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Vol. II
Rev. 0

Groundwater/Vadose Zone Integration Project Background Information and State of Knowledge

United States
Department of Energy

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PREFACE

This *Project Background Information and State of Knowledge* document provides supporting materials that help readers understand the following elements:

- The Hanford Site environmental setting.
- The waste disposal history of the Hanford Site.
- The regulatory framework and management strategies in effect at the time that the Integration Project was established.
- The technical state of knowledge regarding key technical areas within the scope of the Integration Project.

The *Project Background Information and State of Knowledge* is one of many documents and management tools that communicate the breadth and complexity of the Integration Project (see Figure 1).

The primary documents and management tools that provide an introduction to the Integration Project fall into three general groups: the Project Description, the Project Baseline, and Project Management Systems.

Three companion volumes make up the set of Project Description documents: These include the *Project Summary Description*, the *Background and State of Knowledge*, and the *Science and Technology Summary Description* documents. These volumes are strategic in nature; therefore, their contents should be relatively fixed over time. This document, for example, will only be revised if DOE directs a change in the Integration Project mission or scope. These three volumes were developed out of materials that were contained in previous drafts of an Integration Project *Project Specification* document. Review comments on the December 1998 draft of the *Project Specification* indicated that its materials should be broken out into these separate documents, so that the information would be more focused and easier to read. These volumes will be completed and released during calendar year 1999.

Project Baseline documents, which complement Project Description documentation, include detailed planning information for the Integration Project as a whole (for example, the *Multi-Year Work Plan* [MYWP], *Long Range Plan* [LRP], and *Detailed Work Plan* [DWP]). These documents and tools describe the dynamic planning process that supports implementation of Integration Project scope. A high-level description of the processes that the project uses to develop and revise these documents and tools is provided in Volume I.

Details on how the Integration Project is structured are captured in the complete set of Project Management documents. Project roles, responsibilities, and authorities are defined in the *Groundwater/Vadose Zone Integration Project Management Plan* (DOE/RL-98-56). Management protocols and procedures also are part of this documentation set.

The S&T Roadmap was revised and is being issued as Volume III of the Project Description. The S&T Plan is still in draft form, and is available to interested parties at www.bhi-erc/vadose.

Figure 1. Primary Project Documents and Management Tools.

ACRONYMS

AEA	Atomic Energy Act
ALARA	As Low As Reasonably Achievable
ALE	Arid Lands Ecology
ARAR	Applicable or Relevant and Appropriate Requirements
AME	Assistant Manager for Environmental Restoration
ASDP	Arid Site Demonstration Project
ASME	American Society of Mechanical Engineers
BHI	Bechtel Hanford, Inc.
BPA	Bonneville Power Administration
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*
CFEST	Coupled, Fluid, Energy, and Solute Transport
COC	Contaminants of Concern
CRBG	Columbia River Basalt Group
CRCIA	*Columbia River Comprehensive Impact Assessment*
CRE	Center of Risk Excellence
CRU	Columbia River United
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
D&D	Decontamination and Decommissioning
DNAPL	Dense Non-Aqueous Phase Liquids
DNFSB	Defense Nuclear Facility Safety Board
DOE	U. S. Department of Energy
DOH	Washington State Department of Health
DQO	Data Quality Objective
DST	Double Shell Tank
DWP	*Detailed Work Plan*
DWS	Drinking Water Standards
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EM	Environmental Management
EMI	electromagnetic induction
EMP	Environmental Monitoring Plan
EMSL	Environmental Molecular Sciences Laboratory
EMSP	Environmental Management Science Program
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ERA	Expedited Response Action
ERC	Environmental Restoration Contractor
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
FDH	Fluor Daniel Hanford, Inc.
FFTF	Fast Flux Test Facility
FRC	field research centers

FSUWG	Future Sites Uses Working Group
FY	Fiscal Year
GPMP	*Groundwater Protection Management Plan*
GW/VZ	Groundwater and Vadose Zone
HAB	Hanford Advisory Board
HDW	Hanford Defined Waste
HEAL	Hanford Environmental Action League
HLW	High Level Waste
HRA-EIS	Hanford Remedial Action Environmental Impact Statement
HTI	Hanford Tanks Initiative
HQ	Headquarters
ILAW	Immobilized Low Activity Waste
IPL	*Integrated Priority List*
IRM	Interim Remedial Measures
Kd	Coefficient Distribution
LANL	Los Alamos National Laboratory
LAW	Low Activity Waste
LFI	Limited Field Investigations
LLBG	Low-Level Waste Burial Ground
LLW	Low-Level Waste
LRP	*Long Range Plan*
MOA	Memoranda of Agreement
MOU	Memoranda of Understanding
MTCA	*Model Toxic Control Act*
MUST	Miscellaneous Underground Storage Tanks
NABIR	Natural and Accelerated Bioremediation Program
NAPL	Non-Aqueous Phase Liquids
NAS	National Academy of Sciences
NASQAN	National Stream Quality Accounting Network
NEPA	*National Environmental Policy Act*
NPT	Nez Perce Tribe
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
OBER	Office of Biological and Environmental Research
OBS	Organizational Breakdown Structure
OEA	Office of External Affairs
ORIGEN2	Oak Ridge Isotope Generation and Depletion
OST	Office of Science and Technology
OU	Operable Unit
PA	Performance Assessment
PBS	*Program Baseline Summary*
PCB	Polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PHMC	Project Hanford Management Contract
PI	Public Involvement
PM	Project Manager

PMP	*Project Management Plan*
PNNL	Pacific Northwest National Laboratory
PRTR	Plutonium Recycle Test Reactor
PTS	Progress Tracking System
PUREX	Plutonium Uranium Extraction
RARA	Radiation Area Remedial Action
RCRA	*Resource Conservation and Recovery Act*
REDOX	Reduction Oxidation
RI/FS	Remedial Investigation/Feasibility Study
RL	Richland Operations Office
ROD	Record of Decision
S&M	Surveillance and Maintenance
S&T	Science and Technology
SAC	System Assessment Capability
SALDS	State-Approved Land Disposal Site
SARA	*Superfund Amendments and Reauthorization Act of 1986*
SEPA	*State Environmental Policy Act*
SESP	Surface Environmental Surveillance Project
SRS	Savannah River Site
SST	Single Shell Tank
STCG	Science and Technology Coordination Group
SWITS	Solid Waste Information Tracking System
TBP	Tributyl Phosphate
TDR	Time Domain Reflectometry
TEDF	Treated Effluent Disposal Facility
TIMS	Thermal Ionization Mass Spectrometry
TLD	Thermoluminescent Dosimetry
TRAC	Track Radioactive Components
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRU	Transuranic
TSD	Treatment, Storage, and Disposal
TWINS2	Tank Waste Information Network System
TWRS	Tank Waste Remediation System
UPR	Unplanned Releases
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
YIN	Yakama Indian Nation
WBS	Work Breakdown Structure
WIDS	Waste Information Data System
WIPP	Waste Isolation Pilot Project

1.0 HANFORD SITE SETTING

1.1 OPERATIONAL OVERVIEW OF THE HANFORD SITE

In 1943, under the auspices of the Manhattan Project, the U.S. Army Corps of Engineers selected the Hanford Site as the location for nuclear reactor and spent fuel processing facilities (Figure 1-1). The Hanford Site mission was to produce plutonium for nuclear weapons. This required a large military-industrial complex that included fuel manufacturing facilities, nuclear reactors (to produce plutonium), chemical processing (to separate and purify plutonium), waste management practices (to store and dispose of nuclear waste), and research (to support the overall Hanford Site mission). Table 1-1 summarizes the operational history of the primary facilities that supported the Hanford Site defense mission.

Beginning operations in 1944, nine production reactors located in the 100 Area of the Hanford Site irradiated uranium to produce plutonium. These reactors irradiated approximately 100,000 metric tons of uranium fuel. Eight of the reactors were graphite-moderated and used Columbia River water for once-through cooling. These reactors were shut down by 1971. The ninth reactor, a dual-purpose reactor (N Reactor), used recirculating water coolant and produced both plutonium and steam for electricity. N Reactor operated until 1987, and is now deactivated.

Two test reactors were also constructed and operated at the Hanford Site. The Plutonium Recycle Test Reactor (PRTR) was a heavy-water moderated test reactor located in the 300 Area. The PRTR is now retired and has been deactivated. The Fast Flux Test Facility (FFTF), a sodium-cooled reactor located in the 400 Area, was used to test fuels and materials for advanced nuclear power plants. In 1993 the FFTF began transitioning towards permanent shutdown. One commercial nuclear power plant, operated by the Washington Public Power Supply System, is located on the Hanford Site and is still operating.

Chemical processing operations during nuclear production generated high-level radioactive liquid wastes. About 245 million liters (65 million gallons) of high-level waste (HLW) are stored at the Hanford Site in 177 large underground tanks. The tanks, divided into 18 groups (or “farms”), are located in the 200 Area. Of the original single shell tanks (SSTs), 67 of the 149 have leaked or are assumed to have leaked a combined amount of about 3.8 million liters (1 million gallons) of contaminated liquid to the soil column. Recent estimates of tank leaks push the estimates of volumes and curies lost higher. The 28 double shell tanks (DSTs) built since 1968 have an improved design for better containment (a tank within a tank), and have not leaked.

The solid waste generated from past operations consists of low-level radioactive waste, low-level mixed waste, transuranic (TRU) waste, and hazardous waste. The current inventory of solid waste buried or stored in underground trenches and above-ground facilities is about 87,000 m^3 (114,000 yd^3) in the 100 Areas, 379,000 m^3 (495,000 yd^3) in the 200 Areas, and 159,000 m^3 (208,000 yd^3) in the 300 Area. A commercial low-level radioactive waste disposal facility, operated by US Ecology, is located on Washington State leased land southeast of the 200 East Area.

Figure 1-1. Hanford Site Location.

Table 1-1. Facility, Period of Operation, and Associated Hazardous Substances.

Type of Operation	Operating Period	Hazardous Substances	Map Reference
Production Reactors			
105-B Reactor	1944 to 1968	AFP, TRU, Haz, Asb, Rad Equip	100-BC Area
105-D Reactor	1944 to 1967	AFP, TRU, Haz, Asb, Rad Equip	100-D Area
105-F Reactor	1945 to 1965	AFP, TRU, Haz, Asb, Rad Equip	100-F Area
105-H Reactor	1949 to 1965	AFP, TRU, Haz, Asb, Rad Equip	100-H Area
105-DR Reactor	1950 to 1965	AFP, TRU, Haz, Asb, Rad Equip	100-D Area
105-C Reactor	1952 to 1969	AFP, TRU, Haz, Asb, Rad Equip	100-BC Area
105-KW Reactor	1955 to 1970	AFP, TRU, Haz, Asb, Rad Equip, Irr Fuel	100-K Area
105-KE Reactor	1955 to 1971	AFP, TRU, Haz, Asb, Rad Equip, Irr Fuel	100-K Area
105-N Reactor	1963 to 1987	AFP, TRU, Haz, Asb, Rad Equip	100-N Area
Test Reactors			
PRTR	1961 to 1968	AFP, TRU, Haz, Asb, Rad Equip	300 Area
FFTF	1980 to 1994	AFP, TRU, Haz, Asb, Rad Equip, Irr Fuel	400 Area
Fuel Reprocessing			
T-Plant	1944 to 1956	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
B-Plant	1945 to 1952	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
REDOX	1952 to 1967	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
PUREX	1955 to 1972	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
Nuclear Materials Processing			
UO_3 Plant	1951 to 1972 and 1984 to 1989	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
Plutonium Finishing Plant	1949 to 1980 and 1984 to 1992	AFP, TRU, Haz, Asb, Rad Equip, SNM	200-West Area
U-Plant Uranium Recovery	1952 to 1957	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
Fuel Fabrication	1943 to 1967	Haz, Rad Equip, Asb Uranium	300 Area
By-Product and Waste Processing			
Waste Scavenging (U-Plant)	1953 to 1957	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
Cs and Sr Recovery (B-Plant)	1967 to 1979	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
Cs and Sr Encapsulation (WESF)	1974 to 1985	AFP, Haz, Asb, Rad Equip	200-East Area
Waste Evaporators	1951 to 1989, 1 of 3 remains in service	AFP, TRU, Haz, Asb, Rad Equip	200-East and West Areas
High Level Liquid Waste Storage			
SSTs and DSTs	1944 to Present	AFP, TRU, Haz, Rad	200-East and West Areas

AFP - Radioactive Activation and Fission Products
TRU - Transuranic Materials
Haz - Hazardous Materials
SNM - Special Nuclear Materials
Asb - Asbestos
Irr Fuel - Irradiated Reactor Fuel
Rad Equip - Radioactively Contaminated Equipment

After over 40 years of operations, the Hanford Site plutonium production mission has been completed, leaving a large amount of nuclear waste as part of its legacy. By volume, two-thirds of all the nuclear waste in the U.S. Department of Energy (DOE) complex is stored or disposed at the Hanford Site. Over 1,600 contaminated waste sites associated with reactor areas, chemical processing areas, and fuel processing areas have been identified. Starting in 1986, the Hanford Site mission began changing from plutonium production to environmental restoration and remediation.

1.2 ENVIRONMENTAL SETTING

The Hanford Site lies within the semi-arid Pasco Basin of the Columbia Plateau, in south-central Washington State (Figure 1-1). Public access to this land is restricted. Only about 6% of the total Hanford Site surface land area has been affected by Hanford Site operations.

1.2.1 Climate and Meteorology

The average annual precipitation at the Hanford Site is 16 cm (6.3 in.) Most precipitation occurs during the winter, with more than half of the annual amount occurring from November through February. The prevailing wind direction is from the northwest, in all months of the year, with frequent strong winds from the southwest. Daily maximum average temperatures range from 2°C (35°F) in late December and early January to 35°C (95°F) in late July. The annual average relative humidity is 54%. Humidity is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%.

1.2.2 Geology

The major geologic units in the Hanford Site area are the Miocene Columbia River Basalt Group (CRBG) and intercalated sedimentary rocks of the Ellensburg Formation. These are overlain by younger (Mio-Pliocene) sedimentary rocks of the Ringold Formation, the early "Palouse" soil/Plio- Pleistocene Unit, and the Pleistocene cataclysmic flood deposits of the Hanford Formation (Figure 1-2).

The CRBG, which comprises the principal rock unit at the Hanford Site, is a sequence of flood basalt flows that erupted between 6 and 17 million years ago. The Ellensburg Formation consists of a series of sedimentary units that are interbedded between many of the basalt flows of the CRBG. The Ringold Formation overlies the youngest basalt flow, and consists of semi-consolidated clay, silt, pedogenically altered sediment, fine- to coarse-grained sand, and granule-to-cobble gravel. The primary facies of the Ringold Formation are fluvial gravels, fluvial sands, overbank deposits and paleosols, and lacustrine deposits. Ringold strata typically are situated below the water table.

The Plio-Pleistocene Unit is made up of sandy gravels that separate the Hanford Formation and the Ringold Formation in the east-central Cold Creek syncline and at the east end of the Gable Mountain anticline (east and south of the 200 East Area). These gravels are up to 25m (75 feet) thick. Along the western margin of the site, the "Palouse" soil separates the two formations. The Hanford Formation consists of pebble to boulder sized gravel, fine to coarse-grained sand, and silts of unconsolidated deposits from ice age flooding. The Hanford Formation generally lies above the water table throughout most of the Hanford Site, except in the 100 and 300 Areas.

Recent work has shown that there are laterally extensive layers of five-grained soils in the Hanford formation (so-called paleo soils). Paleo soils are expected to be key in understanding moisture flow in the vadose zone underlying the 200 Area.

Figure 1-2. Major Geological Units at the Hanford Site.

1.2.3 Hydrology

1.2.3.1 Surface Water Hydrology. Surface water at the Hanford Site includes the Columbia River (northern and eastern sections), riverbank springs along the river, springs on Rattlesnake Mountain, and onsite ponds. In addition, the Yakima River flows along a short section of the southern boundary of the Hanford Site.

1.2.3.2 Vadose Zone Hydrology. The hydrology in the vadose zone is influenced by the texture of the geologic units in the Hanford and Ringold Formations, the thickness of the unsaturated sequence, low precipitation, and high evapotranspiration. These conditions significantly influence the time required for contaminants to reach the water table. Perched water has been known to occur beneath a few active release sites, and is located above fine grained sediments.

1.2.3.3 Groundwater Hydrology. The unconfined aquifer generally occurs in the semi-consolidated silts, sands, and gravels of the Ringold Formation. These sediments were deposited by the Columbia River as it meandered across the central Pasco Basin several million years ago. The Ringold Formation is less transmissive to water than Hanford Formation sediments. The aquifer ranges in saturated thickness from 0 m (near the margins of the Pasco Basin) to approximately 60 m (200 ft) near the center of the Basin.

Both natural and artificial sources of water recharge the aquifers within the Pasco Basin. The most significant volume source is irrigation water from the Columbia Basin Project, although this influence is limited to the area north of the Columbia River. Artificial recharge caused by Hanford Site operations historically has produced major groundwater mounds in the 200 East and 200 West Areas. The reduction or cessation of waste disposal has resulted in declines in water table elevations, and is changing contaminant plume characteristics.

Groundwater plumes move in directions that are approximately perpendicular to the water table elevation contours. Chemical and radiological contaminants detected in the groundwater above Drinking Water Standards (DWS) are shown in Figures 1-3 and 1-4. During the Hanford Site's operating history, changes in the volume of liquid waste disposed to the soil column have altered the shape of the water table, resulting in alterations to migration patterns.

The interaction between the groundwater and the Columbia River is an important element in assessing contaminant impacts on the river system. River water moves in and out of the banks during daily stage fluctuations, causing variable water quality characteristics in shoreline monitoring wells. In addition, the interface zone between the river and the aquifer has characteristics that may retard or modify contaminants that are transported by groundwater.

1.2.4 Water Quality of the Columbia River

The State of Washington has classified the stretch of the Columbia River from the Grand Coulee Dam to the Washington-Oregon border (which includes the Hanford Reach) as Class A, Excellent. Class A waters are required to be suitable for essentially all uses, including raw drinking water, recreation, and wildlife habitat. State and federal DWS apply to the Columbia River and are currently being met. Radionuclides detected in the river during 1997 included tritium, strontium-90, iodine-129, and uranium. Radionuclide measurements of total alpha and total beta approximately 5% (or less) of the applicable DWS of 15 and 50 pCi/L, respectively. Tritium measurements continue to be below state and federal DWS. Nonradiological constituents detected in the river consist mostly of metals and anions, in concentrations below state and federal DWS. All nonradiological water quality standards are met for this Class A-designated water.

Groundwater contaminants from the Hanford Site's past waste disposal practices continue to enter the Columbia River from riverbank springs and seeps, as well as from the interface between the river bed and groundwater. Aluminum, chromium, iron, manganese, nitrate, and trichloroethylene, as well as strontium, technetium, tritium, carbon-14, and uranium, are entrained in groundwater plumes that intersect the river along the 100 Area shoreline. Aluminum, iodine, iron, manganese, nitrate, technetium, and tritium entered the river along the portion of shoreline extending from the old Hanford Townsite to below the 300 Area. Chromium and uranium were discharged to the river along the 300 Area shoreline, in addition to the other contaminants. The contaminant concentrations in spring water are typically similar to, but lower than, those found in near-shore groundwater wells. Chromium in excess of federal ambient water quality criteria for the protection of aquatic life has been detected at the

Figure 1-3. Distribution of Chemical Contaminants in Groundwater.

Figure 1-4. Distribution of Radioactive Contaminants in Groundwater.

riverbed/groundwater interface along portions of the 100 Area shoreline. Chromium levels in this pore water are above protective levels for salmon alevin hatched from salmon redds (nests) in the gravel river bottom in the Hanford Reach area of the river.

1.2.5 Ecology

The ecology of the Hanford Site is characterized as a shrub-steppe ecosystem. Fifteen different soil types have been identified, varying from sand to silt and sandy loam. Shrub-steppe ecosystems are typically dominated by a shrub overstory with a grass understory. The existing plant communities at the Hanford Site are becoming increasingly more important from an ecological perspective. Expanding agricultural and urbanization developments in the Columbia Basin region continue to destroy and fragment the few remaining large tracts of shrub-steppe habitat. The shrub-steppe habitat is considered a priority habitat by Washington State because of its relative scarcity, and because of its requirement as nesting/breeding habitat for several state and federal species of concern. A 1994 survey of Hanford Site plants and animals by the Nature Conservancy of Washington discovered 18 species of insects and 3 plants that are new to science. This report stated that the Hanford Site is now known to support more than 100 populations of 15 rare native plant taxa, making the Hanford Site a botanical "island of diversity" in the shrub-steppe of the lower Columbia Basin.

Several areas, totaling 670 km^2 (260 mi^2) on the Hanford Site, have been designated for research or as wildlife refuges. These include the Fitzner Eberhardt Arid Lands Ecology (ALE) Reserve; the Saddle Mountain National Wildlife Refuge (managed by U.S. Fish and Wildlife Service); and the Wahluke Slope Wildlife Area (managed by the Washington State Department of Wildlife).

1.2.5.1 Vegetation. Of the 590 species of vascular plants recorded for the Hanford Site, approximately 20% are considered non-native. Native shrublands occupy the largest area in terms of acreage, and comprise 7 of the 9 major plant communities at the Hanford Site. Of the shrubland types, sagebrush-dominated communities are the predominant type, with other shrub communities varying with changes in soil and elevation. Common shrubs include native big sagebrush, three-tip sagebrush, antelope bitterbrush, gray rabbitbrush, and spiny hopsage. Common native grasses include bluebunch wheatgrass, Sandberg's bluegrass, needle-and thread grass, Indian ricegrass, bottlebrush squirreltail, and prairie junegrass. Cheatgrass has replaced many native perennial grass species, and is well established in many low-elevation (<244 m [800 ft]) and/or disturbed areas. Trees afford unique terrestrial habitat at the Hanford Site. Currently, approximately 23 species of trees occur on the site. The most commonly occurring species are black locust, Russian olive, cottonwood, mulberry, sycamore, and poplar. Many of these non-native species are aggressive colonizers and have become established along the Columbia River (e.g., mulberry, poplar, Russian olive), serving as a functional component of the riparian zone.

Riparian habitat includes sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River flood plain. Vegetation that occurs along the river shoreline includes emergent water milfoil, water smartweed, pondweed, sedge, reed canarygrass, and bulbous

bluegrass. Trees include willow, mulberry, and Siberian elm. Other riparian vegetation occurs in association with perennial springs, seeps, artificial ponds, and ditches on the Hanford Site.

Emergent riparian (wetland) habitat occurs infrequently along the Hanford Reach, and has important ecological significance because of the net loss of wetland habitat elsewhere within the region. Emergent species include reed canarygrass, common witchgrass, large barnyard grass, rushes, and sedges.

