchten-Mualem model (van Genuchten 1980 and Mualem 1976) are widely used to estimate $K(\theta)$. Khaleel et al. (1995), however, found

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considerable disagreement, especially in the intermediate to low moisture range, between actual $K(\theta)$ measurements and those predicted by the van Genuchten-Mualem model for the coarse-textured sediments from the Hanford Site.

Knowledge level: The knowledge level for this data gap is low. Currently, for flow modeling to support the field investigation reports and tank closure risk assessments, the van Genuchten-Mualem approach is used to describe the closed-form analytical relations for the moisture retention and $K(\theta)$ input parameters. The laboratory-measured moisture retention and unsaturated hydraulic conductivity data are fitted simultaneously using a curve-fitting code to obtain the desired parameters. To obtain a better fit of the fitted van Genuchten curve to actual measurements, the saturated hydraulic conductivity (K_s) is treated as a fitted parameter, as opposed to treating K_s as a fixed parameter. While such an approach appears to be reasonable for the intermediate moisture regime, the approach is relatively untested for the low moisture contents of the order of 2 to 4 percent (on a volume basis). A primary limitation is the general lack of experimental data for the desired moisture regime. However, a number of data sets are available (Wright et al. 1994; Khaleel and Relyea 1997; Khaleel and Heller 2003) that provide data on Hanford soil properties at low water contents.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this data gap is medium. The ultracentrifuge method may provide the best opportunity for collecting additional direct measurements of unsaturated hydraulic conductivity at low moisture contents. However, the ultracentrifuge method suffers from potential subsidence of samples during rotation in the centrifugal field. Moisture content data at low moisture contents can also be obtained in the laboratory using a vapor adsorption technique. The direct measurements will be combined with methods to extrapolate data under wet and intermediate water contents to low moisture contents.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B.

Path forward: The path forward for resolution of this data gap consists of reviewing past Hanford work on soil hydraulic properties (e.g., ultracentrifuge measurements) and at other sites to extend existing database on relatively wet and intermediate water contents down to low moisture contents more relevant to vadose zone conditions that will be characteristic of closed tank farms. Modeling can be performed to determine if the potential errors at the low water contents will have significant impact on performance assessment simulations.

Limitations: Data are sparse on Hanford sediment properties (e.g., unsaturated hydraulic conductivity) for low moisture contents under arid recharge conditions.

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4.5.6 Contaminant Dispersion in Groundwater

Description: Groundwater contaminant plumes disperse as they move downgradient. This process is represented in numerical groundwater transport models in the form of dispersion coefficients.

Origin: This data gap is new; groundwater transport was not a major focus of the TFVZ Project Phase 1 characterization.

Information Type: Analysis.

Impact: The impact of this data gap depends on location. Impacts from groundwater dispersion are expected to be low at tank farm fence lines because of the relatively short transport distances; but, impacts will be high at the Columbia River because of the longer travel distances. At the tank farm fence lines, dilution is primarily the result of low vadose zone water and contaminant flux mixing with relatively high groundwater flux. However, as the distance from the tank farm fence lines increases, dispersion becomes more important.

Knowledge Level: Low. Dispersion values are calculated based on theory.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. Extensive groundwater monitoring data are available that may be useful for analysis.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 2 (Scope outside of TFVZ Project).

Path Forward: The path forward is to use Hanford Site groundwater monitoring data in groundwater transport model calibration and to perform history matching.

Limitations: There are limited groundwater field data sets for interpretation and development of dispersion estimates. Because of overlapping Hanford groundwater plumes, separating those groundwater plumes is difficult. Changing groundwater flow directions over time at numerous locations complicates the analysis.

4.5.7 Anisotropy and Vadose Zone Lateral Flow

Description: The heterogeneous nature of Hanford sediments results in significant moisture-dependent anisotropy and lateral flow, depending on the flow regime. This has been illustrated by the moisture content profiles at the controlled field injection experiment (also known as the Sisson and Lu site) in 200 East Area. This site was recently used for a series of infiltration tests (Ward et al. 2006). The measured moisture content profiles at the Sisson and Lu injection site after serial injection of water and tracers clearly illustrate significant lateral spreading.

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The preponderance of lateral migration of water and solutes is also evident elsewhere at the Hanford Site. The tank 241-T-106 leak (115,000 gallons) is the largest known tank leak. The leak occurred in 1973 at a bottom edge of the tank. The vadose zone profile clearly shows that, even after 20 years of migration, the peak concentrations of the long-lived mobile radionuclide are primarily found within fine-textured horizons at a depth of 35 to 40 m (115 to 130 ft) below ground surface (bgs) and well above the water table (Freeman-Pollard et al. 1994; Serne et al. 2004b). These field data suggest that the natural heterogeneity of the Hanford sediments plays an important role on lateral flow and transport, and the significant lateral migration which is in fact induced by media heterogeneities is highly effective in containing the vertical extent of plumes within the vadose zone for an extended period of time.

Origin: This data gap is new and was defined by emerging work scope.

Type of Information: Data and analysis.

Impact: The impact of this data gap is unclear. Lateral spreading, in general, reduces the potential for vertical migration to groundwater. However, lateral spreading could, in some circumstances, move contaminants into regions of higher recharge and/or higher moisture content, thus enhancing vertical contaminant movement.

Knowledge level: The knowledge level of the impacts of anisotropy and lateral flow on moisture movement and contaminant transport in the vadose zone is medium. The moisture content profiles at the controlled injection site in 200 East Area and the contaminant concentration profiles for the T-106 tank leak in 200 West Area suggest considerable lateral flow and migration. Such behavior is related to moisture-dependent anisotropy. Theoretical work (e.g., Mualem 1984; Yeh et al. 1985a, b, c; Mantoglou and Gelhar 1987; Green and Freyberg 1995; Zhang et al. 2003; Yeh et al. 2005), numerical simulations (e.g., Desbarats 1998; Wildenschild and Jensen 1999b; Polmann et al. 1991;Yeh et al. 2005) and experimental studies (e.g., Yeh and Harvey 1990; McCord et al. 1991; Wildenschild and Jensen 1999a) of field-scale unsaturated flow indicate that the effective hydraulic conductivity tensor for stratified sediments can exhibit moisture or tension dependent anisotropy. Thus, the anisotropy ratio of longitudinal to lateral hydraulic conductivity increases with increasing tension (decreasing moisture content). For solute transport, several studies (e.g., Mantoglou and Gelhar 1985; Polmann 1990; Russo 1993; Harter and Yeh 1996; Roth and Hammel 1996; Birkholzer and Tsang 1997) suggest that the anisotropy caused by small variations in dispersivity of unsaturated media increases with a decrease in saturation.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. Controlled data sets for testing of various theoretical models are limited; additional field experiments could be performed as necessary. A project is underway to evaluate different theoretical and mathematical models to represent anisotropy.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 3.

Path forward: While the theory is well established and moisture-dependent anisotropy is a viable large-scale controlling phenomenon for the ubiquitous lateral migration in Hanford

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sediments (Ye et al. 2005; Yeh et al. 2005; Ward et al. 2006), controlled field sites (other than the Sisson and Lu site and the clastic dike site studied along Army Loop Road) do not exist. Further testing of the theory may be conducted at the Sisson and Lu Site as well as extending results to other locations, such as the BC cribs and trenches and the T-106 tank leak.

Limitations: A limited number of field sites and controlled data sets are available to test methodology.

4.5.8 Small-Scale Stratigraphy

Description: Geologic formations at the Hanford Site are highly heterogeneous at scales of various lengths. A conventional approach to modeling flow and transport in geological formations is to incorporate into flow and transport modeling the overall heterogeneity of the system such as geologic layering. However, grid size used in modeling is often too coarse to include the fine-scale heterogeneities (thin layers, including paleosols) present within individual formations.

Origin: This data gap is new; the importance has emerged based on Phase 1 characterization.

Information Type: Data and analysis.

Impact: The impact of this data gap is indirect. Extensive borehole sediment sampling and neutron moisture logging in tank farm boreholes have created a data base that can be used to determine fine layers a few centimeters thick.

Knowledge level: The knowledge level is medium. The importance of small-scale stratigraphy is highlighted by the site characterization data at the BC cribs and trenches in the 200 East Area and the T-106 tank leak as well as field experimental sites documented in Ward et al. (2006). The waste sites received approximately 30 million gallons of scavenged tank waste, with possibly the largest inventory of technetium-99 (approximately 411 Ci) ever disposed to the soil at the Hanford Site (Corbin et al. 2005). There is no evidence that the BC cribs and trenches waste has reached groundwater, even though the high-volume discharges occurred in the 1950s. In fact, recent characterization data at the 216-B-26 crib suggest that the bulk of the technetium-99 plume is concentrated within a depth of 35 to 40 m (115 to 130 ft) bgs. It is postulated that the unique features of the site (i.e., an alternating sequence of imperfectly stratified fine and coarse layering) had a profound effect on lateral flow and restricted vertical movement of the technetium-99 to almost 50 m (165 ft) above the water table. The laterally discontinuous small-scale fine layers increase lateral flow and restrict the vertical migration of contamination from the BC cribs and trenches. The effect of small-scale features in an imperfectly stratified medium is also evident at the neighboring controlled injection experiment (Ye et al. 2005; Yeh et al. 2005; Ward et al. 2006), where field data demonstrate that higher moisture contents associated with fine silty layers and relatively low moisture contents associated with coarse layers produce pronounced lateral flow.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is low. Small-scale features are typically difficult to characterize because of the directional (vertical)

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nature of borehole drilling. Additional field experiments could be performed and methods have been developed to extrapolate structural information to borehole data (Ward et al. 2006).

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 3.

Path forward: The path forward consists of reviewing existing characterization data and collecting additional data to ascertain the lateral extent of the small-scale features controlling vadose zone flow and transport and frequency of occurrence in vertical as well as lateral directions. Geostatistical analyses will be used to describe spatial correlation lengths and other parameters. The existing database will allow transfer of postulated relationships from one site to other sites with similar geologic characteristics.

Limitations: Availability of data on the lateral extent of small-scale features will always be limited because of the vertical orientation of drilling. Additional field experiments could be performed as necessary.

4.5.9 Upscaling Hydraulic Properties

Description: Geologic formations at the Hanford Site are highly heterogeneous at various length scales. A conventional approach to modeling flow and transport in geological formations is to incorporate an overall description of system heterogeneity (such as geologic layering) into flow and transport modeling. An alternative approach is to define an equivalent homogeneous medium with upscaled (effective or macroscopic) flow and transport properties and thereby predict the mean flow and transport behavior at the field scale. To represent a heterogeneous medium by its homogeneous equivalent, one needs to estimate the effective flow and transport properties that represent this equivalent homogeneous medium.

Origin: This data gap is new, with importance established based on Phase 1 characterization.

Information Type: Analysis.

Impact: The impact of this data gap is direct. Hydraulic properties affect contaminant travel time through the vadose zone. For past tank and waste site releases (the category of waste sources with the greatest impact), groundwater impacts are inversely proportional to the travel time.

Knowledge level: Medium. In recent years, several studies have been conducted on deriving upscaled flow (i.e., effective unsaturated hydraulic conductivity and moisture retention) and transport (i.e., effective macrodispersivity) properties for vadose zone sediments at the Hanford Site. These include a conditional simulation approach (Rockhold et al. 1999) to derive effective unsaturated conductivity; an unconditional stochastic theory based numerical simulation approach (Khaleel et al. 2002) to derive effective unsaturated conductivity and macrodispersivity; and a connectivity–tortuosity tensor concept (Zhang et al. 2003) for estimating effective unsaturated conductivity. A stochastic theory based effective parameter approach was used in deriving large-scale flow and transport modeling parameters for field

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investigation reports (Knepp 2002a and 2002b) and closure risk assessment (Connelly 2004). This approach relies on small, laboratory-scale measurements to obtain large-scale, macroscopic parameter estimates.