1.2.5.2 Wildlife. Included in the 290 species of terrestrial vertebrates observed on the Hanford Site are approximately 40 species of mammals, 240 species of birds, 3 species of amphibians, and 9 species of reptiles. Grasshoppers and darkling beetles are among the more conspicuous of the approximately 600 species of insects that have been found on the Hanford Site. Species of potential concern to remediation activities include mule deer, coyote, badger, beaver, black-tailed jackrabbit, Nuttall's Cottontail, the Great Basin pocket mouse, deer mouse, bald eagle, ferruginous hawk, Swainson's hawk, burrowing owl, loggerhead shrike, long-billed curlew, sage sparrow, mallard duck, and Canada goose.

1.2.5.3 Aquatic Ecosystems. The Columbia River is the dominant aquatic ecosystem at the Hanford Site, and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. The Columbia River has been dammed both upstream and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, section of the Columbia River in the United States above Bonneville Dam.

There have been 44 species of fish identified in the Hanford Reach. Of these species, chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Both chinook salmon and steelhead trout also spawn in the Hanford Reach. Other fish of importance to tribal entities and sport fishermen are whitefish, shad, sturgeon, smallmouth bass, crappie, catfish, walleye, and perch. The destruction of other mainstream Columbia spawning grounds by dams has substantially increased the relative importance of the Hanford Reach spawning areas.

1.2.5.4 Threatened and Endangered Species. Threatened and endangered plants and animals identified at the Hanford Site, as listed by the state and federal governments, are shown in Table 1-2. No plants or mammals on the federal list are known to occur on the Hanford Site. There are, however, three species of birds on the federal list of threatened and endangered species, and several species of plants and animals that are under consideration for formal listing by both state and federal governments.

Several state and federal species of concern use the shrub-steppe habitat for nesting/breeding activities. Because of its importance to these species, and its relative scarcity, the state of Washington considers the shrub-steppe a priority habitat.

Table 1-2. Threatened (T) and Endangered (E) Species.

Common Name	Scientific Name	Federal	State
Mammals			
Pygmy rabbit[a]	*Brachylagus idahoensis*		E
Birds			
Aleutian Canada goose[b]	*Branta canadensis leucopareia*	T	E
American white pelican	*Pelecanus erythrorhychos*		E
Bald eagle	*Haliaeetus leucocephalus*	T	T
Ferruginous hawk	*Buteo regalis*		T
Peregrine falcon[b]	*Falco peregrinus*	E	E
Sandhill crane[b]	*Grus canadensis*		E
Plants			
Columbia milk-vetch	*Astragalus columbianus*		T
Columbia yellowcress	*Rorippa columbiae*		E
Dwarf evening primrose	*Oenothera pygmaea*		T
Hoover's desert parsley	*Lomatium tuberosum*		T
Northern wormwood[a]	*Artemisia campestris borealis* var. *wormskioldii*		E
Insects			
Oregon silverspot butterfly[a]	*Speyerra zerone*	T	T

(a) Probably not currently occurring on the site.
(b) Incidental occurrence.

1.3 CONDITION OF HANFORD SITE ECOSYSTEM

There are various levels of surface contamination being remediated at the Hanford Site. Figures 1-5 and 1-6 illustrate the location of principal contaminants that have been identified in the vadose zone (the soil layer above the water table). Some of these contaminants remain relatively fixed in the vadose zone, while other contaminants, of a mobile nature, have migrated to the water table and have contaminated the groundwater above DWS. These figures provide specific information derived from process knowledge, historical data, and characterization/remediation efforts that have been completed to date.

1.4 WASTE MANAGEMENT AND DISPOSAL PRACTICES SUMMARY

The waste management and disposal practices utilized through the nuclear production years resulted in the contamination issues discussed earlier in this section. See Section 2.0 for details of these management and disposal practices.

During the early years, the effort at the Hanford Site was focused on maintaining production goals. Waste management received less attention. This focus on production, coupled with a lack of attention to and understanding of environmental processes, led to the current levels of Hanford Site contamination. One of the principal drivers during the early production years was the lack of high-level storage space in the tanks. This led to decisions to dispose radioactive wastes to the soil. For example, in the mid 1950s, 4.8 million gallons of high level radioactive supernatant liquid waste and 1.9 million gallons of evaporator sediment from the B and T plants were disposed of in the soil. In the 1940s waste was cascaded through a series of tanks, to allow solids to settle out in the earlier tanks, and only the supernatant liquid reached tanks at the

Figure 1-5. 100 Area/300 Area - Principal Contaminants of Concern.

Figure 1-6. 200 Areas - Principal Contaminants of Concern.

end of the cascade. As tank capacity became strained, authority was granted to dispose of a portion of the HLW from the T and B plants to the soil after cascading through three tanks. This process is one of the factors that complicate inventory and source term calculations that are based on operational history.

The Hanford Site has, through an approximately 50-year period of chemical processing, discharged liquids to the ground with the intent of utilizing the soil's physical and geochemical capacity for retaining radioactive and hazardous chemicals. Throughout this period several waste disposal design assumptions concerning the soil's physical and geochemical capacity for retaining these materials have been proven to be overly optimistic. In point of fact, liquid discharge to the soil are currently the largest source of contamination to groundwater and the Columbia River and will remain so for the near future.

Originally, highly active radioactive waste was scheduled for storage in the buried underground tanks. The low activity waste (LAW) was scheduled to be mixed with the high volumes of uncontaminated cooling water and disposed in surface lakes. But the LAW volume was recognized as being too voluminous to store in tanks. Concerns about surface evaporation leaving exposed contaminated in soils that would be spread by frequent strong winds required another solution. The proposed solution involved reverse wells (injection wells) that ranged in depth from 150 to 300 feet. However, reverse wells were quickly regarded as a mistake due to plugging and difficulties in tracking the subsurface spread of contaminants. Shallow discharge to the soil by buried cribs and tile fields then became the standard mode of disposal for low activity/high volume liquid wastes. When tank storage space became critical, supernate was allowed to decant off of tank waste and cascade to cribs.

A report by Parker and Piper, issued in 1949, recognized that "wastewater discharges to the soil in the 200 Areas had created two distinct mounds and a low bridging spur between the 200 East and 200 West Areas." It was postulated that "available data indicate that these mounds will continue to grow if disposal sumps are used as in the past, but this growth can be largely controlled as desired, by changing the sites of the disposal sumps." It was further postulated that such mounds would "act as groundwater dams behind which contamination can be controlled." In reality, the mounds became the driving forces that provided transport in the groundwater for such mobile contaminants as tritium, ruthenium, and nitrate.

Waste disposal to the soil occurred with the assumption that, in general, evapotransporation greatly exceeded rainfall and there was no net recharge from surface infiltration from precipitation. Rainfall and snowmelt were not expected to percolate through the soil column to the groundwater. This assumption was the fundamental basis for allowing large quantities of concentrated waste to be discharged to the soil in such engineered structures as cribs and specific retention trenches. Parker and Piper reported that exploration borings from the desert yielded subsurface samples that were "almost dusty dry." Their field observations indicated that "ordinarily, over most of the area at least, rainfall infiltrates to a depth of only a few inches or a few feet below the land surface, and that subsequent evaporation and transporation dissipate that infiltrate." However, they also pointed out an inference "that infrequently – owing to rain of extraordinary intensity and duration, or to melting of an abnormal snowpack – some water infiltrates naturally below this relatively thin zone of intermittent wetting and desiccation by

climatic processes." The authors also postulated that, if liquid wastes were continuous, exceeding the soil's specific retention capability, such excess would drain to the aquifer. This concern was countered by the assumption that, although wastewater might reach the aquifer, "such may not be true of dissolved or suspended constituents in those wastes, because such constituents may be extracted, transiently or permanently, through physical-chemical reaction with particles of the earth materials penetrated."

The amount of recharge at the Hanford Site is known to depend on surface soils and vegetation type. Surface manipulation practices such as gravel covers and herbicidal control of vegetation are commonly used to protect workers and limit the spread of surface contamination. These practices may provide conditions where surface infiltration of precipitation and snowmelt can percolate through contaminated soil to the groundwater. Gravel over tank farms, coupled with short circuiting of much of the soil depth by unsealed boreholes, are thought to be a major contributors to the movement of tank waste toward, and into, the groundwater. The extremely hostile chemical and physical properties of fluids that leaked from SSTs and associated transfer structures have been postulated to alter (or overwhelm) the soil's capacity to hold up radionuclide transport in the vadose zone under the tanks, thus providing an increased likelihood of impacting the groundwater.

2.0 OPERATIONAL HISTORY OF WASTE DISPOSAL AT THE HANFORD SITE

Note: The materials in this section are taken from "Waste Management" (C. H. Deford), which can be found at http://www.hanford.gov/docs/rl-97-1407/waste_mgnt/index.htm.

2.1 HIGH LEVEL RADIOACTIVE LIQUID WASTE

According to the US Department of Energy, high level radioactive waste is "highly radioactive waste material resulting from the reprocessing of spent nuclear fuel. It includes liquid waste produced directly in reprocessing and highly radioactive solid waste derived from the liquid.

2.1.1 Sources and Characterization

Five chemical separations plants were Hanford's primary sources of high level radioactive waste, although small additional quantities came from the Plutonium Finishing Plant and elsewhere. T and B Plants were the pioneer plants that operated from the mid 1940s through 1956. Improved technologies led to the Reduction-Oxidation Plant (REDOX) that operated from 1952 to 1967, and to the Plutonium-Uranium Extraction Plant (PUREX) that operated from 1955 to 1988. U Plant (221-U) operated from 1952 until 1958 to recover uranium from T and B Plant high level radioactive waste. All plants used complex, toxic and corrosive chemicals in their separation processes.

At each separations plant, operators dissolved the irradiated uranium fuel rods in nitric acid, first to remove the protective outer jacketing, and then to reduce the uranium metal to a liquid state. They then extracted plutonium from the uranium nitrate solution and sent it to the Plutonium Finishing Plant to be purified into plutonium metal.

Each step of the plutonium extraction process produced high level radioactive waste that was transferred through underground lines to large underground storage tanks located in tank farms near each separations plant. Much of this high level radioactive waste continues to be in storage today.

Each subsequent separations plant employed technologies that reduced the quantity of high level radioactive waste per unit of irradiated fuel processes. For instance, PUREX generated only about 250 gallons of high level radioactive waste per ton of irradiated fuel, a major improvement over the 10,000 gallons per ton generated by T and B Plants. However, production capacity also increased with PUREX processing an amazing 33 tons of fuel per day, compared with T or B Plant's mere 30 tons per month in their best and final years. Ultimately, nearly 245 million gallons of high level radioactive waste, containing 210 million curies of radioactivity, were transferred to Hanford's 177 underground storage tanks from the five separations plants (Anderson 1990, Gephart and Lundgren 1997).

B and T Plants used bismuth-phosphate chemistry in a batch process employing repeated dissolution, precipitation, and centrifugation, which produced about 10,000 gallons of high level radioactive waste per day. Process chemicals included nitric acid, phosphoric acid, bismuth phosphate, sodium dichromate, bismuth nitrate, potassium permanganate, sodium nitrate, and others. All of these, plus aluminum, uranium, plutonium, and numerous fission products were included in the high level radioactive waste. The highly acidic waste was acid neutralized with large quantities of sodium hydroxide before transfer to the storage tanks (Anderson 1990).

REDOX came on line in 1952 with an improved separation process and different chemistry. Its solvent extraction process used methyl isobutyl ketone (hexone), aluminum nitrate, nitric acid, sodium dichromate, and other such chemicals. REDOX high level radioactive waste included all of these chemicals plus solutions containing ferrous ions.

PUREX became operational in 1955 as Hanford's final and most advanced separations plant. Designed to separate plutonium, uranium and neptunium from irradiated reactor fuel, PUREX used a continuous flow extraction process, involving tri butyl phosphate, saturated kerosene, nitric acid, oxolic acid, ammonium fluoride, ammonium nitrate, and numerous other chemicals. All became part of the PUREX high level radioactive waste stream. After passing through waste concentrators, a reduced and highly concentrated waste volume of 250 gallons per ton of processed uranium was achieved. Production, however, increased to a dramatic 33 tons per day, largely offsetting the net waste volume decrease that might otherwise have been realized (Anderson 1990).

High level radioactive waste is difficult to characterize. The differing chemical separation processes employed over time produced twenty-six different waste streams that were chemically dissimilar but which were combined in the underground tanks to form even more complex waste combinations. Exposure to air, heat, cascading, settling, radioactive decay, kinetics, and subsequent chemical treatments further complicated the nature of the high level radioactive waste with radical differences developing from tank to tank. The addition of sodium hydroxide, an acid neutralizer, caused portions of the waste to form solid particles and to separate into layers. Evaporation of liquids led to salt cake and slurry formation, causing further uneven distribution of chemical compounds and radioisotopes. Waste was transferred from tank to tank as it went through subsequent treatment and isotope recovery campaigns. All of these factors contributed to waste complexity and to the difficulty of sampling and characterizing in order to plan the remediation of the high level radioactive waste.

High level radioactive waste characterization is further complicated by the activities of U Plant, which was used from 1952 to 1958 to recover valuable uranium from T and B Plant high level radioactive waste. U Plant was originally constructed as a bismuth-phosphate chemical separations plant, identical to its sister plants, B and T. But its capacity proved unnecessary and it served only as a training facility until 1952 when it was redesigned for its new mission.

Since B and T Plants extracted only plutonium from the uranium fuel elements, the resulting high level radioactive waste remained rich in uranium. The high value of uranium drove a decision to convert U Plant to a uranium recovery mission. Using tri butyl phosphate and saturated kerosene chemistry, U Plant reprocessed T and B Plant high level radioactive waste to

recover uranium. Its waste stream included tri butyl phosphate, saturated kerosene, nitric acid, oxalic acid, and other chemicals. Unfortunately, the U Plant uranium recovery process generated about twice as much waste as it processed, placing additional strain on the storage tank farms which were nearing capacity.

2.1.2 Facility Descriptions

Facilities associated with high level radioactive waste include the five chemical separations plants, the lines and encasements used to transfer high level radioactive waste about the 200 Areas, diversion stations, storage tanks, and evaporator buildings.

The primary method used to transport high level radioactive waste across the Hanford Site was through underground process lines that ran, for the most part, through concrete encasements. Most process lines are 3-inch diameter, stainless steel pipe with welded joints. Encasements are underground concrete fixtures designed to contain and protect from one to seven process lines. The encasements vary in width, depending on the number of lines within them. Diversion stations located at the process facilities and tank farms permit rerouting of high level radioactive waste through different lines to alternate locations.

For high level radioactive waste, the lines carried the liquid to underground storage tanks, clustered into tank farms. Storage tanks are of two types. Both types, single-shell and double-shell tanks, are cylindrical shaped concrete structures with carbon steel inner. Single-shell tanks have a single inner liner while double-shell tanks have two liners with a space between them. This space provides a pathway by which leakage from the inner liner may be trapped, collected, detected, and recovered. Leakage has occurred only from single-shell tanks.

Single-shell tanks are generally smaller but more numerous than double-shell tanks. Starting in 1945, 149 single-shell tanks were constructed, providing 94 million gallons of storage capacity. They range in capacity from 55,000 to 1 million gallons and are buried with their upper surfaces 6 to 11 feet below grade. The earth cover provides shielding from the intense radiation of the high level radioactive waste, permitting tank farm workers to move about the areas above the tanks. Numerous and various openings exist in the tank dome to accommodate vents, filters, detection tubes, probe access wells, pumps, cameras, and the many kinds of instrumentation necessary to monitor content of the tanks.

The 28 newer double-shell tanks provide a storage capacity of 31 million gallons. They range in size from 1 to 1.1 million gallons and are buried 7 feet below grade. Similar openings exist in the tank dome to provide instrumentation, process, and sampling access to tank contents.

To reduce the volume of waste, operators sent the waste from the tanks to the waste evaporator buildings. Waste evaporator buildings are large, rectangular concrete structures. The evaporators were steam-heated containers, which boiled the liquid out of the particulates, leaving a condensate from the evaporated liquid and concentrated slurry. The condensate could be treated as low level liquid waste and so was disposed of in nearby trenches or cribs. Evaporation generated thick, high level radioactive waste slurry that was returned to the high level radioactive waste underground storage tanks, where it cooled and formed salt cake. Approximately

200 million gallons of liquids were evaporated from high level radioactive waste storage tanks in this manner (Gephart and Lundgren 1997).

2.1.3 Waste Minimization

Waste minimization has been a key element of Hanford's high level radioactive waste management program. Reducing the volume of high level radioactive waste has taken several forms, the most successful being concentrating waste by REDOX and PUREX and evaporating off the liquid. Also, cesium-137 was scavenged from the high level waste, which changed its designation and allowed it to be handled as a low level waste. A chronological description of these waste minimization and other waste management activities demonstrates the importance in reducing the volume of high level radioactive waste to be stored in the limited underground tank resource.

1944-1945	First alkaline slurries of high level radioactive waste were transferred from T and B Plants to the 64 original, underground tanks. Waste was cascaded through a series of tanks to allow solids to settle out in the earlier tanks and only the supernatant liquid (liquid left on the surface) to reach tanks at the end of the cascade. T and B Plants originally produced over 10,000 gallons of high level radioactive waste for each ton of uranium processes.
1948	As underground tank storage capacity became strained, authority was granted to dispose of a portion the high level radioactive liquid waste from the T and B plants in the soil after cascading through three tanks.
1947-1948	42 new single-shell tanks constructed.
1949	Hot Semiworks (C Plant) began operations to pilot technologies for REDOX and PUREX processes and generated high level radioactive waste.
1950-1952	18 new single-shell tanks constructed.
1951	242-T and 242-B Evaporators began processing T and B Plant high level radioactive waste stored in tank farms to reduce volume by boiling off the liquid. Together they processed over 16 million gallons of waste, achieving over 80 percent reduction in volume. The concentrated waste was returned to the storage tanks and the evaporated condensate was disposed of in the soil.
1952	U Plant began a 2-year uranium recovery campaign, generating between 5,500 and 9,200 gallons of waste per ton of uranium in 1952. Waste evaporators reduced this rate to 3,600 gallons but could process only about 700,000 gallons per month, while U Plant generated over 1.7 million gallons per month of high level radioactive waste. Scavenging of U Plant high level radioactive waste with potassium ferrocyanide to settle out cesium-137 permitted disposal in the soil of 11.6 million gallons of relatively inactive supernatant liquid. Another 29 million

gallons of high level radioactive waste were disposed of in the soil after scavenging at U Plant removed long half-life fission products (Anderson 1990).

Cesium-137 scavenging continued for many years with about 41 million gallons of supernatant liquid discharged in the soil. About 150 tons of ferrocyanide are thought to be contained in 18 underground tanks (Gephart and Lundgren 1997).

1952 REDOX began operation, generating high level radioactive waste at a rate of 4,378 gallons per ton of uranium in 1952.

1953 Self-concentration was approved for REDOX high level radioactive waste at S Tank Farm. Self-concentration involved disposing of vapor condensates in the soil instead of returning it to the underground tank. Over the life of the REDOX Plant, self concentration and REDOX process improvements reduced REDOX high level radioactive waste generation rates from 4378 gallons per ton of uranium in 1952 to 594 gallons per ton of uranium by 1964 (Anderson 1990).

1953-1955 21 new single-shell tanks constructed.

1954-1956 In addition to disposing of the low level liquid waste in the soil, the sediment on the bottom of the evaporators was also disposed of as low level waste. From 1954-1956, 4.8 million gallons (10,200 curies) of high level radioactive supernatant liquid waste and 1.9 million gallons (11,600 curies) of evaporator sediment from the B and T plants were disposed of in the soil. Disposal was limited to areas of soil capable of retaining liquid without its penetrating through to the water table (Anderson 1990).

Chemical scavenging of high level radioactive waste from the B and T plants was also accomplished during this period. Ferrocyanide compounds were added to high level radioactive waste to cause cesium-137 to settle out, thus allowing the resultant cesium-free supernatant liquid to be disposed of in the soil. From 1954-1956, 3.1 million gallons were disposed of in this manner. In total, these waste volume reduction efforts reduced the high level radioactive waste volumes in underground storage from the B and T plants by a factor of 3.25, reducing net waste generation from 17,000 gallons per ton of uranium to 5,240 gallons per ton of uranium (Anderson 1990).

1955 PUREX began operating, eventually generating high level radioactive waste at a rate of 250 gallons per ton of uranium and processing 33 tons of uranium per day. PUREX high level radioactive waste was sufficiently concentrated that its heat producing fission products caused the waste liquid to boil. This self boiling accelerated to a point in 1957 that boil off reached 10 gallons per minute, and it became necessary to add water to the waste liquids to maintain a reasonable level (Anderson 1990). Self-boiling ended the practice of cascading.

All PUREX high level radioactive waste was acid neutralized with large quantities of sodium hydroxide, greatly increasing the waste volume.

1963-1964 4 new single-shell tanks constructed.

1966 Thorium recovery campaign generated 1.4 million gallons of high level radioactive waste.

1968-1988 28 new double-shell tanks constructed.

1968-1978 B Plant operated to recover cesium and strontium. This process recovered strontium-90 from high level radioactive waste sludge and cesium-137 from high level radioactive supernatant liquid waste stored in underground tanks. Removal of these isotopes from the high level radioactive waste had the effect of reducing the heat generating capacity of the waste. The strontium and cesium isotopes were encapsulated for the Oak Ridge National Laboratory isotope program. Remaining waste was evaporated with condensates disposed of in the soil and the concentrates returned to underground storage. A large inventory of encapsulated strontium and cesium remains stored at the 200 East Area Waste Encapsulation and Storage Facility.

1973-1976 Two new evaporator plants, 242-S and 242-A came online. 242-A remains operational today.

Over the history of the Hanford Site, the volume of high level radioactive waste that was stored was reduced by almost 80 percent. Of the approximately 245 million gallons of high level radioactive waste generated and stored from all processes, approximately 55 million gallons remain in the underground storage tanks today, awaiting treatment and permanent disposition. Approximately 190 million gallons were removed through the methods such as evaporation and scavenging or through tank leakage. (Gephart and Lundgren 1997, Anderson 1990).

2.1.4 Incidents

Numerous incidents relating to high level radioactive waste have occurred over the operating history of the Hanford Site. Two examples of incidents are given here to demonstrate the challenge and complexity of managing high level radioactive waste: a violent chemical reaction at a tank farm and leaking transfer lines.

One type of incident was a violent chemical reaction that occurred in 1953 in an underground vault at the U Tank Farm, causing surface contamination in the area adjacent to the vault. Cleanup crews placed lead sheeting over the contaminated area and covered the sheeting with clean soil to prevent spreading the contamination (GE 1953).

Another type of incident was leaks from transfer lines. Transfer line leaks occurred when line sections separated or when temporary connecting jumpers loosened, causing contamination of the soil adjacent to the leak sites. Because the resulting liquid contaminate was quickly absorbed

by the gravel soil, cleanup crews typically remediated the problem by removing the contaminated soil for burial elsewhere or covering the contaminated area with an overburden of clean soil (Maxfield 1979).

An example of such a line leak occurred near T Plant in 1955 when leaking contaminants formed a pool on the surface that produced radiation readings of 100 rads/hour near the surface. The spilled liquids were allowed to soak into the soil which was then covered with fresh soil and then with asphalt (Maxfield 1979).

2.1.5 Storage Tank Leakage

Due presumably to the corrosive nature of high level radioactive waste, the temperature ranges generated by decaying fission products, and the aging of the storage vessels, some of the single-shell underground storage tanks have begun to leak. While the actual mechanism of leakage is uncertain, it seems probable that the causes include stress, corrosion, cracking, and mechanical tearing of the liner (Anderson 1990). Sixty-seven single-shell tanks (but no double-shell tanks) are known or suspected to have leaked.

The single-shell tanks are steel-lined concrete vessels with a design life of 20 years. That life has been exceeded by over 30 years and will have been exceeded by 50 years before workers can remove all waste by 2018 in accordance with the Tri-Party Agreement (Ecology 1994). Despite the 20-year life expectancy, leakage of the single-shell tanks began with a 55,000-gallon leak in 1956, only 10 years after the first tanks were built. The most severe tank leak occurred at the T Tank Farm in 1973 when 115,000 gallons of high level radioactive waste were released in the soil.

As tanks continue to age, additional instances of leaking are likely to occur. As of 1995, as much as 1 million gallons of waste may have entered the soil beneath the tanks. This volume is estimated to contain as much as 1 million curies of radioactivity, mostly from cesium-137 (Gephart and Lundgren 1997). Recent analyses identified that the original estimates are understated (Agnew, 1998).

Detecting leaks is difficult. The depth at which the underground tanks are buried, the hazardous nature of high level radioactive waste, and the impossibility of fully emptying tanks makes direct tank inspection nearly impossible. Workers must rely on indirect means to detect and gauge tank leakage by comparing measurements over a period of time. Approximately 800 vertical monitoring wells (dry wells) have been drilled near the single-shell tanks. Radiation readings taken at different depths in the wells give indications of leakage that may have occurred. Lateral wells drilled laterally to extend beneath the tanks are also used (Gephart and Lundgren 1997).

In addition, groundwater monitoring wells are placed at hundreds of locations to detect and measure contaminants that may reach the underlying aquifer. Environmental monitoring has determined that the groundwater under the B-BX-BY tank farms, located in the 200 East Area, has been contaminated with chemical and radiological contaminants either from leaking tanks or spills (DOE 1998a).

When tanks are discovered to have leaked, cleanup crews applied several remedies. Waste was transferred to sound, usually double-shell tanks. Diatomite was added to some tanks to solidify the remaining liquids. Finally, tank evaporators were used to further reduce the fluid levels and minimize further leakage to soil.

2.2 LOW LEVEL RADIOACTIVE LIQUID WASTE

Low level radioactive waste is defined as any radioactive waste not classified as high level or transuranic waste, spent nuclear fuel, or byproduct material. It is typically contaminated with small amounts of radioactivity dispersed in large amounts of material, but some high activity and/or high concentrations can exist. Low level radioactive waste may exist in liquid or solid form. This section discusses low level radioactive liquid waste. Low level radioactive solid waste is discussed in the following section.

All Hanford program areas generated low level radioactive liquid waste that was disposed of into the soil near the facility generating the waste or into the Columbia River. Several methods were devised to dispose of low level radioactive liquid waste in the soil, including open ponds and trenches, reverse wells, French drains, and cribs. Some methods were discarded due to adverse environmental impacts. The method used was dependent on the degree of waste concentration and/or the presence of radioisotopes that gave off high-energy radiation. The following sub-sections discuss how these methods were used to dispose of low level radioactive liquid waste generated from the various Hanford Site areas.

2.2.1 100 Areas

Hanford production reactors generated low level radioactive liquid waste that was disposed of into the soil through cribs and trenches or directly into the Columbia River through effluent lines.

The eight original reactors used vast quantities of Columbia River water to cool the reactor cores to safe operating temperatures. This cooling water created the greatest volume of low level radioactive liquid waste. Hanford's ninth reactor, N Reactor, used a different cooling system design that did not discharge cooling water directly into the river.

The purified water entered the reactor cores at flow rates up to 200,000 gallons per minute. Passing in direct contact with the reactor fuel elements, the cooling water carried away heat created by the fission processes occurring in the fuel, and maintained the core temperature at desired levels. At exit, the water temperature had been raised to near boiling (90-95 C).

The high neutron flux of the reactor core activated elements in the cooling water, creating such isotopes as calcium-41, chromium-51, and zinc-65. The water was also contaminated with activation products from the reactor core and with fuel element fission products such as strontium-90 and cesium-137, and transuranics, such as uranium and plutonium when fuel cladding failures occurred (DeFord and Einan 1995). The radioisotopes of greatest environmental impact from this process were sodium-24, neptunium-239, arsenic-76, zinc-65, and phosphorus-32 (HEDR 1994).

After passing through the reactor, the cooling water was transferred through effluent lines to a retention basin located near the river where it was held for 2.5 to 4 hours, allowing it to cool and short-lived radionuclides to decay. From the retention basin, the water passed through an outfall structure and large underground followed by underwater pipes to the river bottom at mid channel. The outfall structure was designed to divert effluent to an open concrete spillway if the underground line were to become plugged.

The quantity of radionuclides released to the Columbia River in reactor effluent began high and increased over time. From five radionuclides alone, over 200,000 curies were released to the river in each of the first two full years of reactor operations, 1945 and 1946. This rate doubled three times between 1945 and 1960 to over 2 million curies in 1960. The volume of reactor effluent had increased ten fold as cold war demands for plutonium production led to reactor power level increases and the construction of five additional reactors. The year 1960 represented the all time high rate, and annual deposits of low level radioactive liquid waste to the river began to diminish after that as the reactors without closed-loop systems began to shut down at an approximate rate of one per year (Clukey 1957, HEDR 1994). Table 2-1 is a summary of curies released to the Columbia River from five radioactive materials between 1944-1972. For a more complete listing of radionuclides released to the Columbia River, see Table 2.3-9 in the Reactor Operations Section.

Table 2-1. Annual Summary of Curies of Five Radioactive Materials Released to the Columbia River from the Hanford Site, 1944-1971. (Heeb and Bates 1994, p. vii)

Year	Sodium-24	Phosphorus-32	Zinc-65	Arsenic-76	Neptunium-239
1944	905	216	708	1178	17060
1945	34900	2890	10518	20340	192100
1946	28360	2190	8688	14212	153400
1947	25450	1860	7457	12319	127840
1948	33970	2219	8362	15772	151100
1949	46870	3175	11713	24660	214600
1950	72590	4027	14546	30510	279900
1951	99020	3333	11153	23660	261700
1952	132690	5050	9037	34740	259000
1953	202500	8688	8691	98940	316200
1954	243400	7261	21910	91380	391600
1955	318000	7184	26670	139530	419400
1956	407800	7722	31940	134280	450300
1957	644700	12325	27560	212130	500100
1958	751400	18484	27180	293300	422300
1959	1019000	17993	32030	218400	275100
1960	1382900	19490	42720	236900	354800
1961	1096300	21526	47110	166890	243910
1962	1094200	13845	56010	86660	257100
1963	887900	11738	14920	100630	211800
1964	960000	12311	15710	114480	247500

Table 2-1. Annual Summary of Curies of Five Radioactive Materials Released to the Columbia River from the Hanford Site, 1944-1971. (Heeb and Bates 1994, p. vii)

Year	Sodium-24	Phosphorus-32	Zinc-65	Arsenic-76	Neptunium-239
1965	764500	12126	13379	124600	168400
1966	613000	7365	9656	74600	78950
1967	671900	10118	15360	94010	114970
1968	499500	8632	7734	71670	99790
1969	359200	5478	6451	61250	59820
1970	178041	1759	3394	20253	36879
1971	13200	235	386	2440	3540
Sum	12582196	229239	490993	2519734	6309159

N Reactor used a closed-loop cooling system that did not discharge cooling water directly to the river. Instead, water heated by the reactor core passed through a heat exchanger, yielding much of its heat, and then returned to the core in a continuous, closed, loop. As cooling water became contaminated, it was bled off and routed to a covered trench for disposal in the soil.

Workers disposed of low level radioactive liquid waste in numerous cribs from sources such as overflow of fuel storage basins, decontamination activities, drainage from building filters, and floor drains. Some reactor sites also used a crib to dispose of highly contaminated cooling water from a single process tube that had been contaminated by a ruptured fuel element. In some cases, this crib was merely an open pit into which effluent was directed through a hose attached to the rear face of the reactor (WIDS 1998).

Fuel element failures caused by a rupture in the cladding were an all-too-frequent occurrence at Hanford production reactors with nearly 2000 occurring between 1951 and 1965 (DeNeal 1965). Some were no more than a pin-hole-sized breech in the outer, protective cladding of a fuel element. Others were more severe and exposed much of the fuel element's irradiated uranium fuel to the cooling water, which became grossly contaminated with uranium, fission products, and trace quantities of plutonium.

In the early years of fuel rupture experience, water from only the affected process tube was diverted from the rear face of the reactor to a crib where it was disposed of in the soil. In later years, the cooling water from the affected process tube was allowed to mix with that from all other tubes and, after cooling in the retention basin, was either released to the river or to a large trench that had been excavated for that purpose. Water diverted to these riverside trenches was allowed to percolate into the soil rather than being released directly to the river. This provided for ion exchange with the soil and for additional radioactive decay before the effluents eventually reached the river through the soil.

2.2.2 Experimental Animal Farm

An additional source of low level radioactive liquid waste was the Experimental Animal Farm located at the 100-F Area. The Experimental Animal Farm operated from 1945-1976 to measure

the effects of ionizing radiation on living organisms. Early researchers focused on the effects of reactor effluents on Columbia River fish. Later, researchers included the use of swine, sheep, dogs, rats, and plants.

Operations varied widely depending on the nature and scope of the particular experiment but generally involved the introduction of radioisotopes into living tissue with follow-up study to identify and measure its effect over time. Researchers tested the effect of iodine-131, strontium-90, cesium-137, isotopes of plutonium and uranium and other isotopes by having the animals inhale, ingest, and absorb the isotopes or by inoculating the animals with them (DeFord 1993).

Low level radioactive liquid waste streams included contaminated cleaning water resulting from animal pen cleaning, waste from the radio-botany and pharmaceutical labs, and various liquid waste from the biology lab. Most low level radioactive liquid waste went to 100-F cribs or trenches. Some was injected into reactor effluent and flushed to the Columbia River through the reactor outfall or passed directly to the Columbia River through a separate waste line and outfall (DeFord 1993).

2.2.3 200 Areas

Numerous sources of low level radioactive liquid waste have existed in the 200 Areas. Five chemical separations plants generated many forms of low level radioactive liquid waste. The Plutonium Finishing Plant added its share, including waste such as carbon tetra-chloride. Waste evaporators, used to reduce the volume of high level radioactive waste, produced large quantities of low level radioactive waste in the form of condensate that was released in the soil. Scavenged waste from some high level waste tanks was also disposed of in the soil as low level radioactive liquid waste.

In 1945-1946, all 200 Area low level radioactive liquid waste that did not meet the prevailing criteria for high level waste was disposed of in the soil in open trenches and ponds. Narrow, radioactively contaminated beach zones developed, which were intruded upon by insect, bird, and animal life. These along with high winds spread contaminants to nearby downwind locations. After 1946 to protect personnel and the environment, only low level radioactive liquid waste with low activity continued to flow to open ponds and trenches. The deactivated ponds and trenches were flushed with fresh water and eventually backfilled (WIDS 1998).

Rather than dispose of low level radioactive liquid waste with higher activity in open ponds and trenches, in 1946 workers increasingly disposed of it below grade where contamination would be confined to sub-surface soil. To do this, numerous reverse wells were placed into service. These were deep, well-like shafts with perforated casings, which were drilled to a depth above groundwater. The wells had a tendency to become plugged with solids suspended in the low level radioactive liquid waste and had the disadvantage of introducing the waste liquids near groundwater. Reverse well use was discontinued after about a year and no new ones were constructed.

French drains were constructed about the same time as reverse wells. French drains are shallow shafts used to dispose of low volumes of low level radioactive liquid waste with low activity.

The shaft is typically a 3-6 foot concrete pipe about 36 inches in diameter, which is buried vertically and filled with rock or gravel. The liquid usually entered the shaft from a waste line at the top of the pipe, which was at ground level and flowed through the pipe to the soil below. French drains continued to be used through the operational history of the Hanford Site for disposal of low level radioactive liquid waste with low activity. Numerous French drains are scattered throughout the Hanford production areas.

French drains were largely replaced with cribs of various design. These were constructed with their upper surfaces only a few feet below grade to maximize the distance to groundwater, yet avoid the surface contamination problems associated with open ponds and trenches. Cribs are underground chambers used to dispose of large volumes of low level radioactive liquid waste. They were usually constructed of loosely spaced timbers, creating a chamber of more than 1000 cubic feet. The liquid would percolate through the chamber to the underlying soil. Numerous cribs exist in the 100, 200, and 300 Areas. Some cribs were used in conjunction with settling tanks in which waste solids would settle out before the supernatant liquid waste passed on to the cribs.

Over time, some cribs began to fail due to silt or chemical deposits, and overflow drain fields were attached to improve dispersal in the soil. These were not unlike the drain fields used in sanitary sewage systems, and they proved equally effective for low level radioactive liquid waste. Since 1960, many cribs have been constructed with drain fields, and a few drain fields have been constructed without cribs (WIDS 1998).

Open trenches and ponds as large as 50 acres continued in use for low level radioactive liquid waste with low activity or that was highly diluted, such as steam condensate and cooling water from certain contaminated facilities (WIDS 1998).

2.2.4 300 Area

Low level radioactive liquid waste management and disposal at the 100 and 200 Areas was largely decentralized, with each facility manager responsible for waste generated at that facility. Dedicated cribs, French drains, ponds, and trenches supported most facilities.

The 300 Area differed from its sister areas in that the management and disposal of low-level radioactive liquid waste was centralized. From their construction in 1944, the many 300 Area laboratories and fuel manufacturing facilities were connected to a common process sewer that collected low level radioactive liquid waste and disposed of it in a single process pond located east of the area near the river.

The original process pond, a 353,000 square foot by 5-foot deep facility, overflowed its banks in 1945, and a retaining dike was added. The cause was determined to be poor percolation to the soil resulting from buildup of impermeable precipitants on the bottom of the pond. Waste level rose over time and the dike failed in 1948, releasing over 14 million gallons of low-level radioactive liquid waste into the Columbia River. The dike was repaired, and the pond returned to service (Young and Fruchter 1991).

A second pond was constructed immediately north of the original, and the bottoms of both were periodically scraped with the scrapings piled onto the dikes to further reinforce them. The ponds continued in operation until 1974 when they were replaced by a pair of 1500-foot process trenches.

Additional low level radioactive liquid waste processing improvements occurred in the mid-1950s when the Radioactive Liquid Waste System was constructed to replace the aging and by then leaking process sewer. Of modern design and stainless steel materials, the Radioactive Liquid Waste System fed a low level radioactive liquid waste retention and neutralization facility capable of sampling and diverting high activity waste to tanker trucks for disposal at 200 Area cribs. Low level radioactive liquid waste with low activity continued to flow to the 300 Area ponds and trenches. A railroad load-out facility with shielded railcars was added in 1965 to replace tanker trucks (DeFord 1994).

The Waste Acid Treatment Facility became operational in 1975 to process waste acids disposed of by various 300 Area laboratories. This waste was sampled, neutralized, centrifuged, and otherwise processed before being released for disposal to various locations including 200 Area waste disposal sites. Prior to 1975, 300 Area acids were disposed of in 300 Area ponds and trenches along with all other low-level radioactive liquid waste (DeFord 1994).

A few cribs and French drains were used in the 300 Area as needed to meet specific and usually temporary needs of laboratories and other facilities (DeFord 1994).

2.2.5 400 Area and Fast Flux Test Facility

The Fast Flux Test Facility is a test reactor, with associated facilities located in the 400 Area. Although several French drains exist for disposal of cooling water and floor drain waste, no low-level radioactive liquid waste is known to have been disposed of in the soil at this facility.

2.2.6 Incidents

Several incidents involving low level radioactive liquid waste have already been mentioned in the preceding paragraphs. A few additional descriptions will help to demonstrate the scope and complexity of managing low level radioactive liquid waste.

- The groundwater has been contaminated by waste from U Plant. The 216-U-1 and 2 Cribs are side by side facilities that received U Plant cell drainage and other low level radioactive liquid waste during the operation of U Plant for its uranium recovery mission. About 4000 kilograms of soluble uranium were drained to the cribs and became insoluble as it reacted with the soil beneath the cribs. Acid waste, inadvertently discharged to the cribs, combined with the uranium, making it both soluble and mobile in the soil column but in insufficient volume to move the uranium far enough in the soil to reach groundwater. A new high volume, low activity waste crib, 216-U-16, was installed nearby. Low level radioactive liquid waste discharges to the new crib were sufficient by 1985 to collect atop an impermeable caliche layer located about 165 feet below the crib. The low level radioactive

liquid waste moved laterally along the caliche layer, passing beneath the 216-U-1 and 2 Cribs and transporting the now soluble uranium through openings in the caliche layer to groundwater beneath. Groundwater contamination was detected soon thereafter and pump-and-treat techniques were used in 1985 to remove uranium contaminants from the groundwater. Uranium contamination levels were thereby reduced from 72,000 picocuries/liter to 17,000 picocuries/liter (Baker et al. 1988).

- The Process Waste Sewer has leaked in the 300 Area. Portions of the stainless steel lines in the 300 Area Process Waste Sewer have become rusted and have leaked low level radioactive liquid waste into the underlying soil.

- The reactor retention basin has leaked and overflowed. Each Hanford production reactor, except the N Reactor, used large metal or concrete retention basins to hold contaminated cooling water for a few hours before releasing it to the Columbia River. Each of these basins has developed leaks, allowing low level radioactive liquid waste to escape to the underlying soil. Also, basin outflow gates have become blocked, causing the basin to overflow and form, in one case, a deep erosion ditch flowing to the nearby river bank.

- Cribs have overflowed and vegetation has become contaminated. Occasional overflows would occur at cribs when low level radioactive liquid waste was introduced at rates greater than the underlying soil could absorb. In these cases, low level radioactive liquid waste would sometimes overflow through the crib vent pipes, contaminating the surface area at and near the crib. Deep-rooted vegetation, such as Russian thistle, would sometimes intrude into contaminated soil, resulting in the plant becoming contaminated. Burrowing animals such as rabbits and gophers would also intrude into underground contaminated soil, becoming contaminated in the process and spreading that contamination about in the wake of their movements.

2.3 LOW LEVEL RADIOACTIVE AND TRANSURANIC SOLID WASTE

Radioactively contaminated solid waste has been disposed of by shallow earth burial since the beginning of Hanford operations in 1944. Burial grounds were established in support of each of the Hanford production programs, including fuels manufacturing, reactor operations, chemical separation, plutonium purification, and research and development. Each burial ground has received vast quantities of low level radioactive solid waste. At least 28 sites in the 100 Areas, 28 in the 200 Areas, and 11 in the 300 and 600 Areas have been used for this purpose (WIDS 1998, Miller and Wahlen 1987).

Solid waste includes non-liquid, non-soluble material ranging from municipal garbage to industrial waste that contains complex and sometimes hazardous substances. Radioactive solid waste includes materials that are contaminated with radionuclides. Low level radioactive solid waste is defined as radioactive waste that is not classified as high level or transuranic waste, spent nuclear fuel, or byproduct material. Low level radioactive solid waste is frequently found

mixed with non-radioactive hazardous waste and is called mixed low level waste. When mixed with transuranic waste, it becomes transuranic mixed waste.

Solid waste volumes at the Hanford Site since 1944 and including those that will be produced over the next 20 years have been estimated as follows (DOE 1992):

Hazardous Waste	6,100 cubic meters
Low level radioactive solid waste	89,000 cubic meters
Mixed low level waste	36,000 cubic meters
Transuranic mixed waste	22,400 cubic meters

Management practices for Hanford burial grounds may be generally described as follows (Dorian and Richards 1978):

1944 - 1954

- No intensive waste segregation program. Hazardous waste, low level radioactive solid waste, and transuranic waste were commingled for disposal
- Combustibles and non combustibles buried in the same trench
- Burial records contain minimal information
- Decentralized disposal with virtually all waste buried near point of origin

1955 - 1965

- Alternate disposal methods and sites studied, documented, and, in some cases, implemented
- Intentional burning of combustible low level radioactive solid waste in burial trenches began and ended in 1955
- Records improved

1966 - 1973

- Burial grounds centralized. Central landfill constructed for sanitary solid waste
- Measurement of burial materials improved
- Burial records much more complete
- Some segregation of waste by category

- Beginning in 1968, increasing amounts of low level radioactive solid waste transported to 200 Areas for disposal

- After May 1970, all transuranic waste stored or disposed of in the 200 Areas

Post 1973

- Sanitary solid waste disposed of at the Hanford Site Solid Waste Landfill
- All low level radioactive solid waste disposed of in the 200 Area burial grounds
- Environmental Restoration Disposal Facility constructed in 1995

2.3.1 Low Level Radioactive Solid Waste

Some types of low level radioactive solid waste, such as contaminated protective clothing, are common to all production programs and, therefore, to all burial grounds, while other waste types are unique to the facility that generated them.

General descriptions of the contents of low level radioactive solid waste burial grounds are available, but detailed content descriptions are typically available only for the latter years of Hanford operations. This results from minimal burial ground record keeping requirements during the early years.

100 Areas

Fuel elements received from the 300 Area were loaded into Hanford's production reactors and exposed to intense neutron bombardment (the process that causes small quantities of uranium to transform into plutonium). These reactor operations generated significant quantities of low level radioactive solid waste, which workers disposed of in the 100 Areas burial grounds and, after 1973 along with the Fast Flux Test Facility waste in the 200 Areas. Twenty-eight major reactor area burial sites exist in the 100 Area (Miller and Wahlen 1987).

The greatest portion of low level radioactive solid waste from the reactor area consists of large quantities of obsolete or failed reactor hardware. To this was added contaminated protective clothing, tools, and miscellaneous process related materials.