The Vadose Zone Transport Field Study documented in Ward et al. (2006) developed several methods for upscaling hydraulic properties. These include development of methods for calculating field-scale hydraulic parameters by inverse modeling of an injection experiment and developing pedotransfer functions for describing fine-scale heterogeneity and incorporating the functions into reactive transport models. The pedotransfer functions are based on grain-size statistics, and thus can be used to extend from one geologic media to other similar media at the Hanford Site.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. While controlled data sets for testing of various theoretical models are limited; additional field experiments could be performed as necessary. In addition, the methodologies developed as part of the Vadose Zone Transport Field Study (Ward et al. 2006) can be extrapolated to similar geologic media with additional field measurements such as borehole neutron logging.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 3.

Status and Path Forward: Several approaches (Yeh et al. 2005, Ward et al. 2006) have been developed and are currently being used in deriving large-scale, macroscopic flow and transport parameters for unsaturated Hanford sediments. The path forward is to compare the various methods, and where appropriate, test the approached against field data (e.g., controlled field experiments at the Vadose Zone Transport Field Study sites [Sisson and Lu site]) in the 200 East Area and along Army Loop Road.

Limitations: A limited number of field sites and controlled data sets are available to test methodologies that have been developed.

4.5.10 Preferential Flow Paths

Description: The vadose zone flow and transport simulations for the field investigation reports and closure risk assessments are based on a porous continuum modeling assumption. This assumption is supported by field data on moisture and contaminant plumes at various controlled and uncontrolled experiment sites. The use of a continuum model precludes considering any preferential pathways such as unsealed boreholes or permeable portions of clastic dikes.

Origin: This data gap is new and is included based on stakeholder comments.

Information Type: Data and analysis.

Impact: The impact of this data gap is indirect. While preferential flow paths exist, they are unlikely to intersect large segments of leaked wastes. It is hypothesized that when preferential flow pathways intersect leaked waste, the cross-sectional area of the intersection is typically

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small. Therefore, preferential pathways are hypothesized not to exert much influence on the transport of leaked wastes from tanks. This conclusion is supported by analyses reported in the S-SX FIR (Knepp 2002a).

Studies suggest that, although preferential flow has been recognized and widely studied under saturated or near saturated flow conditions (Nkedi-Kizza et al. 1983; De Smedt and Wierenga 1984), there is little evidence of it in arid and semiarid climates or under low water flux conditions, particularly where soils are coarse-grained such as those under the Hanford tank farms. While preferential flow may have been important in the migration of tank leaks in the past, it is unlikely to be important in the future under low moisture conditions resulting from natural recharge.

Knowledge level: The knowledge level associated with the impact of preferential flow paths is acceptable. Based on laboratory measurements of clastic dike samples and field investigations from an Environmental Management Science Project (EMSP) (Murray et al., 2003) and previous work by Fecht et al. (1999), the characteristics of clastic dikes are well known. The impacts of clastic dikes have been shown to be small in various Hanford Site risk Assessments (e.g., Wood 1995, Wood 1996, DOE/RL 1999, Mann 2001, Knepp 2002a, and DOE/ORP 2006).

Feasibility of Collecting Data: The feasibility of collecting additional data for this gap is medium to low. Prior to evaluating feasibility of collecting additional data, data collected as part of the EMSP research on clastic dikes will be examined.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 4.

Path forward: The path forward to evaluate the importance of preferential flow will include a review of past work at Hanford (i.e., Fecht et al. 1999 and Murray et al. 2003). Also, the past numerical simulations involving clastic dikes will be revisited to ascertain the contribution of water fluxes through dikes versus that through the surrounding porous matrix.

Limitations: There are no significant limitations. Data are available on the nature, geometry and extent of clastic dikes at the Hanford Site. Data are also available on hydraulic properties of dike filling material.

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4.6 GEOCHEMISTRY

Geochemistry impacts contaminant release (Section 4.3) from waste forms as well as contaminant transport through the vadose zone and groundwater.

4.6.1 Waste Chemistry Effects on Uranium(VI) Mobility in the Vadose Zone

Description: Tank wastes have highly varied and extreme composition histories (far from equilibrium with natural subsurface conditions) with pH values above 14 that influence subsurface uranium(VI) migration by promoting chemical reactions with the native subsurface sediments. All tank wastes had large amounts of sodium and nitrate and most had large amounts of phosphate, sulfate and carbonate. The leakage of these wastes created chemical and mineralogic changes in the sediments beneath the leaking tanks affecting contaminant mobility. For uranium(VI), the presence of dissolved inorganic carbon (carbonate and bicarbonate), phosphate, and pH had large effects on uranium(VI) migration through formation of strong, anionic aqueous complexes that influenced adsorption, solubility, and mineral precipitation. Among the aqueous complexes, those with carbonate ($UO_2(CO_3)_2^{2-}$, $UO_2(CO_3)_3^{4-}$, and $CaUO_2(CO_3)_2^0$) are the most prevalent in Hanford pore waters.

Origin: This was an existing data gap from Jones et al. (1998) that remains. The original data gap was split into this one for uranium and a second data gap for other contaminants (Section 4.6.5).

Information Type: Data and analysis.

Impact: The impact is direct for uranium(VI) in the Hanford vadose zone.

Waste chemistry has significantly impacted the subsurface mobility of dissolved uranium(VI) [uranyl; UO_2^{2+}]. While laboratory and field studies indicate that uranium interactions with vadose zone sediments are sensitive to the chemistry and temperature of the released waste fluids, a generalized understanding of these interactions that could allow defensible predictions of future mobility does not exist. For example, the fate of uranium that entered the vadose zone from the BX-102 overfill appears especially enigmatic. Uranium appears to have migrated laterally distances of 25 m and to depths 30 m (82 to 98 ft) below the tank bottom quickly during the overfill event itself. But subsequent to the overfill event, a significant amount of the uranium has precipitated as sodium uranyl silicates within deep fractures in mineral grains, thus limiting the amount of uranium available for transport (Appendix D of Knepp 2002b, Liu et al. 2004b, Catalano et al. 2006, and McKinley et al. 2007). At borehole C3832 near tank TX-104, uranium appears to be quite mobile in the vadose zone within the Hanford formation but upon reaching the Cold Creek lower subunit, which is enriched with caliche, a moderately strong binding of uranium(VI) is found. More details are found in Appendix D of Myers (2005). Solid phase characterization of uranium(VI)-rich sediments from the vadose zone near the BX-102 overfill and the TX-104 leak suggests that the geochemical reactions responsible for uranium retardation

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are strikingly different between these two sites. These differences are tentatively attributed to differences in waste chemistry and temperature, but additional research is needed to establish clear cause-effect relationships. Ongoing research on uranium(VI) mobility in vadose zone and aquifer sediments from the 300 Area (not tank related) has also demonstrated that waste composition can have long-term effects on uranium(VI) mobility by influencing the chemical nature and physical location of sorbed uranium (Qafoku et al. 2005, Wang et al. 2005, and Catalano et al. 2006). More work is needed to understand the interrelationships between waste stream chemistry and sediment mineralogy on the mobility of uranium at the Hanford Site.