200 Areas

After irradiation in a reactor core, the reactor fuel was removed and delivered to one of Hanford's chemical separations plants (B Plant, T Plant, REDOX, and PUREX) located in the 200 Areas. Here the reactor fuel was dissolved in acid and introduced to a complex, wet chemical process that extracted the small quantities of plutonium from the uranium matrix of the reactor fuel.

Low level radioactive solid waste generated in this and related processes was disposed of in 200 Area burial grounds. As with reactor operations, the majority of solid waste was

contaminated process hardware made useless by failure or obsolescence. To these were added construction and demolition waste resulting from upgrades to the chemical system tools and protective clothing, and miscellaneous process related materials. Also included were soil and other materials contaminated by various chemical plant spills and leaks.

Some large, highly contaminated items are stored on flatbed railcars in the PUREX railroad tunnels that will require future decontamination or disposal in the 200 Area burial grounds (Anderson 1996).

The product of the chemical separations plants was an impure plutonium nitrate solution that was delivered to the Plutonium Finishing Plant for purification. The Plutonium Finishing Plant is located in the 200 West Area. Its processes generated low level radioactive solid waste that was disposed of in 200 West Area burial grounds. Again, obsolescent process hardware and materials such as tanks, pumps, piping, valves, and instrumentation provided the greatest quantity of waste. To these were added contaminated tools, protective clothing, rags, filters, and other materials.

300 Area

Fuel elements for the Hanford reactors were manufactured at Hanford's 300 Area from uranium stock. Using extrusion and cladding processes housed in the 306, 313, 314, and 333 Buildings, workers produced vast quantities of rod-shaped, reactor fuel elements and shipped them to Hanford's nine production reactors for irradiation. Numerous types of contaminated solid waste resulted from the fuel manufacturing processes, including industrial hardware and tools, protective clothing, equipment, glassware, swipes, and miscellaneous process related materials. The waste stream also included quantities of uranium millings, shavings, and dust resulting from fuel manufacturing processes. Large quantities of contaminated demolition waste were also disposed of during renovation activities at the fuel manufacturing buildings. Until 1973, all low level radioactive solid waste from fuel manufacturing was disposed of in the 300 and 600 Area burial grounds. After that year, 300 Area low level radioactive solid waste was disposed of in the 200 Area burial grounds.

Research and Development

Research and development played an essential role in improving the processes at all stages. Most research and development activities were housed in the 300 Area in laboratory facilities such as the Pile Technology, Radio-Chemistry, and Radio-Metallurgy laboratories, Plutonium Recycle Test Reactor, High Temperature Lattice Test Reactor, High Temperature Sodium Test Facility, and others.

All of these labs generated low level radioactive solid waste, most of which was buried in 300 and 600 area burial grounds. Some research and development labs, especially Radio-Chemistry, produced low level radioactive solid waste with remarkably high dose rates that required special handling and disposal procedures, discussed later in this section.

Two additional major research and development laboratories, Hot Semi-Works and the Critical Mass Facility, were located in the 200 East Area. Low level radioactive solid waste generated there was disposed of in the 200 Area burial grounds. Hot Semi-Works created an additional quantity of low level radioactive solid waste when in 1987 the laboratory was decommissioned and its contaminated demolition rubble was disposed of in the 200 East Area burial grounds (DOE 1998b).

Off Site Waste

Not all solid waste in the burial grounds was generated at the Hanford Site. While early records are incomplete, at least 58 off site waste generators are known to have shipped low level radioactive solid waste to the Hanford Site for disposal, essentially all going into the 200 Area burial grounds. These waste generators include universities, other DOE sites and laboratories, the military, and commercial companies that have been involved in government programs resulting in low level radioactive solid waste.

Types of programs that have generated low level radioactive solid waste disposed of at the Hanford Site include (Anderson 1996):

- Accelerator studies
- Animal studies in DOE facilities and universities
- Basic research
- Cleanup and restoration projects
- Department of Defense waste (U.S. Army and Navy)
- Reactor studies
- Irradiators and sources
- Fuel fabrication facilities
- Laboratory waste.

An unusual form of off site waste received at the Hanford Site is more than 50 reactor compartments from nuclear submarines, which are disposed of in a 200 East Area burial ground. When U.S. Navy nuclear submarines are decommissioned, the entire reactor section of the hull is removed, sealed, and shipped to the Hanford Site for disposal. The intact section is transported by barge to a Hanford receiving dock where the section is loaded onto a massive wheeled trailer for transport to the burial ground.

2.4 TRANSURANIC WASTE

Transuranic waste contains radioactive materials contaminated with isotopes emitting alpha particles that have half-lives of over 20 years in concentrations of more than one ten-millionth of a curie per gram of waste (DOE 1995a). Prior to 1970, transuranic waste was not recognized as a separate waste category and was disposed of in burial grounds as routine waste. Nearly all of it

was buried in the 200 Area burial grounds with only small amounts entering a 100-F Area site and two 600 Area sites (Anderson 1996).

Atomic Energy Commission Immediate Action Directive 0511-21 defined transuranic waste and directed that after May 1970 waste with known or detectable contamination of transuranic waste radionuclides must be segregated from other waste categories. No further burial of transuranic waste was permitted, and it must instead be placed in retrievable storage. This was accomplished through use of a new style burial trench designed to permit transuranic waste recovery at a later date AEC Order 1511, issued in 1973, established a segregation limit of 10 nanocuries/gram. Transuranic waste with concentrations of radioactivity greater than 10 nanocuries/gram must be segregated and retrievably stored. Transuranic waste with lower concentrations need not be segregated. Since 1988, transuranic waste has been stored above ground in the Central Waste Facility.

Prior to 1980, liquid organic waste was sometimes disposed of in low level radioactive solid waste burial grounds. This type of waste was banned from burial ground disposal in 1980 due to its potential chelating effect on other waste in the burial trench and due to its potential damage to ion exchange properties of the soil. Liquid organics were subsequently stored in burial grounds in the same retrievable manner as transuranic waste.

To conform with Washington State Administrative Codes on waste storage, an additional low level radioactive solid waste category was defined in 1987. Hanford's Extremely Hazardous Waste has been segregated and stored as retrievable waste after this date. Also in 1988, mixed waste of fewer than 200 millirem/hour was to be retrievably stored and placed into a storage building to meet Washington State Administrative Codes. Mixed waste of greater than 200 millirem/hour would continue to be buried.

To meet the need for storage of extremely hazardous waste in buildings, the Central Waste Facility buildings were constructed. The first was completed in 1988 with another dozen completed shortly thereafter. These are 4000 square foot buildings that meet Washington State Code, RCRA (42 USC 6901), and other requirements for extremely hazardous waste and low level radioactive solid waste storage. Another seven, 35,000-50,000 square foot buildings have subsequently been constructed or are under construction (Anderson 1996).

2.4.1 Record Keeping

Burial ground record keeping was minimal in the early days of the Hanford Site with little information on the amounts and types of low level radioactive solid waste buried. During the 1950s and 1960s, some documents were issued on waste disposal activities, but these records are not complete. Studies have estimated the volume and radioactivity of previously unrecorded buried waste based upon the ratio of the radionuclides present in the fuel elements and on other known and deduced waste generation and disposal information.

Beginning in the late 1960s, routine reports of low level radioactive solid waste in the 100 and 200 areas became more complete and included the amount of land area used, volume of waste, curie content of the various waste radionuclides, and the coordinates of the burial location.

Since 1971, the contents of burial grounds have been tracked on automated databases. A succession of automated information systems have been used, culminating in the current system, the Solid Waste Information and Tracking System. The Solid Waste Information and Tracking System is a state-of-the-art waste inventory and projection system that can calculate the activity of all radionuclides in each waste container. Its query capabilities include waste generator, date, location where waste was generated, burial location, activity at time of burial, and current activity (Anderson 1996).

2.4.2 Waste Minimization

An essential element of waste management is waste minimization. This includes those practices calculated to minimize the quantity or volume of waste materials requiring disposal. Chief among these are manufacturing practices that are improved to produce less waste and waste volume reduction by compaction, incineration, or other methods. Hanford operations have used all of these and other waste minimization practices.

Low level radioactive solid waste was burned at some Hanford burial grounds to reduce the volume before the Clean Air Act of 1970 and other environmental legislation precluded the practice.

From 1962 to 1973 to salvage plutonium, workers incinerated plutonium contaminated waste that would otherwise have been packaged and buried. Such waste included contaminated filters, rags, paper, protective clothing, gloves, and other combustible items used at the Plutonium Finishing Plant, REDOX, and PUREX. Once incinerated, the plutonium was recovered from the residual ash. The incineration and removal of the plutonium resulted in a 98 percent reduction of this particular waste stream (Anderson 1996). See the sub-section on the 232-Z Incinerator in the Plutonium Finishing Section for more information on recovering plutonium via incineration.

A novel waste minimization activity at Hanford involves the regulated fleet of trucks, tractors, locomotives, railcars, and other high value vehicles that have become radioactively contaminated but continue in use as regulated equipment. Such contaminated equipment would otherwise be disposed of by burial and replaced with new equipment when it was no longer at once repairable. Instead, Hanford has established a program that keeps these regulated vehicles available for work in radiation zones where they are subject to additional contamination. Such vehicles continue in use as long as they may be safely used by operating personnel in protective clothing.

2.4.3 Burial Ground Descriptions

Burial grounds for low level radioactive solid waste vary widely in their size and configuration from small pits at reactor sites to mammoth trench excavations in the 200 Areas. Burial ground designs vary from simple, unlined excavations to lined excavations that permit recovery of pit contents to burial grounds that use underground caissons and burial pipes or vaults.

Burial grounds in the 100 and 300 areas are close to the Columbia River and are underlain with permeable materials. The 200 Areas burial grounds lie on a geologic plateau and are underlain by a considerable thickness of materials with low permeability. Waste buried there is 55 meters

or more above groundwater. Groundwater movement beneath these 200 Areas burial grounds has extremely low flow rates and the soil has a large capacity for ion exchange. The slow movement allows time for ion exchange, which acts to remove and retain radionuclides (Anderson 1996).

Initially, almost all of the radioactive solid waste was buried near the area in which it was generated. Beginning in 1968, however, increasing amounts of waste were transported to the 200 Areas for disposal. Because of increased attention to all radionuclides discharged to the environment, by 1970 most low level radioactive solid waste was disposed of in 200 Area burial grounds. The last 300 Area burial ground closed in miC-1972 and only minor use was made of 100 Areas burial grounds until they fully closed in 1973.

100 Areas

With the exception of the 100-N Area, all 100 reactor sites used burial grounds to dispose of low level radioactive solid waste. Each site had at least one large burial ground and several smaller ones that varied from small burial pits to large burial trenches. For example, the main burial ground at the 100-F Reactor site measured 600 X 500 X 20 feet deep, while the 118-H-5 Thimble Pit, used to bury a single waste item, was only 30 X 2 X 5 feet deep (WIDS 1998).

The vast majority of 100 Area low level radioactive solid waste is reactor components and hardware that became irradiated and required disposal due to wear, failure, or obsolescence. These include items such as aluminum spacers, boron splines, graphite, process tubes, lead shielding, control rods, nozzles, and cadmium sheets. Also included are contaminated tools and protective clothing, glassware, swipes, and miscellaneous process materials (Miller and Wahlen 1987).

The quantities of low level radioactive solid waste from all reactors except N Reactor from 1944 through the end of reactor operations in 1971 are (Miller and Wahlen 1987):

• 1,700,000 aluminum fuel spacers	425 tons
• Lead-cadmium poison elements	1,059 tons lead 44 tons cadmium
• 142,000 boron-aluminum splines	652.5 tons aluminum 8.4 tons boron
• Carbon-14 (graphite and desiccant)	15,500 pounds
• 28,000 process tubes	266 tons aluminum
• Lead (brick, sheet, wool, casks)	258 tons
• Miscellaneous hardware	146 tons

• Cadmium sheeting	800 pounds
• Thermocouple Wire	372 pounds
• Soft waste (paper, plastic, clothing), which contains a very small percentage of total radionuclide inventory but makes up more than 75 percent of the total low level radioactive solid waste volume from all reactors except N Reactor	129,000 cartons

A few small burial sites in the reactor area were established for disposal of single, highly contaminated or irradiated waste items, such as a reactor test loop or a collection of contaminated fuel spacers. An unusual form of low level radioactive solid waste from the Experimental Animal Farm was buried at 100-F burial grounds. Extensive research was conducted on living animals and many were sacrificed as part of the research process. Contaminated animal carcasses were disposed of in a large, vented, steel tank which was periodically topped off with diesel oil and set afire to reduce waste volume. When the tank was no longer needed, it was dragged to the 118-F-6 Burial Ground and buried (DeFord 1993).

After 1973, most low level radioactive solid waste from the reactors, including all waste from the 100-N Reactor, was disposed of in the 200 Area burial grounds.

All 100 Area burial grounds are simple, unlined, trench or pit excavations. None remain in service and all have been backfilled to grade with native soil. Each is identified with signs and radiation warning devices. Most are unfenced with access only controlled through Hanford Site access security.

200 Areas

Because it was expedient to dispose of low level radioactive solid waste near the generating source, burial grounds were opened at nearly all Hanford areas. However, environmental considerations such as water table and proximity to the Columbia River have made 100 and 300 Area sites less desirable. The 200 Areas burial grounds were recognized as superior sites in terms of environmental protection. In 1973, 200 Areas sites became the centralized burial grounds for all low-level radioactive solid waste at the Hanford Site (Anderson 1996).

Operating since 1944, these burial grounds are massive excavations that have received low level radioactive solid waste items as large as contaminated trucks and railroad locomotives. Some burial grounds are as long as 1500 feet and over 90 feet wide at the surface. Most are at least 18 feet deep. Bottom treatment varies with era and type of waste to be disposed. Most have bottoms of native soil with no special treatment. Those designated for retrievable storage may have asphalt paving. For a time, transuranic waste drums were placed in V shaped burial grounds rather than the traditional flat bottom excavations to expedite retrieval of waste (DeFord 1991).

All burial grounds are identified by permanent concrete markers that identify the burial ground by number and flag it as a disposal site for radioactive waste. Most but not all 200 Areas burial grounds are protected by security fencing. Hanford drawings further delineate the location of burial grounds with each individual trench identified.

Prior to 1970, 200 Area burial grounds could be divided into six waste type categories.

- Dry waste burial grounds received low level radioactive solid waste packaged primarily in cardboard boxes containing various forms of dry waste. These included contaminated protective clothing, rags, paper, wood, and soil. Hardware contaminated with plutonium and various forms of off-site waste were also included.

- Industrial burial grounds received low level radioactive solid waste packaged in large wooden containers containing obsolete equipment from chemical plants and 300 Area labs that were heavily contaminated with fission products.

- Construction burial grounds received low level radioactive solid waste with low activity from construction and demolition work.

- Railroad tunnels at PUREX are used to store numerous large pieces of contaminated equipment on railroad flatcars.

- Underground vaults located at 222-B, T, and S Analytical Laboratories received small quantities of low level radioactive solid waste with high activity and dose rate from contamination by mixed fission products and plutonium.

- Caissons located at two burial grounds were used to dispose of low level radioactive solid waste with high activity from the 300 Area hot cells and low level radioactive solid waste with high plutonium content. Caissons are either tubular metal pipes buried vertically in the trench or larger circular tank-like containers made from corrugated metal or concrete, buried in the trench with offset feed chutes reaching above grade (DeFord 1994).

Environmental Restoration Disposal Facility

Constructed in 1995, the Environmental Restoration Disposal Facility is a centralized disposal facility for waste generated during the environmental restoration, deactivation and decommissioning efforts at the Hanford Site and is notable as Hanford's most advanced and most recent disposal site for low level radioactive solid waste.

The facility is a deep trench that will be the central landfill for large quantities of low level radioactive solid waste generated during environmental restoration work. Upwards of 12 million cubic yards of contaminated materials may be stored at the facility. Hazardous and mixed waste will also be disposed of here. The facility is not authorized to receive transuranic waste.

The Environmental Restoration Disposal Facility is in the 200 West Area. The 200 West Area was selected because of its distance from the Columbia River, its elevation above groundwater, and its centralized access to transportation and utility systems.

The Environmental Restoration Disposal Facility has been designed as a series of cells, each of which is 500 feet by 500 feet at the bottom and 80 feet deep and will hold about 600,000 cubic yards of material. Each cell is double lined and built with a leachate to collect and remove moisture. Each will be backfilled to grade with native soil when waste capacity has been reached. Two such cells have been completed and are now receiving waste materials. Additional cells, up to a total of twenty, may be constructed to meet the needs of environmental restoration, deactivation, and decommissioning (DOE 1995b).

300 Area and 600 Area

Fuel manufacturing processes and research and development activities in the 300 Area generated large quantities of low level radioactive solid waste that before 1973 were buried in 300 and 600 Area burial grounds. After 1973, 300 Area low-level radioactive solid waste was transported to the 200 Areas for disposal.

The distinction between 300 and 600 area burial grounds is sometimes confused. Essentially all waste disposed of in both area burial grounds was generated in the 300 Area. However, where other areas located their burial grounds within the area security fences, 300 Area did not. The 600 Area designation was devised to encompass all locations outside of area security fences and so includes those 300 Area burial grounds located adjacent to, but outside of, the 300 Area security fence. For that reason, 300 and 600 area burial grounds are included in this section.

The first burial ground to support 300 Area activities, 618-8, operated for only about a year in 1944. It was located north of the area under what is now an employee parking lot. A second burial ground, 618-1, was also north of the 300 Area and operated for 6 years beginning in 1945. The 618-2 Burial Ground followed in 1951 and operated until it caught fire in 1954. Another, 618-3, was excavated in 1954 but was filled to capacity the following year with demolition rubble from remodeling activities at the fuel manufacturing buildings (DeFord 1994).

Contamination repeatedly being spread, high dose rates, and waste fires in burial grounds near the 300 Area led to planning for burial grounds farther removed from facilities and employees. The 300 North Burial Ground, 618-10, was excavated in 1954 several miles north of the 300 Area and was followed by the 618-11 or Wye Burial Ground even farther north.

In addition to routine low level radioactive solid waste, these burial grounds received waste with a high dose rate from the Radio-Chemistry and Radio-Metallurgy laboratories. Dose rates as high as 5 roentgen/hour were measured during waste disposal activities, and revised disposal methods were developed. To reduce dose rate to burial ground workers who handled the waste during disposal, waste was transported in various kinds of truck-mounted, shielded casks. These casks were designed so the waste containers could be dumped directly into metal caissons. The metal caissons had previously been buried in the disposal trench with only their openings visible

at the surface. Once the waste with the high dose rate was dropped into the caisson, sand or gravel and sometimes concrete was placed in the caisson to reduce the dose rate at the surface.

Numerous instances of burial ground contamination were recorded at 300 and 600 area burial grounds. Most occurred during disposal when waste containers would rupture and contaminants would settle over the site. High dose rates also continued to be a problem until 1968 when nearly all 300 Area low level radioactive solid waste was transported to the 200 Areas for disposal. Disposal to the 300 and 600 area burial grounds were discontinued in 1970 (Gerber 1992).

300 Area burial grounds ranged in size from 4000 square feet to 40,000 square feet. The largest, 618-11, consisted of three burial trenches (each 900 x 50 x 25 feet deep), 50 pipe caissons, and at least 4 large diameter caissons. The pipe caissons were constructed by welding together five bottomless 55-gallon drums. The resulting 15-foot-long cylinders were buried vertically and spaced 10 feet apart in rows. Large diameter caissons were 10 feet high, 8-foot diameter corrugated steel tanks, each buried 15 feet below grade. The caisson was connected to the surface by an offset, 36-inch-diameter pipe through which waste could be dropped into the tank (DeFord 1994).

2.4.4 Incidents

Three categories of incidents involving low level radioactive solid waste occurred with some frequency, mostly in the 1950s and 1960s, and all of which resulted in contamination being spread to burial grounds and adjacent areas. These included fires in the burial grounds, burial containers that collapsed, and contamination spread when waste was in transit to burial grounds.

Fires occurred in 100, 200, and 300 area burial grounds. Most appear to have been caused by spontaneous combustion in waste materials with the fire spreading to adjacent refuse. The spread of contamination was sometimes severe, covered large areas adjacent to the burial grounds, and required major decontamination efforts by Hanford personnel. Fires in 100 and 300 Area burial grounds and the associated spread of contamination contributed to the decision to centralize the disposal of low level radioactive solid waste in the 200 Areas.

One of several burial ground fires in the 300 Area occurred in 1954 when a fire at the 618-4 Burial Ground spread contaminated particles as far as 1500 feet to the northeast with individual particles reading as high as 4.5 roentgen/hour (Anderson 1996).

The collapse of burial containers was an occasional problem at the 200 Area burial grounds where large boxes were frequently used to transport and bury contaminated hardware and apparatus from process facilities. The containers were placed on the floor of the burial trench and the trench backfilled. The weight of the backfill soil would sometimes collapse the burial box, causing a rush of contaminated air from the box interior to transport contaminants to the area of the trench and sometimes beyond. Areas as large as 4 square miles were contaminated in this manner (Anderson 1996).

Similar problems occurred at the burial ground in the 300 Area, especially the 618-10 and 618-11 burial grounds, when paper cartons or metal cans containing waste with high activity would rupture when dropped into pipe caissons, resulting in a column of contaminated air that rose upward in the pipe and onto the surface of the burial ground (Gerber 1992).

Contamination was an occasional problem when highly contaminated materials were transported to 200 Area burial grounds. Contaminants would sometimes escape and would contaminate the roadway, railroad, and/or transport vehicles, requiring significant decontamination over large areas. One such incident occurred in 1957 when a burial box containing REDOX hardware was pulled from its railcar when one of the box swing cables came loose and caught on a railroad tie. The ground where it landed was contaminated to a level of 2 roentgen/hour (Anderson, 1996).

Incidents were not the only source of hazardous conditions at the burial grounds. Even the routine handling of the waste could result in dose rates as high as 200 roentgen/hour (Anderson 1996). To dispose of the waste, employees often had to use heavy equipment with all the hazards incident to bulldozer and crane operations. Backfilling required skillful use of tractors working on steep slopes in soft soil conditions.

3.0 HANFORD SITE REGULATORY AND MANAGEMENT FRAMEWORK

In 1986 the primary Hanford Site mission began changing from plutonium production to environmental restoration (ER) and remediation. The *Hanford Federal Facility Agreement and Consent Order* (*Tri-Party Agreement*), which was first signed in 1989, forms the framework for working with Hanford Site regulators, Tribal Nations, stakeholders, and trustees in defining the scope and priorities for accomplishing the site mission. Elements of the *Tri-Party Agreement*, the Hanford Site work scope prioritization approach, and Integration Project management strategies for key work activities are discussed in this section.

3.1 TRI-PARTY AGREEMENT

The *Tri-Party Agreement* is a legally enforceable agreement signed by the DOE, Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA) for achieving environmental compliance at the Hanford Site. The agreement accomplishes the following:

- It defines *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) cleanup provisions for past contamination.
- It defines *Resource Conservation and Recovery Act* (RCRA) waste treatment, storage, and disposal (TSD) requirements, and corrective actions for waste management.
- It establishes the responsibilities for each agency.
- It provides a basis for budgeting.
- It establishes legally enforceable milestones for achieving cleanup and regulatory compliance.

The *Tri-Party Agreement* provides for the site-wide integration of RCRA and CERCLA requirements into Hanford Site remediation activities, and embodies the priorities of the DOE, Ecology, EPA, Tribal Nations, and stakeholders. The *Tri-Party Agreement* was modified in 1994, with new milestones added to reflect major changes in plans for tank waste remediation. The 1994 modifications also resulted in a fundamental change in the approach taken to Hanford Site cleanup, which emphasized remediation of unsafe sites along the Columbia River.

A listing of federal, state, and local laws and regulations that are relevant to the Integration Project is provided in Volume I, Appendix B. Within Appendix B, Table B-1 presents applicable federal laws and regulations, along with DOE orders. Table B-2 presents state laws and regulations.

3.2 MANAGEMENT STRATEGIES

Management strategies that were in place on the Hanford Site as of December 1998, are described in this section of the text.

A key concept that should be kept in mind when reading this section is that while each strategy has its own strengths and weaknesses, it is the management of the interfaces between strategies, and the integration of strategies, that was lacking at this point in time. This concept will be developed more fully in subsequent sections of this document.

3.2.1 Vadose Characterization and Remediation

Visible progress towards remediation of contamination in the vadose zone was slow immediately after the 1989 signing of the *Tri-Party Agreement*. Initial plans called for intensive and thorough investigations prior to decision-making. Plans for such waste characterization investigations were burdened by heavily prescriptive and protracted review and approval processes, which were performed in a series of stages requiring formal review, comment, and comment resolution stages, which were then followed by public comment periods. Investigations were generally scheduled in a "worst first" priority, and were reflected in *Tri-Party Agreement* schedule milestones. Planned investigations to characterize the nature and extent of contaminants in soil sites were scheduled for up to eight years.

In 1994, *Tri-Party Agreement* negotiations resulted in several significant fundamental changes to the approach taken in Hanford Site cleanup milestones. Two key decisions that were made were as follows:

- A shift in emphasis from investigations to interim cleanup measures.
- Deferral of investigations in the 200 Area for four years, with resources applied to interim action cleanup in the 100 and 300 Areas (except for one vadose vapor extraction system located in the 200 Areas).

Consistent with the 1994 *Tri-Party Agreement* negotiations, the 200 Areas are in the early stages of assessment. Prior to the 1994 agreement, the DOE characterized cribs at the 200-BP-1 Operable Unit (OU) and initiated a treatability test for a permanent barrier. During FY96, the ER Project (in conjunction with Ecology and EPA) developed a strategic plan for characterization and remediation of source term waste sites where liquids and solid waste have been discharged to or buried in the ground. The plan was needed to improve streamlining of the assessment and remediation process, making it more cost-effective, more technically efficient, and enabling the DOE to capture the lessons learned from the 100 and 300 Areas portions of the cleanup.

To balance budget allocations, stakeholder values, and the *Tri-Party Agreement* milestones, current long-range plans show little activity in the near-term for the ER Project in the 200 Areas (due to the priority of emphasizing cleanup in the 100 and 300 Areas). However, current

Tri-Party Agreement change proposals reflect a commitment to complete all RCRA closure/post-closure plans associated with the 200 Areas ER source operable unit by February 28, 2004. All CERCLA characterization is to be completed by December 31, 2008. All remediation is to be completed by December 31, 2028.

3.2.2 Groundwater/Columbia River Management

Groundwater protection actions at the Hanford Site have been based on a) compliance with requirements for water quality protection; and b) responses to prioritization by regulators, Tribal Nations, and stakeholders to focus on contaminants closest to the Columbia River. This approach has resulted in a) implementation of an extensive groundwater monitoring network in the 200 Areas, in compliance with the *Tri-Party Agreement* and RCRA/*State Dangerous Waste Regulations*; and b) focused investigations and interim remedial activities to mitigate groundwater impacts nearest the river in the 100 and 300 Areas (and selective groundwater remediation efforts in the 200 Areas). As part of the interim planning, each major groundwater plume was studied and assessed as to the need for immediate action. The result of this work was the construction of five pump-and-treat systems (DOE-RL, 1995)[*]. Vadose zone and groundwater investigations, and remedial activities, have progressed in the 100 and 300 Areas. Initial efforts are underway to initiate similar investigations and remedial activities in the 200 Area.

A site-wide Groundwater Management Strategy has been adopted to provide an integrated approach to management of groundwater resources. The strategy has, as its mission, the protection of the Columbia River, protection of human health, worker and environmental safety, treatment of groundwater contamination from past practices, and limiting the migration of contaminants from the Central Plateau (200 Areas). The strategy was adopted following consultation with Ecology and EPA, and with input from Tribal Nations and stakeholders. Implementation of the strategy includes continued surveillance of groundwater quality through the site monitoring network of approximately 800 wells, interim remedial actions at high priority operable units (to address contaminant plumes that pose risks to the Columbia River), and interim remedial actions for sites in the 200 Areas that pose risks to migration off the Central Plateau.

Groundwater remediation activities have focused on accelerated groundwater remediation activities in the 100-K Area to address hexavalent chromium in groundwater that discharges into the Columbia River. A groundwater-extraction-well network was designed to intercept a chromium plume. The extracted groundwater is passed through ion-exchange columns, where the chromium is removed; then the treated effluent is returned to the aquifer. Similar pump and treat systems were implemented in the 100-D/DR and 100-H Areas to address chromium discharges to the Columbia River. In the 200 Area two pump and treat systems have been established. These include a system for operable unit 200 UP-l that was constructed to contain the highest portion of a uranium and technetium-99 plume and a system for operable unit 200-ZP-1 to contain the highest concentrations of a carbon tetrachloride plume. Additionally, in the 200 Areas, treatability studies were completed for two additional pump and treat systems.

[*] DOE-RL, 1995, *Hanford Sitewide Groundwater Remediation Strategy*, DOE-RL-94-95, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland Washington.

However, the studies determined that the systems were not feasible. EPA and Ecology concurred that the systems should not be installed. Contaminant plumes that are currently being addressed by accelerated remedial pump-and-treat systems are illustrated in Figure 3-1. The two plumes that did not require pump-and-treat actions are shown in Figure 3-2.

3.2.3 Tank Farms

The Office of River Protection (ORP) River Protection Project (RPP) mission is to store, treat, immobilize, and dispose of current and future Hanford Site tank waste in an environmentally sound, safe, and cost-effective manner. To accomplish this mission ORP has focused on waste tank safety, waste characterization, waste storage, waste retrieval, waste immobilization and waste disposal.

Safety: The safe management of tank waste includes addressing a number of waste tank safety concerns that were identified in the late 1980s, resulting in Public Law 101-50, Section 313, *Safety Measures for Waste Tanks at the Hanford Nuclear Reservation* (also known as the Wyden Amendment). This Public Law placed special restrictions on 54 tanks that had serious potential for the release of highly radioactive material, in the event of uncontrolled increases in temperature or pressure. Without corrective action, these safety issues posed an unacceptable risk for continued operations. The four highest priority safety concerns included flammable gas, ferrocyanide, organics, and high-heat waste issues. The first three issues centered on the potential for in-tank reactions that could result in explosive or flammable conditions. The final issue focused on the potential for large leak loss from a tank to which periodic additions of water were required to cool the wastes. The number of tanks with special safety concerns has been reduced from the original 54 to 38. There are also other lower priority safety concerns being addressed, such as tank integrity.

For information on tank leaks, refer to Volume II, Section 2.1.5 (“Storage Tank Leakage”).

Waste Characterization: The waste characterization activity gathers and provides information on the quantity and characteristics (radiological, chemical, and physical) of the tank waste. Information is obtained from process records and a number of sampling and analytical methods. To date, 131 of the 177 tanks have been sampled, and characterization reports on 112 tanks have been approved by the regulators in accordance with *Tri-Party Agreement* requirements.

Waste Storage: The waste storage function includes a number of tank farm operations. Those of most importance are waste surveillance and maintenance (S&M), DST space management, interim stabilization, and tank farm upgrades.

S&M is necessary to ensure that the waste is safely stored until it can be retrieved for disposal. DST space management is essential since the 28 DSTs are the only tanks used for 1) receiving new waste; and 2) waste pumped from the SSTs. The DSTs also will serve as the blending and feed tanks to supply waste to the privatized treatment and immobilization facilities. Interim stabilization is an activity to remove all the pumpable liquid from the SSTs and transfer it to the DSTs. This reduces the amount of waste available to leak (should a leak develop). Finally, tank farm upgrades are necessary to ensure safe in-tank storage for another 20 to 30 years, while clean-up actions are taking place.

Figure 3-1. Locations of Groundwater Pump and Treat Remedial Operations.

Figure 3-2. Locations of Groundwater Contaminant Plumes for Which Groundwater Pump and Treat Were Not Selected.

Waste Retrieval, Immobilization, and Disposal: The plan for disposing the tank waste is to 1) retrieve the waste from the tanks; 2) separate it into LAW and HLW fractions; 3) immobilize and dispose the LAW fraction containing the bulk of the chemicals, and a small amount of the radionuclides in on-site near-surface vaults; and 4) immobilize and store the HLW fraction onsite until it can be shipped to an offsite geologic repository for disposal. The waste disposal function includes waste retrieval, waste processing (separations, treatment, and immobilization), and storage and disposal.

3.2.4 Spent Nuclear Fuels

The Spent Nuclear Fuels Project addresses the immediate need to move metallic spent nuclear fuel from the present degraded storage conditions in the 105-K East and 105-K West Basins to safe interim storage in the 200 Area. Major objectives include removing and repackaging K Basins spent nuclear fuel into multicanister overpacks suitable for downstream fuel handling and interim storage; drying the fuel to remove free water (to enable safe transport to and staging in the 200 Area); conditioning fuel to remove bound water for safe stable interim storage; removing sludge and debris collected in the K-Basins for disposition as low-level liquid waste or solid waste, in accordance with disposition plans being developed; treating water contained in the basins to maintain water quality; maintaining safe conditions within the K-Basins; reducing tritium levels; and consolidating non-defense production reactor spent nuclear fuel in the 200 Area, pending final disposition.

3.2.5 Other Hanford Site Activities

The Hanford Site contains many surplus facilities remaining from past plutonium production activities. These facilities are now aged and deteriorating. Because the facilities no longer have a production mission, they must be either maintained (to preserve their integrity) or removed to a) preclude the release of potentially hazardous substances to the accessible environment; or b) prevent unacceptable industrial safety risks. S&M activities are required for waste sites and facilities located throughout the site. The purpose of the S&M function for contaminated surplus facilities awaiting decommissioning is as follows:

- Ensure adequate containment of radioactive, hazardous and/or toxic contaminants.
- Provide physical safety and security controls.
- Maintain the facilities in a manner that will minimize potential hazards to the public and workers.
- Maintain systems/equipment that will be essential for decontamination and decommissioning (D&D) activities in a shutdown but standby/operational mode.
- Provide a mechanism for the identification and compliance with applicable environmental, safety, health, and safeguards/security requirements.

In addition, the S&M responsibilities include the transition activities involved with the ER Project's acceptance of facilities from other DOE programs through deactivation processes. The S&M project is responsible for Radiation Area Remedial Action (RARA) of approximately 1,000 inactive waste sites, including 10 RCRA TSD units. The inactive waste sites include unplanned release sites, cribs, trenches, ponds, and burial grounds. The waste sites are located in the 100, 200, 300, and 600 Areas.

4.0 STATE OF KNOWLEDGE

The Integration Project team evaluates work from the perspective of technical information or capability needs for the system, rather than from a viewpoint constrained by the scope and objectives of individual projects. Work is evaluated by grouping activities by technical lines or technical elements. Knowledge gaps, overlapping work scopes, and project inefficiencies are assessed in this evaluation process.

This section briefly describes the current state of knowledge for the key technical areas of work that have been, and are currently being performed, at the Hanford Site. This discussion highlights key deficiencies that have been identified at this point in time. The key deficiencies that are being evaluated by national laboratory teams include the technical areas of inventory, vadose zone, groundwater, and river environment. The determination of risk and monitoring issues, along with underlying applied science needs is underway.

An applied science plan has been developed from this evaluation. This plan, which is linked to Integration Project priorities, is the basis for the Science and Technology (S&T) roadmap. Both the plan and roadmap are provided in Volume III.

Four types of work scope are part of the overall Integration Project: (1) technical information and data needs; (2) methods and capabilities; (3) controls and constraints; and (4) integration. These categories are further subdivided into technical elements, as illustrated in Figure 4-1. The work scope for these technical elements was defined with the assistance of stakeholders, through public workshops.

Technical Information and Data Needs. This category contains the Inventory, Vadose Zone, Groundwater, and Columbia River technical elements. The work scope associated with these elements involves characterization of various features and processes that are essential to development of conceptual models of how the natural system works. The term “information” includes interpretations of field observations, and the output from numerical analyses.

Methods and Capabilities. The Monitoring and Risk Assessment technical elements are included in this category, and contribute to the information and data needs elements. The work scope within the Monitoring element pertains to data collection methods and logistics. Risk assessment activities pertain to using various accepted methods, or developing new methods, to quantify risk to human health and the environment for various scenarios.

Controls and Constraints. This category describes the regulatory path (regulations and legally binding agreements) and remediation options (technological options available for mitigation and/or remediation). These elements form the principal basis for the project’s technical work scope.

Figure 4-1. Integration Project Technical Elements.

Integration. The elements above are integrated within the System Assessment technical element. The System Assessment technical element supplies the unifying focus for all the technical work performed to assess the impacts of contamination on the Hanford Site. This unifying focus is illustrated in Figure 4-2. The work scope of this element consists of the iterative aspects of evaluating information relative to project objectives, and redefining or identifying additional work scope (as appropriate). The goal of the System Assessment technical element is to acceptably quantify the environmental consequences of past, present, and future DOE actions at the Hanford Site, in terms of their impact on human health and the environment. The system assessment capability can then be used for sensitivity and uncertainty analyses, to help set priorities for science and technologies. It can also guide the development of data quality objectives (DQOs) for characterization plans, and establish a consistent set of assumptions, data, and tools for evaluation of remedial options.

The site assessment must accommodate various spatial and temporal scales of interest that are defined by the diverse types and locations of contamination. A central concern is the time period to be assessed. Impacts of mobile contaminants released from past practices of discharging large

Figure 4-2. Major Elements of the System Assessment.

volumes of liquid wastes to the subsurface may be seen within years or decades; however, long-lived radionuclides and chemicals also present longer-term threats to human health and safety. Methods for estimating potential impacts to the public require that areas of future public access and methods of exposure be unambiguously defined.

To achieve the goals defined above, the Integration Project must design, develop, and apply an assessment capability. A system conceptual model upon which the system assessment can be performed is shown in Figure 4-3. Components of this capability currently exist, but they have not been linked in a system assessment model. Other components do not exist. The system assessment capability integrates and coordinates the linkages among the various other technical elements discussed in this section to provide the input that is needed. Through the coordination of input to the system assessment capability, the quality of the overall analysis will be enhanced and the consistency and completeness of the analysis will be improved.

The system assessment capability supports the deficiencies assessment process by identifying key data gaps and sources of uncertainty that affect the risk calculation that is provided to decision-makers. If the calculated risk is unacceptable, and work can be performed in areas of high uncertainty to help refine the calculation, these areas will be targeted for work. Work priorities will then be assigned accordingly.

The technical element discussions provided in this section were initially developed by technical teams made up of representatives from each of the Hanford Site contractors. Materials have been provided to the national laboratory working groups (see Section 4.1 for a discussion of these groups), and their recommendations have been integrated. Work on the system assessment, risk, and monitoring technical elements is in progress. The level of detail provided in each discussion reflects the input of the working groups and, therefore, variability exists between technical elements. All elements discuss three basic topics: the technical scope of the element, the current state of knowledge, and the key technical deficiencies that have been identified to date. The future roadmapping activity will identify the priority deficiencies and the S&T required to mitigate those deficiencies.

4.1 INVENTORY

4.1.1 Scope

Inventory is the total quantity of radiological and chemical constituents used and created at the Hanford Site, and their distribution in facilities, waste disposal sites, the vadose zone, groundwater, and Columbia River ecosystem. A good understanding of inventory is key to a system assessment because the potential groundwater and river contamination is proportional to the amount of radionuclides and chemicals that are disposed on the Hanford Site and capable of migrating from the Hanford Site. The technical information that is needed to determine this inventory includes the following:

- Locations, amounts, and concentrations.
- Characteristics of the radionuclide or chemical compound.

Figure 4-3. System Conceptual Model.

- Mobilization and release mechanisms and rates.

- Change in inventory because of natural processes (e.g., decay), remediation activities, and Hanford Site operations.

In addition to inventory estimates, mechanisms must be identified that describe the release of the inventory from facilities into the vadose zone, unconfined aquifer, or the Columbia River. Because the long-term configuration of the waste inventory depends on future remediation and land-use decisions, a baseline estimate of end-state inventory distributions must be defined for a system assessment.

A holistic approach to quantifying site inventory is central to the inventory technical element scope. To date, inventory estimates for radionuclides and hazardous chemicals have been developed within specific projects. These estimates tend to be conservatively high. No comprehensive analysis has been performed that compares and reconciles the estimates for each facility with estimates of the total Hanford Site inventory. A comprehensive integrated analysis will help ensure that estimates for key contaminants are sufficiently accurate and credible to support a site-wide assessment of environmental impacts and risks.

4.1.2 Current State of Knowledge

The vast majority of the radioactive waste inventory at the Hanford Site was created during the production mission. A conceptual model of the Hanford Site process is shown in Figure 4-4. There were three distinct steps in the production process: fuel fabrication, fuel irradiation, and chemical separation. During the first decades of production work at the Hanford Site, it was common to locate waste disposal sites relatively close to waste-generating facilities. This practice resulted in numerous and varied disposal sites. The most dangerous radioactive wastes were stored in large single-shell tanks (SSTs) in the 200 Areas (Agnew et al. 1997; Kupfer et al. 1997). Large volumes of solid waste (e.g., contaminated tools and protective clothing) were disposed in burial grounds, and large volumes of liquid waste were discharged to shallow subsurface cribs, french drains, injection (or reverse) wells, and specific retention trenches.

More recently, all fuel fabrication and reactor operation activities ended and cleanup of past-practice units began in the 300 and 100 Areas. Low-level waste (LLW) from ongoing operations is disposed in specific burial grounds in the 200 West and 200 East Areas. Most liquid discharges of radioactive wastes have been discontinued, the exception being tritium disposal to the State Approved Land Disposal Site, which received treated water from the 200 Area Effluent Treatment Facility (ETF). Tritium is discharged by permit to this facility because it is not removed during ETF treatment.

A small group of mobile radionuclides and chemicals are known to be of primary interest relative to long-term groundwater contamination, because they have already contaminated the unconfined aquifer and are known to be chemically mobile. The list of radionuclides includes ^{99}Tc, ^{129}I, uranium, and tritium. Chemicals include carbon tetrachloride, trichloroethylene, nitrite, nitrate, cyanide, and chromium. Other radionuclides that are likely to be less mobile but present in groundwater due to direct injection are ^{137}Cs, ^{90}Sr, and plutonium.

Figure 4-4. Hanford Process Conceptual Model.

Radionuclide inventory estimates have been made for waste sites containing large fractions of contaminants on the Hanford Site. A total radionuclide inventory estimate has been established on the basis of Hanford reactor fuel production records, and is considered to be reasonably accurate, but the distribution of inventory among the various waste sites and facilities is not well known. A companion Hanford site-wide inventory of potential groundwater contaminating chemicals has not been established.

Waste disposal sites in the 200 West and 200 East Areas included in the 200 Area Composite Analysis (Kincaid et al. 1998), and are shown in Figures 4-5 and 4-6, respectively. Major types of waste sites and documented inventory sources are discussed in the following paragraphs. Detailed summaries, including tabulated inventory summaries, are provided in Section 4.2.

Tank Waste

Several efforts have been made over time to estimate tank waste radionuclide and chemical inventories. Most recently, a best basis estimate has been completed for current inventory in single- and double-shell tanks (Kupfer et al. 1997; Agnew et al. 1997). This estimate is derived from the Hanford Defined Waste (HDW) model based on processing records, tank operation records, and available tank analysis results (solids and liquids). This model also estimates inventory from tank waste discharged to cribs and leaked from tanks. Numerous tank characterization reports are also available that record sample and analysis data, including the Tank Waste Information Network System (TWINS2) that can be accessed on the Internet through the Hanford Web (http://www.proxy.rl.gov:1050).

Solid Low-Level Waste

The Solid Waste Tracking System (SWITS) database (Clark 1995) accounts for all waste disposed in the low-level waste burial grounds (LLBG). This database is kept current as waste is disposed. Inventories for both inactive and active burial grounds are recorded. Both radionuclides and hazardous chemicals are tracked in SWITS. The completeness of the records decreases for earlier disposed wastes. Radionuclide estimates are provided for all disposed waste, but chemical inventories are generally unavailable for waste disposed prior to 1980, and are only marginally available between 1980 and 1987.

CERCLA Remediation Sites

Inventory estimates for CERCLA sites have been developed from process knowledge, and from sampling and analyses of site materials. CERCLA sites include cribs, ponds, and ditches in the 100, 200, and 300 Areas; decommissioned buildings (reactors, processing plants, auxiliary structures); and inactive solid waste burial grounds. Minimal radionuclide and chemical inventory data exist for many sites, and the process of collecting more detailed inventory information at specific sites is dependent on the remediation schedule. Recent CERCLA efforts have been concentrated on the most contaminated sites in the 100 and 300 Areas.

Figure 4-5. Waste Disposal Sites in the 200 West Area.

Figure 4-6. Waste Disposal Sites in the 200 East Area.

In addition to waste site information, total radionuclide production estimates have also been made based on reactor operation history. Also, other waste streams are present at the Hanford Site that are planned to be disposed offsite (e.g., unprocessed spent fuel from N Reactor currently residing in K Basin and transuranic (TRU) waste stored in the LLBG). No attempt has been made to estimate total site inventories of hazardous chemicals.

Other than project-specific inventory estimates, the most recent attempt at radionuclide inventory estimates across projects is the Composite Analysis (Kincaid et al. 1998) that compiles all existing waste site inventories in the 200 Areas (Table 4-1). This document illustrates the inconsistencies in inventory estimates from a partial Hanford site-wide perspective for a few key radionuclides that have been demonstrated to be important based on past performance assessments and other studies. Two other studies (Kupfer et al. 1997 and Schmittroth et al. 1995) are key references for the Composite Analysis.