Knowledge Level: The knowledge level is low. Studies of uranium(VI) in the vadose zone at several tank farms and at soil waste sites have indicated that uranium(VI) adsorption/precipitation properties vary significantly between locations. Understanding of the mobility and long-term migration potential of uranium(VI) released from tanks and tank infrastructures is lacking.

An especially important technical need is to understand how the tank waste chemical composition may impact the mobility of in-ground uranium(VI) in the vadose zone. As discussed in Knepp (2002a, Appendix D), how the center of mass of uranium has changed from being highly mobile to rather immobile in the vadose zone proximate to tank BX-102 and where the groundwater uranium plume east of the BX tank farm has its source is not adequately understood.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is high. Studies are underway to determine the long-term release and mobility of uranium presently sequestered in the vadose zone.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1A.

Path Forward: Iterative "tiered" characterization will be performed on each new borehole collected in the tank farms. If new contaminants are discovered that were not present in past boreholes, or if the concentration of contaminants are larger than at other boreholes, or if the distribution of any contaminant versus depth appears to be different from past distributions that we understand, then specific attention will be given to improving our understanding of the geochemical attributes of the contaminant. Water, acid, or other reagents will be used to leach the contaminants from the sediments, as an initial assessment of their speciation and mobility. The characterization information will then be compared to the existing knowledge base to see if the results are consistent with current conceptual models of geochemical reaction and retardation. State-of-the-art spectroscopic and microscopic instrumentation such as microbeam-X-ray fluorescence, diffraction, and X-ray absorption spectroscopy will be used to identify the solid surfaces and crystalline structures with which uranium is associated. More involved experimentation to identify how mineral association controls uranium desorption and dissolution kinetics will continue as a part of the Vadose Zone Characterization Project, EMSP, and Tank Farm Vadose Zone science and technology efforts. Efforts of this type will continue at BX-102, TX-104, and in the 300 Area and any new location where significant concentrations of uranium are encountered until we determine what processes are controlling uranium

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geochemistry at each location with the overall goal to determine a "unifying" conceptual model for uranium(VI) fate at Hanford.

Limitations: Mechanistic studies can be difficult and costly. A concerted effort over the past three to four years has been undertaken to identify geochemical reactions controlling dissolved uranium(VI) concentrations in contact with Hanford sediments and to identify the nature and behavior of uranium in contaminated sediments using state-of-the-art instrumental and experimental methods. Results to date have shown that a different reaction series has apparently occurred between uranium and the native sediments at each site, giving rise to sorption complexes of different chemical composition, and thermodynamic and kinetic behavior. Studies continue in hopes of determining some commonalities and basic understanding of the controlling mechanisms. Currently the distribution coefficient (K_d) constructs are assumed to be adequate for determining long term risks, but for uranium(VI), K_ds can vary over a large range depending on waste stream composition and sediment lithologies.

4.6.2 Chemical Interactions between Concrete Shell and Tank Residue

Description: Single-shell tanks (SSTs) that are closed will consist of residual waste surrounded by engineered materials, primarily grouts. The hydraulic and geochemical properties of the concrete shell may affect the rate of release of contaminants from the residual materials and will likely impact future groundwater contaminant concentrations.

Origin: This is a new data gap, included because of expanded scope of the TFVZ Project.

Information Type: Data and analysis.

Impact: The impact of this data gap is unclear. The influence of tank construction components (concrete shell, carbon steel liner, grout fill) has not yet been investigated. Thus, it is unclear which component will be the most significant.

Knowledge Level: The knowledge level is low. No site-specific information has been collected on chemical interactions of waste with tank components. However, geochemical knowledge suggests that the hydrous oxides and hydroxides, which constitute the bulk of both tank sludge and concrete forming minerals and compounds that constitute hardened concrete, should be compatible. The concrete minerals and tank residual sludge both are relatively thermodynamically stable in alkaline to caustic environments. It is not known if trace constituents (the radionuclides, exotic fission products, and so on) in the sludge could have any deleterious impacts on the concrete shell. Also not understood is whether the combination of heat and radiation have had deleterious impacts on the inside of the concrete shell during the last 60 years of storage and what the potential drying of the atmosphere inside the tanks (after retrieval) might have on the concrete dome/mostly empty tank prior to final closure.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. It is unlikely that actual samples of the concrete shell of the single shell tanks will become available for study. However, sampling of residual sludge is part of the baseline closure activities.

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Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B.

Path forward: The path forward consists of performing a literature review on the aging of structural concrete in general with a specific interest on aging in the presence of heat, radiation, active ventilation with air, and immersion in caustic fluids. Hanford-specific information on all aspects of the structural integrity of the concrete SST will be scoured from the historical record to identify useful information. Then a laboratory test plan will be developed to test the interaction of appropriate analog concrete materials (both young and aged) with actual and in some tests simulated tank residuals.

Limitations: It may prove difficult to obtain realistic specimens of aged concrete or actual Hanford SST structural concrete for testing and the amount of actual residual sludge will likely be of limited mass. Most of the work will require use of analogs and at this time it is not clear what testing should be done to accelerate the aging conditions to represent the weathering of concrete to account for thousands of years of interaction.

4.6.3 Chemical Interactions between Tank Fill and Tank Residue

Description: Single-shell tanks that are closed are expected to consist of residual waste surrounded by engineered materials, primarily grouts. The hydraulic and geochemical properties of the grouts used as fill materials may affect the rate of release of contaminants from the residual waste and will likely affect the amount of groundwater impacts.

Origin: This is a new data gap, included because of expanded scope of the TFVZ Project.

Type of Information: Data and analysis.

Impact: The influence of the tank construction components (concrete shell, carbon steel liner, and grout fill) has not yet been investigated. Thus, it is unclear, which component will be the most significant.

Knowledge Level: The knowledge level is low. Limited site-specific information has been collected on this issue; however, assuming that the tanks will be filled with a cementitious grout, geochemical knowledge suggests that the hydrous oxides and hydroxides that constitute the bulk of tank sludge and the cementitious fill will form minerals and compounds that should be compatible. The cement minerals and tank residual sludge both are relatively thermodynamically stable in alkaline to caustic environments. It is not known if trace constituents (e.g., the radionuclides and exotic fission products) in the sludge could have any deleterious impacts on the grout weathering. The ratio of tank residuals to grout fill will be very low such that no significant deleterious interactions should be possible within the bulk volume of grout fill. Any reactions between the grout fill and residual waste should be localized at their interface. Work at Savannah River on grout fill (Langton et al. 2001; Langton et al. 2003, Langton and Harbour 2004, Harbour and Langton 2005; and Harbour et al. 2004a and b) is the current starting place for developing a critical analysis of this issue.

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Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. Samples of the grout fill can be obtained from the Savannah River Site for study. However, the samples will be "young" and no established protocol has been developed to artificially age grouts at this time. Sampling of residual sludge is part of the baseline closure activities but masses will be small so that testing with actual residual sludge will likely require augmentation by tests with simulated sludge.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 1B.

Path Forward: The path forward consists of performing a literature review of the aging of grout and methods to accelerate the aging process to create "aged" specimens for study. Then a laboratory test plan will be developed to test the interaction of appropriately aged grouts with actual and in some tests simulated tank residuals.

Limitations: It may prove difficult to create realistic specimens of aged grout for testing and the amount of actual residual sludge will likely be of limited mass. Most of the work will undoubtedly require use of analogs and at this time it is not clear what testing should be done to accelerate the aging conditions to represent the weathering of grout to account for thousands of years of aging. An appropriate simulant for residual sludge that includes the contaminants of concern (CoC) in a form or matrix similar to actual sludge may also prove to be a challenge. We have not successfully determined the "speciation" of CoCs such as technetium-99, iodine-129, and chromium in the sludge samples that have been studied to date. The uranium in sludge samples studied to date has also been found to be present in several different forms, including a high solubility mineral (čejkaite $[Na_4(UO_2)(CO_3)_3]$), a moderately soluble mineral, clarkeite $[Na[(UO_2)O(OH)] \bullet (H_2O)_{0-1}]$, and perhaps other non-crystalline phases. To date, the sludge samples that have been studied have shown unique bulk concentrations and unique water leaching characteristics for the contaminants of concern. For more details, see Cantrell et al (2006), Deutsch et al. (2004, 2005a, 2005b, and 2006), Krupka et al. (2004, 2006) and Lindberg and Deutsch (2003).

4.6.4 Chemical Interactions between Tank Liner and Tank Residue

Description: Single-shell tanks that are closed will consist of residual waste enclosed by engineered materials, including the carbon steel liner between the concrete shell and the waste. This liner is currently considered the primary barrier between the waste and the vadose zone.

Origin: This is a new data gap, included because of expanded scope of the TFVZ Project.

Information Type: Analysis

Impact: The impact is unclear. The influence of the tank construction components (concrete shell, carbon steel liner, grout fill) has not yet been investigated. Thus, it is unclear which component will be the most significant.

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Knowledge Level: Medium. Knowledge of carbon steel and stainless steel corrosion is available in general literature and some Hanford specific information is also available.

Feasibility of Collecting Data: The recommendation for resolving this gap is to use available data.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 3.

Path forward: The path forward consists of reviewing available literature for information that could be used to evaluate the tank liner's impact on contaminants that leach from the residual wastes left in tanks. Particular attention will be placed on assessing impacts of steel corrosion products as contaminant adsorbents and attempts will be made to consider differences caused by the highly varied chemical history amongst the single shell tanks.

Limitations: The chemistry of each single shell tank appears to be unique. It will be difficult to assemble existing information into one or just a few simple conceptual models of tank liner impacts.

4.6.5 Impact of Natural Soil Organic Content on Contaminant Transport

Description: Some organic acids are hypothesized to accelerate transport of key contaminants.

Origin: This data gap is new and is defined based on stakeholder comments.

Type of Information: Data and analysis.

Impact: The impact of this gap is low. The natural soil organic matter in the subsurface sediments below Hanford disposal facilities is very low, generally <0.05 to 0.1 weight percent carbon. The organic carbon value does rise slightly, to values <0.5 %, in regions where paleosols are evidenced and sometimes in the Cold Creek upper subunit of the Hanford formation.

Knowledge Level: The knowledge level is acceptable. For the 200 Areas of the Hanford Site a data base of ~180 total organic carbon measurements for sediments are available (see \\wd40900\AGGDATA\AGGPublic\COS Min Database\Database Project\Master Database.xls). In the data base, total organic carbon averages 0.51 weight percent, with a standard deviation of 0.086 weight percent. The negative values arise because organic carbon is not directly measured but is the difference between a total carbon measurement and an inorganic carbon measurement. If one assumes that all the organic carbon in the sediment is capable of forming strong complexes with radionuclides then it would be important to understand the solubility of the organic carbon-radionuclide complexes. The dissolved organic carbon content of the vadose zone pore water would control the mobility of radionuclides as opposed to the total organic carbon content of the sediment. No "speciation" measurements have been made on vadose zone pore water dissolved organic carbon content to our knowledge, but while measuring anions we have observed some peaks in the ion chromatograms that have been attributed to small polar

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carboxylic acids (formic, acetic, and oxalic). The concentrations of these three carboxylic acids in vadose zone pore water for uncontaminated sediments range from less than detection (<0.1 mg/L) to ~10 mg/L for each organic acid. The vadose zone pore waters from contaminated sediments underlying tank farms contain these three organic acids at variable concentrations from below the detection limits up to a few tens of mg/L for several samples and for a few samples as high as a few hundred mg/L for acetate and oxalate. Sediments from below suspected leaking tanks in the TX and B tank farms showed lower organic acids than contaminated sediments from near tank T-106 or tank BX-102 (see Serne et al. 2002f, 2002g, 2004a, and 2004b for details).