Differences in the Kupfer et al. (1997), Agnew et al. (1997), and Schmittroth et al. (1995) Totals

Kupfer et al. (1997) and Agnew et al. (1997) present global estimates of waste inventories in the single- and double-shell tanks. In developing their estimate of the low-level fraction of tank wastes for immobilization and disposal, Schmittroth et al. (1995) present an estimate of total tank wastes in both double-shell tanks and SSTs. However, significant differences appear in the estimates of key radionuclides ^{14}C, ^{99}Tc, and ^{238}U, because different split factors were applied in these studies for the chemical processing steps that followed production of isotopes in the reactors.

In the case of ^{14}C, the difference may be related to the assumption in the more recent model (Agnew et al. 1997; Kupfer et al. 1997) that all ^{14}C was routed to the tanks. A portion is suspected to have been lost to the atmosphere during fuel dissolution. Differences with regard to ^{99}Tc are related to the assumed amount exported with uranium to other facilities in the DOE complex. Finally, the amount of ^{238}U is similar in Schmittroth et al. (1995) and Kupfer et al. (1997), 296 and 322 Ci, respectively, but different than in Agnew et al. (1997), 906 Ci in tanks.

The apparent over-prediction of the HDW model (Agnew et al. 1997) for uranium in the tanks can be attributed to the use of a conservative factor for the fraction of uranium metal waste that was not recovered.

Carbon-14

The greatest inventory of ^{14}C at the Hanford Site (42,200 Ci) is in the graphite cores of the production reactors. Significant inventories of ^{14}C are also associated with the Environmental Restoration Disposal Facility (ERDF) (3,800 Ci) and the commercial LLW disposal facilities (3,850 Ci).

Significant differences exist between the Schmittroth et al. (1995) estimate of 769 Ci and those of Agnew et al. (1997) and Kupfer et al. (1997), 4,910 Ci and 4,808 Ci, respectively.

Table 4-1. Summary Table of Inventories Considered in the Composite Analysis.

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
Agnew[b] All Tanks	4.78E+03		6.30E+01	7.73E+02	3.26E+04	9.06E+02
Agnew[b] Cribs	1.24E+02		1.64E+00	2.63E+01	8.68E+02	1.31E+03
Agnew[b] Leaks	1.44E+01		2.04E-01	1.85E+00	1.07E+02	4.63E-01
Agnew[b] Total Site	4.91E+03		6.48E+01	8.01E+02	3.35E+04	2.22E+03
Kupfer[c] Global Tank Inventories	4.78E+03		6.61E+01	7.73E+02	3.26E+04	3.22E+02
Schmittroth[d] Total	7.69E+02		6.61E+01	1.03E+03	2.72E+04	2.96E+02
Total[e]	5.00E+04	3.45E+02	1.71E+01	1.05E+03	2.49E+04	6.60E+04
Total minus US Ecology	4.62E+04	3.11E+02	1.13E+01	1.05E+03	2.48E+04	5.50E+04
Total minus (cores + US Ecology)	3.95E+03	7.60E+00	1.13E+01	1.05E+03	2.48E+04	5.50E+04
Total minus (cores + US Ecology + ERDF)	1.50E+02	7.60E+00	1.13E+01	1.05E+03	2.48E+04	8.00E+02
ORP ILAW	7.69E+00	0.00E+00	6.62E+00	1.03E+03	2.23E+04	1.78E+01
ORP SST Leaks – cmplx[f]	3.15E-01	0.00E+00	5.99E-02	5.60E-02	5.22E+01	2.45E-03
ORP SST Leaks – ncmplx[g]	4.11E+00	0.00E+00	6.78E-01	7.32E-01	4.59E+02	3.21E-02
ORP SST Losses - cmplx	1.44E-01	0.00E+00	2.88E-03	7.47E-03	5.76E+00	3.14E-04
ORP SST Losses - ncmplx	3.52E+00	0.00E+00	6.23E-01	6.27E-01	4.67E+02	2.75E-02
ORP SST Residuals - cmplx	1.17E+00	0.00E+00	5.74E-03	2.79E-01	3.84E+00	3.24E-01
ORP SST Residuals - ncmplx	2.86E+01	0.00E+00	1.54E-01	7.70E+00	1.06E+02	4.42E+00
ORP DST Residuals - cmplx	8.28E+00	0.00E+00	0.00E+00	0.00E+00	8.62E+01	0.00E+00
ORP DST Residuals - ncmplx	1.49E+01	0.00E+00	0.00E+00	0.00E+00	1.25E+02	0.00E+00
216[h] liquid discharges + 241[i]	3.65E+00	2.40E-01	1.94E+00	2.93E-01	9.37E+02	1.57E+02
218[j] 200 W[k] pre-1988	2.89E+01	1.45E+00	6.18E-01	1.77E+00	6.01E+01	1.92E+02
218 200 E pre-1988	7.94E+01	5.22E+00	4.25E-01	6.36E+00	2.15E+02	9.85E-01
218 200 W post-1988	1.74E+01	8.33E-01	2.10E-01	1.07E+00	5.15E+01	3.46E+02
218 200 E post-1988	1.35E-01	8.87E-03	4.21E-02	1.08E-02	3.66E-01	6.68E-02
ERDF	3.80E+03	0.00E+00	0.00E+00	0.00E+00	6.57E+00	5.43E+04
Production Reactor Cores	4.22E+04	3.03E+02	0.00E+00	0.00E+00	1.09E-01	4.00E-03
US Ecology	3.85E+03	3.44E+01	5.77E+00	0.00E+00	6.56E+01	1.09E+04

a Inventories have been decayed to a common date of 2050.
b See Agnew et al. (1997).
c See Kupfer et al. (1997).
d See Schmittroth et al. (1995).
e Sum of estimated inventories of sites included in the first iteration of the Composite Analysis.
f cmplx = complexed wastes.
g ncmplx = noncomplexed wastes.
h 216 refers to past-practice liquid disposals.
i 241 refers to tanks associated with reverse wells.
j 218 refers to solid waste burial grounds.
k W and E refer to the 200 West Area and the 200 East Area, respectively.

Global estimates of ^{14}C by Agnew et al. (1997) and Kupfer et al. (1995) were based on an assumed 100% delivery of ^{14}C in fuel to the waste tanks. Consequently, their estimates of ^{14}C may be high.

Significant differences exist between the Schmittroth et al. (1995) estimate of 769 Ci and those of Agnew et al. (1997) and Kupfer et al. (1997), 4,910 Ci and 4,808 Ci, respectively. Global estimates of ^{14}C by Agnew et al. (1997) and Kupfer et al. (1995) were based on an assumed 100% delivery of ^{14}C in fuel to the waste tanks. Consequently, their estimates of ^{14}C may be high.

Regardless of the inventory in the tanks, the future location of 99% of the tank inventory after chemical separation into high-level and low-activity waste streams and immobilization is not clearly identified. One percent (1%) of the tank inventory is assigned to the immobilized low-activity waste (ILAW). Ninety-nine percent (99%) is assigned to the immobilized high-level waste. However, the high-level waste may be a vitrified glass waste form, and it may not capture volatile iodine isotopes. Furthermore, the integrated database for spent fuel and radioactive waste (ORNL 1997) shows 4.42 Ci of ^{14}C in ILAW and only 0.0911 Ci in high-level waste glass canisters at the Hanford Site following completion of the chemical separation and immobilization campaigns.

Chlorine-36

As with ^{14}C, the graphite cores are the dominant source of ^{36}Cl at the Hanford Site (302 Ci). To investigate the potential significance of ^{36}Cl in other Hanford Site wastes, a 1-ppm level of ^{35}Cl contamination was introduced in the Oak Ridge Isotope Generation and Depletion (ORIGEN2) simulations of irradiated fuel. There are no data on the actual ^{35}Cl impurity levels in DOE fuel irradiated in the graphite core production reactors at the Hanford Site. However, it is believed the 1-ppm level is within an order of magnitude of the true value. This level of impurity has been used to forecast the level of ^{36}Cl in aged fuel. Fuel ratios and the inventory of ^{137}Cs were used to build ^{36}Cl inventory into inventories for solid waste burial grounds and liquid discharge sites. If significant impacts from ^{36}Cl are forecast, it is important to remember they may not be real. If such a forecast occurs, it will be important to determine chlorine impurity levels in DOE fuels and develop a true estimate of its potential contribution to dose.

Iodine-129

Total inventory values for ^{129}I are fairly consistent among the past and present Tank Waste Remediation System (TWRS) inventories. However, while ~65 Ci were projected to reside in Hanford Site tanks, fewer than 11 Ci were accounted for in the Composite Analysis as remaining at the Hanford Site after closure. Of this amount, the majority could reside in the ILAW from the tanks. Little of the highly volatile ^{129}I inventory may remain in the ILAW.

The total inventory estimate is based on the assumption that all ^{129}I was routed to the tanks. Such an assumption neglects losses of iodine to the atmosphere, disposals of iodine to solid waste burial grounds and cribs, and the storage of two silver reactors in the second Plutonium

Uranium Extraction (PUREX) tunnel.[1] Kupfer et al. (1997) estimated that 71% of the iodine may have been routed to tanks, and the remainder (i.e., 29% or ~18 Ci) to the atmosphere or ground.

The volatile character of iodine implies it will not be captured in a vitrified high-level waste and subsequently exported from the Hanford Site. Some may be identified as leaving the Hanford Site as TRU waste. With this exception, an upper bound for the final disposal of ^{129}I at the Hanford Site could include the entire inventory generated at the Hanford Site (~65 Ci). This is approximately a factor of six more ^{129}I than was accounted for in the first iteration of the Composite Analysis, in which an estimated 10% of the original tank inventory (6.6 Ci) was assigned to ILAW.

Selenium-79

The global inventories of ^{79}Se in the tanks were relatively consistent among the assembled inventories (i.e., Agnew et al. 1997, 773 Ci; Kupfer et al. 1997, 773 Ci; Schmittroth et al. 1995, 1,030 Ci). It was assumed that the entire ^{79}Se inventory in the tanks will be contained in the ILAW (Mann et al. 1997). Fewer than 20 Ci were assigned to the other tank inventories (e.g., tank leaks, solid waste burial grounds, and liquid discharges).

It is anticipated that ^{79}Se inventories for the Hanford Site will be reduced by a factor of eight in the near future, based on a recent update of the decay half-life of this isotope (Kupfer et al. 1997). The significance of ^{79}Se as a contributor to dose should decrease proportionately.

Technetium-99

The estimates produced by Schmittroth et al. (1995) for the ILAW disposal were used in this analysis to represent the ILAW. Schmittroth et al. (1995) estimated a total 27,200 Ci of ^{99}Tc in the tanks. Of that total, 22,300 Ci are to go into ILAW and the remaining 4,900 Ci are to go to high-level waste glass. Agnew et al. (1997) and Kupfer et al. (1997) present global estimates of the amount of ^{99}Tc produced at the Hanford Site and stored in the single- and double-shell tanks. The Agnew et al. (1997) and Kupfer et al. (1997) estimate of 32,600 Ci ^{99}Tc in the tanks is higher than the Schmittroth et al. (1995) estimate because they decided to show a bounding inventory value, and therefore neither took into account the ^{99}Tc exported from the Hanford Site. Schmittroth et al. (1995) documented that an estimated 20% of the ^{99}Tc produced at the Hanford Site was lost from the tank waste. Most of this 5,000- to 6,000-Ci inventory was co-processed with the uranium oxide metal and sent off site.

The different estimates of ^{99}Tc disposed to ground are inconsistent. Based on track radioactive components (TRAC) model results, it was estimated that liquid discharge sites have received ~930 Ci of ^{99}Tc (Waite 1991). Based on data in the tank characterization reports for liquid tank wastes, the tanks were estimated to have leaked ~460 Ci and to lose ~470 Ci of ^{99}Tc during retrieval. Based on the TWRS Environmental Impact Statement (EIS) database (DOE and Ecology 1996) and the assumption of 1% volume remaining following recovery operations,

[1] Reddick, J., 1993, *PUREX and U03 Plant Inventory Estimates* (letter to D. Washenfelder, Westinghouse Hanford Company, September 29), Los Alamos Technical Associates, Kennewick, Washington.

~320 Ci of ^{99}Tc will be in tank residuals. Based on aged-fuel ratios and the inventory of cesium, another 325 Ci of ^{99}Tc are assumed to reside in the solid waste burial grounds. These disposal inventories, which total ~2,500 Ci, are based on a number of different models.

Ultimately, aside from the ILAW, the 2,500 Ci inventory of ^{99}Tc estimated to be lost to or disposed in the subsurface environment at the Hanford Site is less than 10% of the total ^{99}Tc inventory at the Hanford Site. An effort to generate a fully consistent inventory estimate could yield lower estimates of losses and disposals. For example, because of its solubility, most of the ^{99}Tc should be removed from the tanks during the tank waste recovery campaigns, and less than the estimated 320 Ci here should remain in the tank residuals. Similarly, if sluicing methods are used to recover tank wastes, it is likely that contaminant concentrations in sluicing losses from the tanks will be lower than contaminant concentrations in tank wastes. Thus, the estimated 470 Ci of ^{99}Tc lost during tank waste recovery operations, which were based on tank waste radionuclide concentrations, would decrease. Finally, the Agnew et al. (1997) model provides an estimate of only 107 Ci of ^{99}Tc lost in past tank leaks compared to the 460 Ci estimated here. Clearly, a lower inventory of loss and disposal could result from a consistent or best-estimate inventory estimate. However, there is also uncertainty in the future ^{99}Tc waste streams that privatization contractors may generate and return to the DOE for disposal.

Uranium-238

Kupfer et al. (1997) reconciled the HDW model results for uranium (906 Ci of ^{238}U) and tank sample data (322 Ci), and decided that the sample data were more representative of the uranium inventories. The discrepancy among TWRS total inventory estimates of uranium is attributed to the factor used to describe the fraction of metal waste not recovered. However, estimates in Waite (1991) for uranium in tank waste discharges to cribs and specific retention trenches, and estimates provided by Coony[2], are much lower than estimates that appear in Agnew et al. (1997). Coony estimated 47.5 Ci of ^{238}U as compared to 1,310 Ci estimated by Agnew et al. (1997). The Agnew et al. (1997) inventory of ^{238}U sent to the ground in liquid discharges may also be an overestimate, because it is based on the factor assumed for uranium metal recovery.

An unrealistically high estimate of ^{238}U is included in the ERDF inventory (i.e., 54,300 Ci). This inventory estimate is based on maximum observed ^{238}U concentrations in sediments at CERCLA sites in the 100 and 300 Areas. The composition of uranium in ERDF has the signature of enriched uranium, but this is an artifact of using maximum observed concentrations of uranium isotopes to estimate the total inventory disposed. The US Ecology commercial LLW disposal facility also contains a considerable inventory of ^{238}U (10,900 Ci).

[2] Coony, F. M., 1997, *Questions on Crib Releases in the 200 Areas* (e-mail to C. T. Kinkaid, Pacific Northwest National Laboratories, November 5), Waste Management Federal Services, Richland, Washington.

4.2 VADOSE ZONE

4.2.1 Scope

The scope of the Vadose Zone technical element encompasses the characterization, modeling, and monitoring of the unsaturated zone beneath the Hanford Site. The geographic focus is on areas that (1) underly liquid waste disposal sites and tanks; (2) have the potential for leaks or leaching; and (3) have experienced past leaks and spills. Also included are selected areas away from the focus areas, such as areas representative of background conditions, and areas that have the potential to become contaminated in the future. Numerical modeling supports the characterization by simulating flow and transport processes believed to occur within the vadose zone. Specific topics include (1) subsurface contamination (i.e., characteristics of past disposal and leakage including chemistries, volume, and distribution); (2) surface hydrologic features and processes (e.g., winter rain and snowmelt, water line leaks, infiltration, deep drainage, and evaporation rates); and (3) subsurface geologic and hydraulic features and processes (e.g., stratigraphy, structures, physical properties, geochemistry, and microbiology of the sediments above the water table). Information is needed to better understand the vertical and/or horizontal distribution and movement of contaminants to the water table. Monitoring confirms the movement through the vadose zone.

Sufficient information will be collected to provide (1) a representative and credible depiction, at appropriate temporal and spatial scales, of contaminant distributions beneath waste, spill, and disposal sites; (2) early warning of potential surface or groundwater contamination problems so that corrective actions can be taken; and (3) credible numerical simulations that acceptably depict the movement and fate of contaminants in the vadose zone. Information generated by this technical element will support remedial actions, such as the design of surface and subsurface barriers, and in situ remediation techniques. It also supports decisions regarding mitigative protective measures (e.g., interim surface covers), restrictions on artificial recharge and, therefore, future land use.

4.2.2 Current State of Knowledge

The vadose zone is defined as the hydrologic region that extends from the soil surface to the water table. At the Hanford Site, the vadose zone can range from less than 1 m to more than 100 m, and contains waste inventories from past waste disposal practices (e.g., direct liquid waste disposal to the ground via engineered facilities) and from unplanned releases (e.g., SST leaks). The vadose zone is thickest in the 200 Areas and thinner in the 100 and 300 Areas. It generally consists of unsaturated sediments. However, saturated sediments are sometimes found in perched water table zones within the vadose zone. Transport of groundwater and contaminants through the vadose zone is influenced by texture, consolidation, and cementation of sediments; thickness of the vadose zone; moisture infiltration rates; and geochemistry of the waste form and the sediments. The current knowledge of the controls on contaminant movement and distribution in the vadose zone will be discussed first in this section.

Vadose zone characterization has been accomplished to date by drilling, sediment sample collection and analysis, and geophysical logging. Drilling around tanks, cribs, and trenches has

provided considerable information about vadose zone lithology and stratigraphy, but only limited hydrologic and geochemical information has been obtained. In a few cases, drilling was used to identify tank leaks. Analyses of sediments for radionuclides, chemicals, and heavy metals have helped quantify the extent of contaminant plume migration at selected locations. Site-specific characterization data will be the second major topic presented in this section.

Finally, numerical modeling is used to assess contaminant migration through the vadose zone. The strengths and weaknesses of the current modeling approaches and codes are discussed in the final installment in this section.

4.2.2.1 Controls on Contaminant Movement and Distribution. Physical and chemical controls constrain the movement of contaminants that enter the vadose zone environment. Three primary groupings of controls are described below:

- Geologic
- Hydraulic
- Chemical.

A summary of site conditions (specific to the 200 Areas) that may control contaminant movement and distribution is presented in Table 1-2 (DOE 1997). With minor modifications (e.g., vadose zone thickness and vegetation), the summary is applicable to the Hanford Site in general.

Geologic Controls

Of the primary controls on contaminant movement and distribution on the Hanford Site, the knowledge of the general geology is the best understood. This is primarily because of concerted efforts to interpret the accumulated data from the drilling of numerous boreholes, especially in the vicinity of waste disposal operations. There are detailed characterization data for the site that reveal important differences in the geology of the waste site areas (Lindsey 1992, 1995; Lindsey et al. 1992; Hartman and Peterson 1992; Peterson et al. 1996; DOE-RL 1993f, 1994a, 1994b; Thorne et al. 1993; 1994).

The site is arid (average precipitation 160 mm) and, prior to waste operations, the surface typically consisted of eolian silts or sands and supported a shrub-steppe plant community (Dirkes and Hanf 1997). The waste disposal area excavations and corings have exposed two major geologic formations in the vadose zone, the Hanford formation (gravels, sands) and the underlying Ringold Formation (gravels, silt lenses). The Hanford formation is geologically young, having been derived from cataclysmic flooding during the Pleistocene (1.6 Ma to 13 Ka), while the Ringold Formation is composed of sediments deposited by the ancestral Columbia River between 8.5 Ma and 3 Ma. A buried soil (Plio-Pleistocene formation) exists at the top of the Ringold Formation in the 200 West Area, but is absent in the 200 East Area.

100 and 300 Areas. In the 100 and 300 Areas, the vadose zone is relatively thin, ranging from about 1 to 30 m in thickness. It is generally composed of recent surficial deposits and portions of the Hanford formation and/or Ringold Unit E. Sediments from the upper strata of the Ringold Formation within the 100 and 300 Areas are characterized by complex interstratified beds and

Table 4-2. Summary of Site Conditions That May Affect Contaminant Fate and Transport. (2 Pages) (from DOE 1997)

Parameter/ Property	Representative values/conditions for 200 Area sediments	General Considerations
Natural recharge	0 to 100 mm/yr via precipitation	Recharge via precipitation is affected by surface soil type, vegetation, topography, and year-to-year variations in precipitation. Gravelly surface soils with no vegetation facilitate recharge. Well-vegetated, fine-grained surface soils minimize recharge. Recharge may be impacted by episodic events including high-intensity rainfall events and rapid snowmelt. Evapotranspiration potential is moderate to high depending on time of year, lowest in winter when recharge potential and precipitation is highest. Waste sites that are vegetated and are capped with fine-grained soils (Radiation Area Remedial Action interim-stabilized sites) or impermeable covers should have little to no net precipitation recharge or leachate generation. Net infiltration is influenced by topography and soil hydraulic properties. In instances where precipitation or snow melt is sufficient to generate runoff, low-lying areas and gravelly surface soils/fill occupying may serve as collection basins for runoff and locally increase net infiltration.
Vegetation	Sparse to moderate densities	Vegetation of the 200 Areas Plateau is characterized by native shrub steppe interspersed with large areas of disturbed ground with a dominant annual grass component. The vegetation in and around active ponds and ditches (riparian zone) on the 200 Areas Plateau is significantly different and higher in density than that of the surrounding dryland areas and provides locally higher evapotranspiration potential and radionuclide uptake. Changes in vegtation (shrubs to grasses) induced by various disturbances (fires, excavation, etc.) alter rooting depths and may increase recharge. Vegetation may remove chemicals upward in or from the soil, bring them to the surface, and subsequently introduce them to the food web.
Soil moisture	2% to 10% by volume	Containment fluxes cannot be determined by soil moisture contents but depend on hydraulic conductivity and capillary pressure relationships which can be highly variable in Hanford's layered sediment. Ambient moisture contents are typically higher in finer grained sediments than in coarse-grained sediments. Much of the vadose zone Hanford sediment is coarse-grained. Waste sites that received sufficient discharges to maintain localized saturated conditions in the vadose zone maximize downward pore water velocities and associated contaminant movement.
Vadose zone thickness	55 to 104 m (central plateau)	The thicker the vadose zone, the greater the potential for contaminants to interact with sediments. Vadose zone thins out from the 200 West and 200 East Areas north to Gable Gap.

Table 4-2. Summary of Site Conditions That May Affect Contaminant Fate and Transport. (2 Pages) (from DOE 1997)

Parameter/ Property	Representative values/conditions for 200 Area sediments	General Considerations
Soil chemistry	Alkaline pH Low oxidizing Redox state Ion-exchange capacity dependent on contaminant and % fine-grained soil particles Very low organic carbon content, <1%	The mobility of radionuclides and other inorganic elements depends on the chemical form and charge of the element or molecule, which in turn depends on waste- and site-related factors such as the pH, Redox state, and ionic composition. Buffering or neutralizing capacity of the soil is correlated with the calcium carbonate content of the soil. 200 Area sediments generally have carbonate contents in the range of 0.1% to 5%. Higher carbonate contents (10%) are observed within the Plio-Pleistocene caliche layer. Additional buffering capacity is provided by hydroxides of iron, aluminum, manganese, and silicon. Acidic solutions are buffered to more neutral basic pH values when contacting Hanford sediments. Many constituents/contaminants precipitate or adsorb to the soil under neutral to basic pH conditions. The vadose zone is generally an oxidizing environment. Redox-sensitive elements from highly oxidized waste streams may become less mobile (are reduced) when contacting the vadose zone, which has a relatively lower oxidizing potential. Conversely, reduced waste streams could be oxidized when introduced into the vadose zone and thereby increase the mobility of Redox-sensitive elements. Many contaminants of concern (COCs) in 200 Area waste streams are present as cations. Sediments have sufficient cation-exchange capacity to adsorb many of these cations. Considering the substantial thickness of vadose zone (50 to 140 m), the total cation-exchange capacity of a column of soil is substantial. 200 Area sediments have a poor affinity for anions because of their negative charge. Sorption to organic components is considered to be minimal considering the low organic content. Sorption to the inorganic fraction of soils may dominate over sorption to soil organic matter. Mineralogy affects the abundance of sorption sites as well as the availability of ions for precipitation. Soil components that contribute to adsorption of inorganic compounds such as clays and organic matter are generally minor components in 200 Area sediments. Diffusion of contaminants into micropores of minerals can occur. Microorganisms in the soil may degrade organic chemicals and inorganic chemicals.
Soil texture	High sand and gravel content (~70 to 80 wt%), moderate in silt content (10 to 20 wt%), and low clay content (<1 to 10 wt%) and stratified	Coarse-grained nature of sediments which dominate the Hanford Site, generally provides for a quick-draining media. However, variations of the soil stratigraphy with depth, such as the presence of low-permeability layers, impedes the downward movement of liquids. Sediments are generally more permeable in the horizontal direction than in the vertical direction because of the stratified nature of the sediments. This facilitates the lateral spreading of liquids in the vadose zone and reduces the downward movement. Under unsaturated conditions, coarse-grained layers overlain with finer grained materials retard the movement of pore water because of the capillary barrier effect. Under saturated conditions, layers of finer grained soil such as silt layers and the Plio-Pleistocene unit function as localized aquitards. Where substantial quantities of liquid waste were disposed, perched water may form above these layers. These phenomena increase the potential for lateral movement of liquids. If perched water is laterally expansive, it can mobilize wastes beneath adjacent waste sites. Sorption to sediments increases as particle size decreases. Suspended solids/particulates in waste streams are likely to be physically filtered by the sediments at the boundary of the waste site.

lenses of sand and gravel. Ringold Formation deposits are generally more cemented and better sorted than those from the Hanford formation. Ringold strata typically contain a lower percentage of angular basaltic detritus than Hanford formation deposits. The Hanford formation is characterized by dark grayish-brown to dark olive-gray sandy gravel, typical of the gravel-dominated facies, with some silt and local sand stringers. The upper portion of the unit generally exhibits a pebble to boulder gravel, which becomes finer with depth, to a very

fine-to-medium pebble gravel. Lenses of gravelly sand and sand occur locally. Detailed conceptual models for the 100 Areas are provided in Peterson et al. (1996).

200 Areas. The vadose zone beneath the 200 Areas ranges in thickness from about 55 m in the western portion of the 200 West Area (beneath the former U Pond) to 104 m in the southern part of 200 East Area. Stratigraphy of the vadose zone differs significantly beneath the 200 East and 200 West Areas.

At the 200 East Area, the vadose zone is composed either entirely of Hanford formation sediments, or a combination of Hanford and Ringold sediments, depending on the specific location. Where Ringold sediments are above the water table in the 200 East Area, they are Ringold Unit A sands and gravels or, in a few places, the lower Ringold mud unit that overlies the Ringold A Unit (DOE-RL 1997e). However, the vadose zone in the 200 East Area is predominantly Hanford formation gravels and sands. The Hanford formation may be divided into the following subunits: gravel (H1), sand (H2), and gravel (H3). H1 ranges from 11 to 37 m thick, is dominated by the gravel facies, and contains significant interstratified horizons dominated by the sand facies. The unit is thinnest in the southwestern part of the site and thickens to the north and east. Outcrop observations show that silt-rich interbeds are present and are normally a few to tens of centimeters thick. Silty horizons as much as 1 m thick and continuous up to distances of at least several hundred meters also are present in H1. These horizons are capable of generating perched water conditions. The contact between unit H1 and underlying strata generally is very irregular. These irregularities are the result of the interfingering nature of these deposits, which results in the absence of a distinct bounding surface. The sands of unit H2 are thickest (up to 55 m) in the southwestern part of the site while pinching out toward the east and north. Unit H3, defined by the abundance of the gravel facies, thickens to the north and northeast, from 12 to 45 m thick. Like H1, interbeds of the sand and silt facies are present throughout unit H3. Also like H1, these silts have the potential to generate perched water conditions. The interstratified sands and gravels found at the base of H2, referred to as unit H2a, are locally well developed beneath the eastern to central part of the site. Although each of these units are defined on the basis of a dominate lithology, significant subordinate lithologies are intercalated in each unit (Wood et al. 1995).

Beneath the 200 West Area, three major stratigraphic units are present. From top to bottom, these are the Hanford formation, the Plio-Pleistocene unit, and the Ringold Unit E. The early Palouse soil is also found above the Plio-Pleistocene unit in some parts of the 200 West Area. Calcium carbonate content is typically less than 1% in the Ringold Formation Unit E, less than 1% in the upper Ringold unit, as much as 10% in the early Palouse soil/Plio-Pleistocene unit, and less than 2% in the Hanford formation (DOE-RL 1997e). The characterization of soil samples from wells indicates that small lenses of fine-grained material are interspersed in the Hanford formation. These appear to be no more than 3 to 6 m thick with a lateral extent of hundreds of feet or less (Wood et al. 1995).

More poorly understood than the general geologic framework are features that cross-cut the geology such as clastic dikes (i.e., vertical fissures), discontinuities in compacted zones, and the presence of unsealed or poorly sealed wells. All these features add to the complexity of moisture

flow (Fecht et al. 1998) and contaminant movement (DOE 1997a-d), and may result in the rapid transport of contamination to the groundwater table with minimal interaction with the sediments.

Hydraulic Controls

The flow of water through unsaturated soils in the vadose zone depends in complex ways on several factors, including the rate of water infiltration at the soil surface, the moisture content of the soil, textural heterogeneity in the soils, and soil hydraulic properties. Hydraulic data for the vadose zone is limited. Data catalogs and reviews on hydrology can be found in Connelly et al. (1992a, 1992b); Hartman and Peterson (1992); DOE-RL (1993a, 1993c); Thorne et al. (1993, 1994), and Wurstner et al. (1995). Soil hydraulic properties are compiled in Khaleel and Freeman (1995), and recharge information is available in Gee (1987) and Fayer and Walters (1995). Programmatic data needs (e.g., remedial investigations at selected operable units) have also resulted in limited sampling of the deep vadose zone. No complete hydrologic property data sets exist for any of the tank farms or other key waste sites.

Infiltration of water to the vadose zone provides the driving force for downward migration of contaminants. Moisture may come from artificial sources such as waste water disposed to cribs, leaks from tanks, leaking water lines (etc.). Water may also come from natural rainfall and snowmelt. Disposal of water to cribs, ponds, and ditches has largely ceased. However, water is still disposed to a few regulated facilities. Recharge from natural precipitation across the Hanford Site is highly variable, both spatially and temporally, ranging from near zero to more than 100 mm/yr depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). It is highest in areas with coarse-grained soil at the surface and no vegetation cover, which is often the case in tank farms and at other waste sites.

Perched zones may form when water moving downward through the vadose zone accumulates on top of low-permeability soil lenses, highly cemented horizons, or above the contact between a fine-grained horizon and an underlying coarse-grained horizon. The Plio-Pleistocene unit and early Palouse soil is the most significant aquitard in the 200 West Area above the water table and a major component controlling the accumulation of perched water beneath sites where effluent was discharged. The Ringold lower mud sequence also represents a potential perching layer (DOE-RL 1997e).

Unsaturated hydraulic conductivities may vary by several orders of magnitude depending on water content. Water content measurements in the 200 Area vadose zone have historically ranged widely from 1% to saturation (perched water) from liquid disposal activities, but typically range from 2% to 10% under ambient conditions. Connelly et al. (1992a, 1992b) and Khaleel and Freeman (1995) summarized hydraulic conductivity measurements taken on 200 Area soils with various water contents. For Hanford formation samples taken in the 200 East Area, vadose zone hydraulic conductivity values at saturation ranged from about 10^{-6} to 10 cm/sec, with many of the values falling in the 10^{-5} to 10^{-3} cm/sec range. However, under unsaturated conditions at a 10% moisture content, hydraulic conductivity ranged from about 10^{-16} to 10^{-5} cm/sec, with many of the values falling in the 10^{-10} to 10^{-5} cm/sec range. Calculated unsaturated conductivities for Ringold Unit A gravel samples ranged from less than 10^{-18} to 10^{-10} cm/sec at water contents near 10%, and from 10^{-7} to 10^{-5} cm/sec at saturation water contents of 38% and 57%, respectively.

Ringold lower mud samples had unsaturated hydraulic conductivities ranging from less than 10^{-18} cm/sec at a 10% water content to approximately 10^{-9} cm/sec at saturation (57%).

Geochemical Controls

Geochemical interactions in the vadose zone that affect the migration of contaminants are dependent on the chemical nature of the migrating waste and the chemical and mineralogic makeup of the sediments. Descriptions of waste forms and the mineralogic/chemical nature of Hanford Site sediments are documented in numerous summary documents (e.g., BHI 1995a-f, DOE-RL 1992a-d, DOE-RL 1993a-e, DOE-RL 1997e). A more limited set of references is available that summarizes key interactions (Serne and Wood 1990; Ames and Serne 1991). Much of the material presented in this discussion of geochemical controls has been developed by a team of contributors from the National Laboratories, as well as representatives from Richland Operations Office (RL), Hanford Site contractors, regulators, Tribal Nations, and stakeholders that met in Vadose Zone Chemistry working groups in three meetings during the period of April 1998 through September 1998.

Hanford waste migration in the vadose zone is best characterized as a multi-reaction suite that, at various times, can act to mobilize, transform, retard, or immobilize waste constituents. The migration rate of contaminants is affected by processes such as precipitation/dissolution, sorption, filtration of colloids and suspended particles, and diffusion into micro pores. Whether a given reaction series or physical process will predominate is dependent on the chemical identity of the contaminant waste form and the mineralogic, organic, and surface chemical properties of the subsurface strata the waste encounter. In general, Hanford soils are neutral to slightly alkaline, oxidizing, very low in organic carbon content (<1%), and have a variable ion-exchange capacity that is dependent on the fraction of fine-grained particles present. The presence of micro- or thin layers of finer grained sediments can have a significant effect on chemical interactions and waste migration. Other than for the ion-exchange capacity of select strata, the limited range for the chemically significant attributes means that little can be gained in attempting to further differentiate Hanford Site sediments. Most of the emphasis should be placed on defining the controlling reactions involved in the more chemically extreme waste forms.

One general measure of a contaminant's distribution between soil and water is the soil-water distribution coefficient (K_d). This coefficient is experimentally derived, and is usually expressed in units of milliliters per gram. A relatively high K_d value indicates that the contaminant will tend to be retained on the soil particles and thus indicates a relatively low mobility, whereas a relatively low K_d value indicates that the contaminant will tend to remain dissolved in water and thus indicates a relatively high mobility. The concept of K_d does not illuminate the mechanics of the reaction processes that control contaminant distribution. The specific suite of interactions between waste forms and the native sediment are least understood for wastes that are chemically aggressive (e.g., high ionic strength, high or low pH, complexant-rich). At some waste sites, the chemistry of the waste streams disposed to ground have appreciably altered the chemical environment of the near-field sediments. Such changes in geochemistry likely alter the sorption properties of the sediments, and may increase the relative velocity of contaminant migration until the contaminant reaches a zone where the chemistry has not been altered. How far contaminants

in these highly aggressive waste streams (e.g., some tank wastes) migrate, and the dominant processes involved, is not well-understood from either laboratory studies or from field characterization efforts.

Away from the zone of aggressive chemical interaction, sorption tends to be the dominant process affecting contaminant mobility. The retention of contaminants by sorption has been described by the linear sorption isotherm model, assuming that the sorption process is fast and reversible (Serne and Wood 1990). The distribution coefficient, K_d, is a parameter that quantifies the retardation of contaminants in relation to water velocity in the linear sorption isotherm model. K_d values have been determined through laboratory experiments for many radioactive species in Hanford Site soils. A compilation of these values is provided in Appendix E of Kincaid et al. (1998), and a listing of relative contaminant mobilities is provided in Table 1-3. Many contaminants may not exhibit a linear isotherm for various reasons, and it is important to characterize the concentration dependence of sorption over relevant ranges.

The K_d for a contaminant can be significantly affected by the following:

- Composition of the waste stream in terms of major and minor ions.
- The pH of the waste and the ionic strength.
- The mineralogic and organic composition of the sediments and surface saturating ions.
- The presence of organic and chemical complexants in the waste.
- Other processes (e.g., biodegradation, oxidation-reduction).

Effects of pH and Ionic Strength

The pH of the waste can increase the mobility of some contaminants. Many transition metals, lanthanides, and actinides are more soluble in acid solutions than in neutral or mildly basic (pH<= 10) solutions. When contacting Hanford Site sediments, acidic solutions are generally quickly buffered to more neutral pH values. As the pH increases, most metals and radionuclides react either by adsorption reactions onto hydrous oxides, carbonates, and clays, or precipitate as insoluble phases. The percent removal from solution usually dramatically increases over a very short span of pH values. For some metals, adsorption becomes essentially complete (100%) as pH increases from 2 or 3 up to 4 or 5 (Serne and Wood 1990). Although many contaminants become more mobile in an acidic environment, increased alkalinity can also have the effect of increasing the mobility of select contaminants. Plutonium, which is typically one of the least mobile of the Hanford Site contaminants (e.g., ^{90}Sr), has moderate mobility at pH values above 8.

For some inorganic contaminants (e.g., ^{90}Sr), ion exchange is the dominant mechanism leading to desorption. High ionic strength tends to drive the equilibrium toward desorption rather than sorption.

Effects of Sediment Composition

Because Hanford Site soils are generally neutral to alkaline, there is a net negative charge on the soil particles that facilitates sorption of cations. Conversely, anionic species are either only weakly sorbed or not sorbed at all.

Table 4-3. Contaminant Mobility in Hanford Soils.
(2 Pages) (from DOE-RL 1997e)

Contaminant	Normal Mobility	Factors Affecting Mobility
Cobalt-60	Low	Highly sorbed by cation ion exchange at pH<9; readily reacts with organics and inorganic ions to form more mobile complexes (e.g., with ferrocyanide or phosphates).
Strontium-90	Moderate	Sorbs by cation ion exchange, but competes for sites with calcium. May immobilize as a coprecipitate in the mineral apatite formed by phosphate wastes. Highly mobile in acidic conditions. Mobility is increased by organics (e.g., tributyl phosphate).
Technetium-99	High	Generally present as pertechnetate anion, which is relatively nonadsorbing.
Ruthenium-106	High	Highly influenced by presence of nitrite or nitrate; short (1-year) half-life offsets high mobility.
Cesium-137	Low	Highly sorbed by cation ion exchange. Competes for sites with potassium and sodium. Mobile. Does not tend to form soluble inorganic or organic complexes. More mobile at low pH.
Uranium-238	High	Highly mobile at low pH and at pH>8 where soluble anionic carbonate complexes can form. However, uranium forms insoluble precipitates with phosphate that are highly immobile.
Plutonium-239/240	Low	Maximum sorption occurs in pH range of 4 to 8.5 as a result of formation of insoluble precipitates. Sorption is less at low pH (<4) and high pH (>8.5). Plutonium can form more mobile complexes with co-disposal of organics (e.g., tributyl phosphate, hexone, dibutyl butyl phosphate).
Americium-241	Low	Behaves similarly to plutonium.
Cadmium	Moderate to high	Mobile as a dissolved metal for most waste streams in Hanford soil column conditions.
Carbon tetrachloride	High	Used as diluent for Plutonium Finishing Plant (PFP) separations processes. Not highly sorbed by Hanford soils, which are low in organic carbon content.
Chloroform	High	Degradation product of carbon tetrachloride; may be formed during chlorine treatment of potable water supplies.
Chromium	High	Generally present as an anion (chromate), which is mobile in the +6 valence state.
Cyanide	High	Anionic species that is essentially nonadsorbing; forms complexes with cationic species, increasing their mobility.

Table 4-3. Contaminant Mobility in Hanford Soils.
(2 Pages) (from DOE-RL 1997e)

Contaminant	Normal Mobility	Factors Affecting Mobility
Dibutyl butyl phosphonate	(a)	Used as a solvent with carbon tetrachloride diluent in PFP separations process for americium-241 removal. Potential for increased mobilization of americium-241 and plutonium-239/240 due to complexation.
Hexone (methyl isobutyl ketone)	(a)	Used as solvent for plutonium and uranium in REDOX separations process. May increase radionuclide mobility due to formation of organic complexes.
Hydrazine	(a)	Strong reductant, soluble in water. Breaks down into mobile amines or ammonium ions in water.
Nitrate	High	Anionic species, nonadsorbing, considered to travel with water.
Tributyl phosphate	(a)	Used as solvent in extraction of plutonium and uranium in PUREX and Uranium Recovery Program and for plutonium in PFP separations processes. May increase radionuclide mobility in soil column due to formation of organic complexes.
Trichloroethylene	High	Not highly sorbed by Hanford soils, which are low in organic carbon content.

[a] Organic compounds: Generally considered to be mobile due to low organic carbon content of Hanford soils.
Mobility factor: High = K_d 0 to 5; Moderate = K_d 5 to 100; Low = K_d >100.
K_d = soil-water distribution coefficient
PUREX = Plutonium Uranium Extraction
REDOX = Reduction Oxidation.

Mineralogy affects the abundance of sorption sites as well as the availability of ions for precipitation. Sorption is a reversible to partially reversible surface reaction. It occurs in Hanford Site sediments on the surfaces of oxides, layer silicates (micas, illites, vermiculites, and smectites), and calcium carbonate. Both ion exchange and surface coordination reactions are important. Hanford Site contaminants most susceptible to sorption reactions are ^{137}Cs, ^{90}Sr, uranium, and ^{60}Co.

Sorption increases as soil particle size decreases. Filtration and ion exchange also increase with decreased soil grain size. Filtration effects are more pronounced for contaminants that form insoluble precipitates.

For organic contaminants, partitioning to the soil from the water is affected by the organic carbon content of the soil. There is a soil/organic matter partition coefficient (K_{oc}) that is similar in concept to the soil/water partition coefficient (K_d). Hanford Site soils are low in organic carbon content (less that 0.1 wt%). Therefore, estimated K_{oc}s for the principal organics of concern are generally less than 1, indicating high mobility.

Effects of Organics and Chemical Complexants

Water-soluble aqueous complexes form between key Hanford Site radionuclides and dissolved ions (ligands) in wastewater or in the porewater. Strong complexation may shield the

participating radionuclide from adsorption or precipitation reactions, allowing (facilitating) free movement of the contaminant through the subsurface. The solubilizing ligand may be natural (CO_3^{2-}) or part of the waste stream ($EDTA^{4-}$, CN^{2-}). Examples of mobile complexes include $UO_2(CO_3)^{2-}$, CoCN, $CoEDTA^{2-}$, and PuEDTA.

Other Processes

Contaminant concentrations in waste streams may be changed through processes such abiotic/biotic reduction, biodegradation, and/or colloid genesis. Abiotic/biotic reduction is a transformation reaction that induces change of oxidized metal ion valence to a lower state where chemical behavior and reaction chemistry are different from the oxidized form. The reaction is heterogeneous and occurs on mineral surfaces where ferrous iron is present as a lattice substituent or a biogenic surface product. Hanford Site contaminants susceptible to surface reduction include plutonium (V), chromium (VI), uranium (VI), and technetium (VII). All form oxide and hydroxide precipitates with low solubility in the reduced states. Minerals in the vadose zone with sufficient reductive potential include illmenite, magnetite, pyroxenes, amphiboles, and basaltic glass. It is not known whether their surfaces are or are not passivated in the vadose zone by reaction with O_2.

Biodegradation affects the persistence of organics in the subsurface. Biodegradation of water-soluble organics is more rapid under the oxidizing conditions found in Hanford Site soils, whereas the rate of biodegradation of the less soluble organics tends to be very slow. Solvents such as hexone and NPH do not generally persist in Hanford Site soils because they have a low soil adhesion and greater biodegadability than other organics such as carbon tetrachloride.

Submicron-sized precipitates (colloids) may enter vadose zone porewater as acid and basic Hanford Site wastes are neutralized by geochemical reaction with Hanford Site sediments or as strongly hydrolyzing radionuclides (plutonium, americium) precipitate. Colloids may originate from the geomedia as cementing agents are dissolved by high or low pH waste solutions, or may precipitate from mineral dissolution/waste neutralization products (aluminum or silicon) or the waste components themselves [$Al(OH)^{4-}$]. Siliceous and aluminous colloids can adsorb or co-precipitate with contaminants and may facilitate their mobilization through coarse-textured Hanford Site sediments. The presence of plutonium and ^{60}Co in groundwater near the reverse well has been attributed to mobile colloid material. The migration of ^{137}Cs is also speculated to be colloid-assisted in select locations. Studies suggest that if colloids reach the water table from the vadose zone, they will flocculate (or otherwise be removed by diffusional processes), precluding colloid-facilitated transport of radionuclides from disposal sites.

4.2.2.2 Characterization Summaries. Radioactive and hazardous waste in the soil column, burial grounds, and underground tanks at the Hanford Site are potential sources of vadose zone and groundwater contamination. Contamination from past-practice liquid waste disposal and tank leaks potentially have the largest future impact on groundwater contamination, as demonstrated in the first iteration of the Composite Analysis (Kincaid et al. 1998), which looked at superposition of groundwater plumes from waste sources in the 200 Area Plateau. Vadose zone contamination has occurred from solid waste disposal activities as well as liquid waste disposal.