Some general literature that discusses the available field data and specific laboratory studies on enhanced migration of radionuclides attributed to organic chelating agents commonly used in nuclear facility decontamination are available (Serne et al. 1996, and 2002e and references cited within).

Feasibility of Collecting Data: The feasibility of collecting additional data to expand the knowledge level for this gap is medium. Measuring the total organic carbon content of sediments from new boreholes around the tank farms is relatively inexpensive. Determining the specific organic components present and their speciation in sediments and pore waters is difficult and not cost effective at present. Measuring the total dissolved organic carbon content of water extracts and actual pore water is possible, but determining the speciation of the dissolved organic carbon content is difficult and also costly.

Document Support: PA/closure plan, CMS, and Work Plan.

Priority Ranking: 4.

Path Forward: The knowledge level for this data gap is acceptable. If additional information is needed, the path forward would be to continue measuring the total organic carbon content of sediments from new boreholes drilled near the tank farms and to continue to report the concentrations of the three small organic acids that often times show up in the ion chromatograms of the vadose zone pore waters. Unless some unexpected contaminant mobility is observed in the borehole sediments for any particular contaminant of concern that might be attributed to organic complexation, no other more detailed organic analyses will be performed.

Limitations: Measuring the speciation of organics in the sediments or vadose zone pore waters is costly and difficult. Standardized techniques for determining the speciation are not established. Unless unexpected mobility for a contaminant of concern is observed that can be attributed to organic complexation, the low concentrations of organics observed in the Hanford Site sediments or vadose zone pore waters will not be characterized.

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4.7 MODELING

Modeling is used to predict future impacts to assist with determining appropriate remediation of tank farms. These future impacts cannot be simply extrapolated using present data, but rather must be estimated using numerical computer simulations.

4.7.1 Expand Database for History Matching of Simulations

Description: With reliance on numerical models comes a need to ensure the credibility of the model results. One way of building such credibility is the ability to match predictions with field observations. This data gap addresses the need to obtain site-specific data against which history matching of predictive models can be done.

Origin: This data gap is new and is the result of expanded scope of the TFVZ Project.

Information Type: Data.

Impact: The impact is indirect, but potentially significant. An important aspect of the Initial Single-Shell Tank Performance Assessment (SST PA) is the credibility of conceptual model embedded in numerical models of large-scale vadose zone flow and transport, and its basis for use in the performance assessment. Conceptual models gain credibility through history matching.

Knowledge level: The knowledge level is low to medium. As discussed in Section 4.5.9, the unique controlled database at the Sisson and Lu site provides a suitable data set for model history matching. As in the Vadose Zone Transport Field Study, field measurements at other sites must be performed to capture the spatial-temporal evolution of plumes. The geologic structure at the BC cribs and trenches is similar to that of the nearby Sisson and Lu site in the 200 East Area where a portion of the Vadose Zone Transport Field Study was performed. Both sites consist of imperfectly stratified media of fine- and coarse-textured sediments. Field measurements at both sites clearly illustrate the fact that, in the absence of man-made discharges, higher moisture contents are associated with fine-textured sediments and lower moisture contents are associated with coarse-textured sediments. This suggests that the natural moisture contents are in a quasi-equilibrium with natural infiltration (recharge).

While it is important to have data sets from field experiments, conditions in the vadose zone vary between waste sites. Therefore, it is important to collect site-specific information for history matching.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium. Controlled data sets for history matching numerical models are limited, but additional field experiments can be performed and site-specific data can be collected.

Document Support: Performance assessments.

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Priority Ranking: 2.

Path forward: The databases generated by Vadose Zone Transport Field Study at the Sisson and Lu site and the clastic dike on Army Loop Road documented in Ward et al. (2006) are unique at the Hanford Site. Further work on vadose zone transport field studies is needed as well as extending results and methods to other sites such as the nearby BC cribs and trenches. Characterization methods such as SGE, direct push, and drilling provide opportunities to generate site-specific data for history matching. History matching can be pursued for the T-106 tank leak and the leak detection tests in S tank farm.

Limitations: Controlled data sets for history matching numerical models are limited; additional field experiments could be performed as necessary.

4.7.2 Parameter Value Variability Effects on Risk Estimates

Description: Contaminant transport modeling analyses yield a range of environmental impacts and associated risk ranges that may occur because unique values cannot be assigned to input parameter values.

Origin: This data gap is new, resulting from expanded scope of the TFVZ Project.

Information Type: Analysis.

Impact: The impact is direct. Depending on the parameter, inherent variability (e.g., natural heterogeneities and effects of long-term processes on engineered materials) or lack of an adequate data base generate a range of plausible values. Even with additional data, reducing parameter uncertainty and generation of unique values are not expected. Therefore, a range of risk outcomes is unavoidable and a reliable method for addressing the significance of the range of outcomes relative to waste management decisions is needed. Because risk estimates depend on the collective set of input parameter values, methods for interpreting the significance of parameter ranges as they relate to risk and waste management decisions are also needed.

Knowledge level: The knowledge level of the impact on parameter variability impacts on contaminant transport modeling analyses is medium. Two factors must be considered when evaluating ranges of parameter values with respect to their impact on risk uncertainties. First, the reliability of the proposed range of particular parameter values (e.g., the robustness of the supporting data base that quantifies the range) must be established. Second, given the proposed range of values, the impact of the changes in values on risk estimates must be understood. For example, the measured range of sorption distribution coefficient values (K_ds) under simulated ambient vadose zone conditions for numerous constituents has been large (an order of magnitude or more) in various empirical studies. A range in values is expected because multiple chemical processes and variable local geochemical environments control the distribution of contaminants between the liquid and solid phases. However, the impact on risk for contaminants migrating through the vadose zone on the Hanford Plateau depends on the value range. If the range varies from 10 to 1000 mL/g and low recharge rates are imposed and maintained by closure actions such as surface barrier placement, contaminants do not reach the unconfined aquifer during even an extended performance period (e.g., 10,000 year). In this case, the estimated range of the

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sorption parameter has essentially no impact on risk estimates. In this example, evaluation of risk uncertainty impacts because of this parameter variability is unnecessary. Conversely, if the K_d range is 0.1 to 1 mL/g, then environmental impacts (e.g., estimated peak groundwater concentrations) do change depending on the K_d value chosen within the range. In this case the uncertainties provided by this parameter must be considered specifically and in the context of other parameters also affecting estimated risk. Analyses completed in the initial SST PA (DOE-ORP 2006) have indicated that variability in recharge rates and waste source inventories are among the most significant parameters that control the overall migration rate and risk of mobile contaminants.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is variable. Depending on the parameter, additional field or laboratory data can be collected to better define parameter input value ranges needed as input to contaminant transport and overall risk analyses.

Document Support: Performance assessments.

Priority Ranking: 3.

Path forward: The path forward consists of expanding the current set of sensitivity analyses to incorporate additional data that better defines the range of parameter values. Additional sensitivity studies should be performed for other parameters and combinations of parameters to determine the influences on contaminant migration processes. The parameters tested for sensitivity should be part of data bases that are translated into probability distribution functions if the level of characterization supports the process.

Limitations: Quantification of parameter values is limited by natural heterogeneities (e.g., mapping of fine scale hydrologic property domains) and difficulty in quantifying the true processes affecting parameter values (e.g., constituent specific chemical reactions in the sediment/water system). Consequently, precise determination of true parameter value ranges and the likelihood of occurrence for a particular value are difficult to determine.

4.7.3 History Matching Vadose Zone Numerical Models

Description: It is important to understand the quality of results from numerical models. One way to obtain this understanding is comparing such numerical results to field observations. This data gap addresses the need to perform the comparison.

Origin: This data gap is new, resulting from expanded scope of the TFVZ Project.

Information Type: Analysis.

Impact: The impact is indirect, but significantly impacts credibility. Computational simulation models such as those used in the *Initial Single-Shell Tank System Performance Assessment for the Hanford Site* (DOE/ORP 2006) are simplifications of physical reality. Performance and risk assessment models, however, must have broad acceptance within the scientific, regulatory, and stakeholder communities, and should incorporate the large-scale field processes that are known to be significant for Hanford waste disposal activities. For example, the highly heterogeneous

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nature of Hanford sediments has been documented to result in moisture-dependent anisotropy. This is best illustrated by the moisture content profiles at the controlled field injection experiment (also known as the Sisson and Lu site) in the 200 East Area (Ward et al. 2006) and has also been observed at the BC cribs and trenches (Rucker and Sweeney 2004 and Ward et al. 2005).

In the context of vadose zone numerical models, two terms that are frequently used are verification and validation. By verification, a determination is made that the computer code solves the chosen equations correctly. This is typically accomplished by comparison of code results with known analytical solutions and checks on numerical mass balance. For example, the STOMP code used in the initial SST PA for vadose zone flow and transport has undergone extensive testing and verification (White and Oostrom 2000, 2004, and 2006). Validation, on the other hand, is the determination that the embedded model itself (used in the initial SST PA calculations) captures the essential field-scale phenomena with adequate fidelity. History matching is another term used for validation activities and is often applied where data sets do not exist to accomplish full validation.

Knowledge level: The knowledge level for history matching vadose zone numerical models is medium. As discussed above, an important aspect of the initial SST PA analysis is the conceptual model for vadose zone flow and transport, and its basis for use in the performance assessment. As part of history matching of the vadose zone conceptual model and under a separate task, the moisture content data that were collected at the Vadose Zone Transport Field Study at the Sisson and Lu site in the 200 East Area were analyzed by both Ward et al. (2006) and Yeh et al. (2005). A comparison of the observed moisture plume and the simulated moisture plume using an effective unsaturated hydraulic conductivity tensor for the Sisson and Lu site is described in Ye et al. (2005). The effective hydraulic conductivities compare well with the laboratory-measured unsaturated hydraulic conductivity data for small core samples at the site. As discussed in Ye et al. (2005), the spatial moments of the simulated plume based on the effective hydraulic conductivities are in reasonably good agreement with those for the observed plume. Other data sets such as the characterization and BC cribs and trenches and SGE evaluations of tank farms may provide data sets that are useful in history matching.

Feasibility of Collecting Data: The feasibility of collecting additional data to resolve this data gap is medium. Controlled data sets for history matching numerical models are limited; additional field experiments could be performed as necessary (Section 4.7.2) and methods are being developed to relate the electrical response of SGE to contaminant distributions to allow subsurface geophysics to generate data useful for history matching.

Document Support: Performance assessments.

Priority Ranking: 3.

Path forward: The databases at the Sisson and Lu and the clastic dike sites documented by Ward et al. (2006) and history exercises such as those of Ye et al. (2005), Yeh et al. (2005), and Ward et al. (2006) are unique. A need exists for history matching of site-specific models using available data.

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Limitations: Controlled data sets for history matching numerical models are limited, but additional field experiments can be performed and site-specific data can be collected. Currently, SGE surveys cannot be quantitatively linked to contaminant concentrations in the subsurface, although the general shape of subsurface resistivity plumes can be determined.

4.7.4 Near Surface Contamination Risk Assessment

Description: Risk assessments consider the environmental impact of a contaminated accessible environment on indigenous plants, animals, and inadvertent human intruders.

Origin: This data gap is new, resulting from the expanded scope of the TFVZ Project.

Information Type: Analysis.

Impact: The impact is indirect. Proposed tank-farm closure actions provide little opportunity for access to contamination because of the thickness of material (both soil and grout in the tanks) between waste and the local ecosystem. Thus, ecological risk is expected to be significant only if catastrophic failures occur that bring waste closer to the surface. In addition, closure will include systems to reduce the potential for human intrusion.

Knowledge Level: The knowledge level is medium to low. An ecological risk assessment analysis has not been completed. The database that supports the analysis consists of measurements of contamination near the surfaces of tank farms using drywell gamma logging of cesium-137 activity between 0 and 15 ft bgs. Other contaminants have not been measured and some can be scaled from the cesium-137 concentrations using some simplifying assumptions regarding contaminant interactions with near-surface sediments. Coordination between the tank-farm closure and the 200 Area CERCLA waste mediation activities is anticipated to produce site-wide approved methodology for completing this analysis.

Feasibility of Collecting Data: The feasibility of collecting data to resolve this gap is medium to low. Data collection may be revisited through application of SGE and direct-push technologies.

Document Support: Performance assessments.

Priority Ranking: 3.

Path forward: The path forward consists of evaluating ecological impacts following completion of the ecological risk analyses.

Limitations: None.

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5.0   PATH FORWARD

This section summarizes the path forward that will be pursued. Additional detail will be documented in a program plan, which is being developed.

The three parties (the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology) responsible for cleanup of the Hanford Site have established a general approach documented in the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1998, particularly Appendix I). The overall approach is to:

- Retrieve as much waste as technically possible from tanks
- Stabilize the tanks
- Decontaminate and decommission other facilities
- Remediate the contaminated soil
- Minimize moisture coming into the tank farms
- Monitor the impacts

The TFVZ Project supports these efforts. In particular, the project will continue to collect additional field and laboratory data, perform data analysis (whether data collected by the project or from other efforts), develop and test appropriate models for the determination of long-term human health and environmental impacts, and determine the effect of new data on long-term human health and environmental impacts (see Figure 5-1).

5.1   NEW DATA COLLECTION

Data collection to characterize the contaminated vadose zone and groundwater beneath tank farms at the Hanford Site is expensive. Chapter 4 provided information on the important data gaps. Table 5-1 is a summary of key aspects of the data gaps that were identified. The priority for collecting new data to support tank farm performance and risk assessments and tank farm closure will be outlined in the program plan. With the advances made as part of the TFVZ Project in use of high resolution resistivity methods (through SGE) and the hydraulic hammer direct push technology, the cost of collecting new data is reduced.

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Figure 5-1. Path Forward
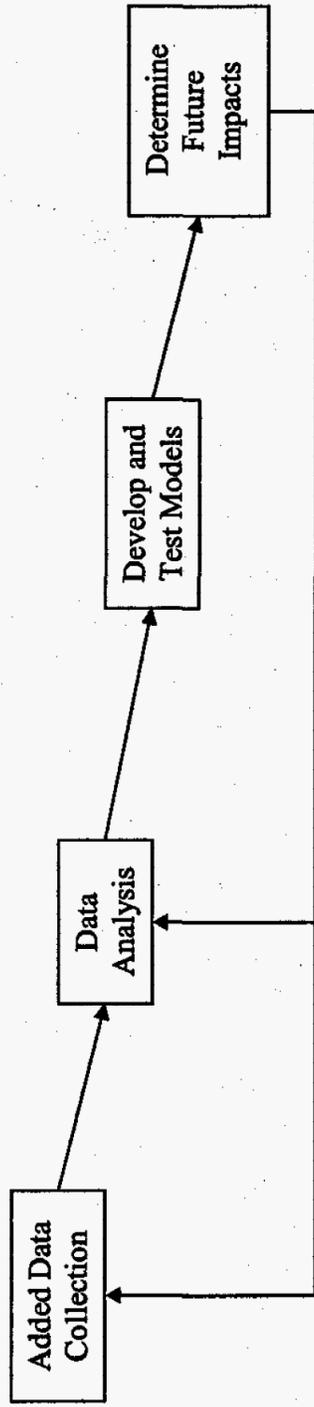
Table 5-1. Data Gap Summary.

Area	Description	Driver
Inventory	Retrieval tank leaks and residual waste concentrations will be measured during and after retrieval.	Key driver for intruder impacts; impacts groundwater analyses.
Existing subsurface inventory	Content and extent of contaminants; Major leaks have been characterized by borehole and direct push sediment samples as well as field gamma logging and high resistivity measurements.	Key driver for groundwater analyses.
Contaminant release	Release models (including effect of tank fill grout leachate).	Key driver for groundwater analyses for residual wastes in tanks.
Recharge	Gravel surface/surface barriers	Key driver for groundwater analyses
Mobile contaminants	What could cause contaminants not presently mobile to become mobile?	Such contaminants drive the groundwater analyses.

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5.2 DATA ANALYSIS

Once sediments are collected in the field, they are analyzed in the laboratory. The laboratory analysis includes determination of contaminants, physical and geochemical properties of the sediments and parameters associated with quantifying contaminant transport. These analytical results are used to reduce the uncertainties associated with predicting future waste movement.

Laboratory analyses are underway on residual tank waste materials to determine the processes that are important for predicting how, when, and the quantity of contaminants leaving closed tank facilities. However, because of the multiple chemical processing campaigns and multiple waste transfers, the residual waste in each tank is likely to be different. Moreover, the nature of materials used to close waste tanks (e.g., the type of filler material) will affect the release rates and must be investigated using laboratory analyses.

Other projects at the Hanford Site (e.g., the Groundwater Remediation Project) are also collecting data of potential use for predicting tank waste contaminant movement. The TFVZ Project maintains close cooperation with these groups to transfer data and information.

5.3 DEVELOP AND TEST MODELS

The largest impacts to groundwater from tank wastes that have leaked to the vadose zone are likely to occur in the future. Therefore, predictive models are needed to estimate future impacts. Some model parameters are fairly well established, but others are uncertain. Other model parameters (e.g., how contaminants will be released from the residual material left in closed facilities) must be measured or estimated. The contaminant fate and transport models used in performance and risk assessment also need to be tested by history matching contaminant transport events to establish confidence in future predictions.

5.4 DETERMINE IMPACT OF NEW DATA

Future predictions provided by performance and risk assessment models will have inherent uncertainties. Some of the predictions depend on decisions yet to be made (e.g., the amount of waste remaining in the tanks at the time of closure, whether or not retrieval leaks will occur, how the contaminated vadose zone and tank farm infrastructure will be remediated, and how tank farms will be closed). Thus, the analyses will need to include evaluation of uncertainty. New data and analyses will be needed to evaluate and reduce the predictive uncertainty and support remediation decisions.

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