Net infiltration data used to estimate recharge have been obtained external to waste sites by a lysimetry network (Gee et al. 1992). Currently, because most of these lysimeters are not operating, the data they provide are limited. Vadose zone characterization has been accomplished to date by drilling, sediment sample collection and analysis, soil-gas sampling, and geophysical logging (most recently, spectral gamma logging).

Vadose Zone Monitoring Wells (Dry Wells)

More than 1,370 dry wells (i.e., not penetrating to the groundwater) have been installed to monitor the vadose zone throughout the Hanford Site (Chamness and Merz 1993). Most of these dry wells are located in the 200 Areas, particularly in the tank farms. Over the years, many different well designs have been used. In addition, modifications have been made to many of the early designs to prevent downward migration of contaminants in areas of active liquid waste disposal. Figure 4-7 illustrates some of the dry well designs being used to monitor the vadose zone (e.g., gamma logging) beneath the Hanford Site. Note that nearly all dry wells are cased with schedule 40 carbon steel, and that many (particularly near liquid waste disposal facilities) have multiple casings and/or cement grout seals to prevent contaminant migration down the outside of the casing.

Drilling around tanks, cribs, and trenches has provided considerable information about vadose zone lithologies and stratigraphy, but only limited hydrologic and geochemical information has been obtained from boreholes. In a few cases, drilling was used to identify tank leaks. Analyses of sediments for radionuclides, chemicals, and heavy metals have helped quantify the extent of contaminant plume migration at selected locations.

Soil-gas sampling has been done to characterize volatile contaminants in the vadose zone at a few select locations at the Hanford Site. Soil vapor extraction is being used to remove carbon tetrachloride from the vadose zone as part of an expedited response action (Hartman and Dresel 1998). The Nonradioactive Dangerous Waste Landfill was also recently surveyed for volatile contaminants in the vadose zone.

For decades, wells have been geophysically logged at tank farms (Price 1996) and at past-practice liquid waste/soil column disposal sites. The logging included both gross gamma and radionuclide-specific spectral gamma logs. Recently, a baseline spectral gamma logging study was undertaken on more than 700 dry wells (see above) for gamma-emitting radionuclides The most abundant contaminant detected by the spectral gamma monitoring in this study is ^{137}Cs, but ^{60}Co, uranium, ^{125}Sb, and ^{154}Eu have also been reported (Hartman and Dresel 1998).

The current borehole logging does not address nongamma-emitting radionuclides (e.g., ^{14}C, ^{99}Tc, ^{129}I) or nonradioactive contaminants (e.g., chromium, nitrate), which are primary constituents of regulatory interest. Physical corings within tank farms have been helpful in a few cases in identifying extent of nongamma emitters at depth but, because of great expense, these data are sparse. The extensive duration for which gross gamma logs are available has been useful in distinguishing tanks that have continued to leak from tanks whose leaks have apparently stabilized. Mass balance, critical for vadose zone evaluations, has not been determined for the

Figure 4-7. Examples of Dry Well Configurations Used to Monitor the Vadose Zone Beneath the Hanford Site.

major leaks because the logging instruments are frequently ineffective (i.e., the spectral gamma detector becomes saturated by high activities) and record only a fraction of the radioactivity present in the most contaminated zones. In addition, in spite of hundreds of monitoring points adjacent to known or suspected leaks, the vadose zone is under sampled with respect to critical hydrologic and geochemical parameters, and the sphere of detection for gamma logging is limited to the immediate vicinity of the logging well. Finally, the drilling operations have not been fully successful in eliminating the dragdown of contaminants along the well casing. Adequate differentiation of what contamination has been carried down the well casing, what has contaminated the inside of the well casing during drilling and sediment removal, and what contamination is in the formation currently is not available. In summary, logging of gamma emitters has identified areas of contamination in the vadose zone, but has severe limitations in identifying the full extent and migration of contaminant plumes, particularly when nongamma emitters are present, as is the general case.

In addition to the tank farms and past-practice sites in the 200 Areas, vadose zone contamination exists in the 100 and 300 Areas. For example, current leaks, as well as past-practice sites in the 100-K Area, are contributing a continuous input of ^{14}C to groundwater (up to 40,000 pCi/L in monitoring wells), even though it has been 27 years since gas condensates were discharged to cribs (Hartman and Dresel 1997). Other contaminants associated with the fuel storage basins in the 100-K Area include significant quantities of ^{90}Sr and ^{137}Cs suspected to be present in the vadose zone beneath the K-East basin and adjacent crib and injection well. Up to 25,000 pCi/L of ^{90}Sr has been observed in groundwater near these facilities (Hartman and Dresel 1997). Recharge from rainfall and snow melt, in addition to fire hydrant leakage, is the suspected driver for this migration through the shallow vadose zone into the groundwater. As another example, at the 100-N Area, approximately 3,000 Ci of ^{90}Sr, 5,000 Ci of ^{60}Co, 3,000 Ci of ^{137}Cs, and 22 Ci of plutonium were discharged to cribs. During operations, these facilities received discharges amounting to 7.2 x10^5 mm/yr. In spite of these massive discharges to the cribs, only ^{90}Sr and ^{60}Co have migrated to the water table. Most of the radiochemical inventory still resides in the bottom of the cribs.

Data catalogs and reviews are available for geology (DOE 1988a) and geochemistry (Kaplan and Serne 1995; Kaplan et al. 1995; Serne and Burke 1997). Recently, cores collected from boreholes in the T and SX Tank Farms have provided chemical characterization data (Freeman-Pollard et al. 1996; Serne et al. 1998), and are providing information on distributions of radionuclides (^{137}Cs and ^{99}Tc) and other chemical species (e.g., chromium, nitrate) that have not been available in the past (e.g., Raymond and Shdo 1966; Womack and Larkin 1971; ARHCO 1973; Routson et al. 1980; DOE 1997a).

A timeline annotated with some of the key characterization reports for Hanford Site facilities is provided in Figure 4-8. Concise summaries of some of the facilities/reports are provided in the following paragraphs.

216-S-1 and 216-S-2 Crib. Two investigations performed nearly a decade apart show that ^{137}Cs contamination remains located in the upper strata immediately beneath the crib site. Strontium-90 is more mobile than ^{137}Cs at this waste site, as indicated by its presence in the groundwater.

Figure 4-8. Timeline of Waste Site Investigations.

The poor sorption of ^{90}Sr is attributed to the chemistry of the waste stream. Based on the distribution of ^{90}Sr, it is suspected that its presence at the water table is in part due to a failed well casing. Figure 4-9 shows the results of two 216-S-1 Crib field investigations (Haney and Linderoth 1956; Van Luik and Smith 1982).

216-A-8 Crib. The 216-A-8 Crib was used from 1955 to 1958 and received 9.3 x 10^8 L of A and AX Tank Farm condensate waste and condenser cooling water from the 241-A-431 Building. The crib was reactivated in 1966 when tank farm condensate was routed back to the crib from the A, AX, and AY Tank Farms. During this campaign, the crib was used until 1978 when a total of 1.15 x 10^9 L of waste had been discharged to the crib. The condensates contained 50 g of plutonium, 112 Ci of ^{90}Sr, 1,080 Ci of ^{137}Cs, 995 Ci of ^{106}Ru, and 368 kg of uranium. The cesium and strontium were retained in the upper zone of the soil column beneath the crib as indicated by Raymond and McGhan (1967), but apparently some gamma-emitting contamination leaked down the side of a characterization borehole after the crib was reactivated in 1966. Figure 4-10 (Smith and Kasper 1983) shows the distribution of cesium and gamma-emitting radiation in one borehole drilled through the crib. The crib was reactivated in the 1980s when PUREX last operated.

241-T-106 Tank Leak. A series of investigations have been performed over a period of two decades. Routson et al. (1980) concluded that all detectable ^{106}Ru movement occurred between 1973 and 1974. Cesium-137 movement is thought to occur at the same time. Maximum plutonium concentrations were found at 9.2 m depth in one well located adjacent to the tank (Routson et al. 1979; ARHCO 1973; Brown et al. 1979) (Figure 4-11). Following the recommendations of a 1989 General Accounting Office audit finding (GAO 1989), another borehole was drilled in 1993. Data from that investigation showed two overlapping zones of radioactive contamination and discrepancies with historical lithologic data. Low levels of ^{60}Co and ^{99}Tc were detected at depths of 36 mand 44 m in Ringold Unit E.

216-Z-9 Trench. Samples from the upper few centimeters of the trench revealed high concentrations of plutonium (20 g/L of sediment). The highest concentration is near the center of the trench floor. Two forms of plutonium are present: particulate and nonparticulate. Actinide concentrations are highest just below the bottom of the facility and decrease within the first 2 m of the underlying sediment (Smith 1973; Price and Ames 1975).

216-A-24 Crib. Measurements from excavations performed as part of a characterization effort showed that the gravel layer retained significant amounts of ^{137}Cs. Soil above the gravel layers did not show contamination. Evidence of plant uptake of radionuclides was demonstrated with the detection of ^{137}Cs in rabbitbrush roots, the upper centimeter of soil, and in the leaf litter. At 15 cm depth, ^{137}Cs was not detected. No data on horizontal distribution or beneath the gravel layer were collected for this study (Klepper et al. 1979).

Figure 4-9. Results of 1956 and 1966 216-S-1 Crib Field Evaluations.

Figure 4-10. Distribution of Cesium-137 and Total Gamma Activity in Well 299-E25-14 Near the 216-A-8 Crib.

Figure 4-11. 214-T-106 Tank Leak - Distribution of Radionuclides.

216-Z-1A Crib. The highest concentration of ^{239,240}Pu (4 x 10^4 nCi/g) and ^{241}Am (2.4 x 10^3 nCi/g) occurs within the first 3 m of sediment beneath the central distribution pipe. Concentrations of actinides in sediment generally decrease with depth, with the exception of silt-rich layers. The maximum vertical depth of actinide penetration is 30 m below the crib bottom. Estimated lateral extent is within a 10-m-wide zone (Price et al. 1979; Kasper et al. 1979). Figure 4-12 shows the total TRU activity distribution for the 216-Z-1A Crib.

216-Z-12 Crib. The highest concentration of plutonium occurred in the sediment immediately below crib bottom (6 x 10^6 pCi/g). Plutonium concentration decreased rapidly with distance from the crib bottom. No plutonium activity greater than 1 pCi/g was detected from 12 to 30 m below the crib bottom. However, silt layers at 30 to 36 m (maximum depth sampled) show low plutonium and americium activity (Figure 4-13) (Kasper 1981a, b; 1982).

216-U-12 Crib. The 216-U-12 Crib received neutralized process condensate and stack drainage from U Plant from 1960 to 1972, and then again from 1981 to 1988. The crib receive a total of 1.5 x 10^8 L of waste containing 104 Ci of ^{90}Sr, <0.1 Ci of ^{137}Cs, and 1,810 kg of uranium. Based on sediment samples collected from a borehole drilled near the crib, cesium was retained near the crib bottom, but the strontium has migrated down the soil column as shown in Figure 4-14 (Smith and Kasper 1983). Smith and Kasper (1983) report that the pH of soil samples collected near the crib were 3.9 at a 6.9 m depth and 6.1 to 6.6 at depths between 33 m and 44 m below ground surface. These data indicate that a considerable amount of low pH wastes were discharged to the crib. This also was provided as the explanation for the depth to which the strontium had moved. The acidic discharge was reacted with the natural calcium carbonate in the soil, and dissolved the solid releasing high concentrations of calcium to compete with strontium for sorption sites. Groundwater in this area has been impacted by operation of the crib, as indicated by elevated levels of ^{99}Tc and nitrate detected in groundwater downgradient of the crib (Williams and Chou 1997).

216-A-10 Crib. The main use of the 216-A-10 Crib was from 1961 to 1973, but some startup wastes were discharged in 1956 and the crib was used sporadically during 1977, 1978, and 1981. During its major operational period, the crib received acidic, high-salt process condensate from PUREX with a pH that ranged from 1.5 to 7.3, and averaged about 2. A total of 2.87 x 10^9 L of waste was discharged to the crib containing 343 g of plutonium, 147 Ci of ^{90}Sr, 134 Ci of ^{137}Cs, 7,270 Ci of ^{106}Ru, and 204 kg of uranium. The cesium and strontium distributions in a borehole drilled immediately adjacent to the crib are presented in Figure 4-15 (Smith and Kasper 1983). It is important to note the differential depths of cesium and strontium movement, even with billions of liters of water passing through the soil column. This crib received additional waste during the 1980s when PUREX was reactivated.

Figure 4-12. Total Transuranic Activity Distribution for the 216-Z-1A Crib.

Figure 4-13. Distribution of Plutonium Beneath the 216-Z-12 Crib.

Figure 4-14. Distribution of Cesium-137 and Strontium-90 in Well 299-W22-75 Near the 216-U-12 Crib.

Figure 4-15. Distribution of Cesium-137 and Strontium-90 in Well 299-E24-15 Near the 216-A-10 Crib.

216-A-30 Crib. The 216-A-30 Crib received 4.30 x 10^9 L of low-salt, neutralized steam condensate from PUREX, and other miscellaneous liquid wastes from 1961 until 1981. It was then reactivated later in the 1980s when PUREX began operations. The crib received a total of 187 Ci of ^{90}Sr, 142 Ci of ^{137}Cs, 196 Ci of ^{106}Ru, and less than 20 kg of uranium. Results from a soil boring near the crib indicated that ^{90}Sr and ^{137}Cs remained near the bottom of the crib within 5 to 8 m below ground surface (Smith and Kasper 1983). When liquid discharges exceeded the infiltration capacity of the crib, the liquids backed up onto the ground surface around the crib and contaminated the shallow subsurface.

216-A-36B Crib. The 216-A-36B Crib receive ammonia scrubber waste from PUREX from 1966 to 1972. The crib received a total of 9.4 x 10^7 L of waste containing 177 g of plutonium, 408 Ci of ^{90}Sr, 427 Ci of ^{137}Cs 137, and 119 kg of uranium. The crib was originally a single crib with one perforated distributor pipe extending the length of the crib. During the first 5 months of its operation, the crib received a much higher than intended radionuclide inventory; therefore, it was decided to isolate the 33-m inlet end of the crib where most of the waste was thought to have infiltrated into the sediments. For the remainder of its life, wastes were discharged to the B portion of the crib. Based on gamma logging and soil borings, the total gamma and ^{90}Sr distributions beneath the crib are presented in Figures 4-16 and 4-17 (Smith and Kasper 1983). It is apparent that cesium contamination (as indicated by gamma contamination) migrated down well 299-E17-4. Strontium data are not available for this location because the well was drilled before the sediments had become contaminated, but it is likely that the strontium distribution would be similar to the gamma contamination.

216-B-62 Crib. The 216-B-62 Crib received alkaline, low-salt process condensate from B Plant from 1973 until 1986. The crib received a total of 2.8 x 10^8 L of waste containing 91 Ci of ^{90}Sr, 170 Ci of ^{137}Cs, and ammonium ion from 0.2M to 0.4M. The presence of ammonium was important because it competes very effectively with cesium for sorption sites on the soil column. This seemed to be the case based on total gamma logs for a nearby monitoring well as shown in Figure 4-18 (Smith 1983). Based on sediment analyses conducted on samples collected from the length of the crib, neither ^{90}Sr nor ^{137}Cs migrated more than 30.5 m below the crib bottom as shown in Figures 4-19 and 4-20 (Smith 1983). It is interesting to note that, in this crib, the ^{137}Cs migrated deeper than ^{90}Sr, and is counter to most other observations. This difference was attributed to the elevated ammonium in the wastes that lowered the cesium sorption, resulting in a deeper migration in the soil column.

Figure 4-16. Total Gamma Distribution Beneath the 216-A-36B Crib.

Figure 4-17. Strontium-90 Distribution Beneath the 216-A-36B Crib.

Figure 4-18. Total Gamma Profiles for Well 299-E28-18 Near the 216-B-62 Crib.

Figure 4-19. Cesium-137 Activity >0.1 nCi/g Distribution Beneath the 216-B-62 Crib.

Figure 4-20. Strontium-90 Activity >0.1 nCi/g Beneath the 216-B-62 Crib.

216-U-1 and 216-U-2 Cribs. In February 1985, uranium concentrations increased abruptly to 0.1 kg of uranium per cubic meter in groundwater underlying the retired cribs. The cribs were estimated to have received over 4,000 kg of uranium between 1952 and 1967. Characterization showed the uranium was present as an anionic carbonate complex that was not sorbed by the soil. The uranium was mobilized by flow from a perched zone of water caused by disposal of cooling water to a nearby crib. Over a 6-month period, more than 30,000 m^3 of groundwater was pumped and treated prior to return to the soil column.

216-Z-8 French Drain. Plutonium and amercium activity was encountered in a zone extending 5 m from the bottom of the french drain (Figure 4-21) (Maratt, Van Luik, and Kasper 1985).

Groundwater Impact Assessments

An evaluation of impacts from liquid waste discharge sites in the 200 Areas was performed per *Tri-Party Agreement* Milestones M-17-00A and M-17-00B in the 1993-1995 timeframe, as followup studies to facility-generated liquid effluent study/waste stream-specific reports. These evaluations examined a number of the then-active ponds, cribs, and ditches to determine if continued liquid discharge would adversely impact the groundwater beneath the sites. Existing data were used where possible, and transport models were used to determine the potential for contaminant migration. In some cases, additional boreholes and test pits were required to characterize the vadose zone and groundwater beneath the waste disposal sites. Some of the sites examined under this program included the 216-B-3 Pond System (PUREX/242-A Evaporator cooling water and chemical sewer), the 216-T-1 Ditch (221-T Plant Headend cooling water and miscellaneous wastes), the 216-S-26 Crib (222-S Laboratory sink waste and steam condensate), the 284-WB Pond (steam generation and water treatment waste liquids), the 216-U-14 Ditch (221-U cooling water and steam condensate), and 216-U-17 (224-U UO3 process condensate).

200 Area Aggregate Area Management Study (AAMS) Reports and Hydrogeologic Models

A 1991 *Tri-Party Agreement* Milestone, M-27-00, specified the preparation of 10 AAMS reports based on a philosophy presented in the *Hanford Site Past-Practice Strategy* (DOE-RL 1991). The AAMS reports addressed the eight major processing areas/plants in the 200 Areas, plus the groundwater conditions beneath the 200 East and 200 West Areas. They represented an alternate approach to the process of characterizing waste sites by operable unit (OU) and sought to simplify the characterization process by using and building on existing data. The reports functioned as remedial investigation/feasibility study (RI/FS) scoping studies in that they gathered available representative environmental and operational information about all facilities as well as the liquid and solid waste sites within the geographic and operational influences of the eight major plants. The documents also outlined an approach for continuing the characterization process, identified preliminary remediation alternatives, identified applicable or relevant and appropriate requirements, defined preliminary conceptual models and assessed health and environmental concerns, identified data gaps for the DQOs, and provided recommendations for waste site characterization based on site hazard evaluations.

Figure 4-21. Plutonium-239 Concentration (pCi/g) Beneath the 216-Z-8 French Drain.

One key set of supporting documents was the preparation of the following two groundwater modeling reports: *Hydrogeologic Model for the 200 West Groundwater Aggregate Area* and *Hydrogeologic Model for the 200 East Groundwater Aggregate Area* (Connelly et al. 1992a, 1992b). These reports compiled and evaluated available hydrogeologic and hydrochemical data collected in each area and developed conceptual hydrogeologic models of the groundwater, including distributions of radiological and chemical contaminants.

Limited Field Investigations Reports

A number of limited field investigations (LFIs) have been performed in the 100 Areas, and several have been performed in the 200 and 300 Areas. These reports consisted of data compilations and evaluations for characterization activities at specific OUs. The OUs in all areas were subdivided according to groundwater or vadose zone contamination, and characterized accordingly by boreholes, test pits, cone penetrometer, and other in situ techniques. Specific characterization goals and test parameters were presented in LFI plans. All 100 and 300 Area LFI reports are complete, and one LFI was conducted in the 200 Areas prior to a recent change in characterization strategy.

Tank Farms Vadose Zone Baseline Characterization

Background and Status

The purpose of baseline characterization is to determine the nature and extent of the vadose zone contamination that originated from tank leaks, pipeline leaks, and surface spills using existing monitoring boreholes. The program is intended to document the extent of the contamination and provide data that can be used to help develop an understanding of contaminant migration characteristics and mechanisms. This program also establishes the current conditions at each of the tank farms and provides a quantified baseline of the contamination against which future monitoring data can be compared to assess changing conditions in the vadose zone.

Spectral gamma-ray log data and the three-dimensional visualizations are the primary pOUucts of the baseline characterization project, and provide an understanding of the vadose zone contamination around the SSTs. This basic understanding of the gamma-emitting radionuclides can be correlated with other radionuclides that are not as easily quantified to develop a more comprehensive understanding of all radionuclide distributions and migration characteristics. Such a correlation is currently being performed for the T-106 contamination plume.

All existing boreholes surrounding the SSTs are being logged, and radionuclide concentration logs are being generated for each borehole, including logs of man-made contaminants (i.e., ^{137}Cs and ^{60}Co), as well as the naturally occurring radionuclides ^{40}K, ^{238}U, and ^{232}Th. The naturally occurring radionuclide logs are useful for defining and correlating the lithology.

Individual log data from boreholes surrounding a particular tank are correlated to develop an understanding of the three-dimensional contaminant plume distributions. These data are analyzed and interpreted along with historical information regarding geology, tank construction,

tank content information, and historical gross gamma-ray log data, and the results are reported in a tank summary data report for each tank.
Upon completion of the tank summary data reports for each tank in a farm, a tank farm report is prepared. The tank farm report assesses all of the data and information in the tank farm, correlates that information, and provides the results in the form of visualizations and text. The tank farm reports provide all of the information and interpretations resulting from the baseline characterization program.

Geostatistical analytical tools used to correlate the log data between boreholes and across the tank farm quantify the cross-borehole correlations that establish the distribution of the individual radionuclides and define major contamination plumes. The results of the geostatistical structural analysis have enhanced the understanding of the contaminant migration characteristics of each radionuclide.

Three-dimensional numerical models of contamination plumes are created using the geostatistical structure, and visualization software is used to generate three-dimensional representations of the models. These three-dimensional visualizations can be viewed from different perspectives, enhancing the understanding of the contaminant distribution and extent of the contamination. In all cases, known or suspected inaccuracies or error in the visualizations are identified and discussed.

As of December 1998, logging of the boreholes surrounding 134 tanks has been completed, with approximately 758 boreholes logged; 114 tank summary data reports have been issued; and 9 tank farm reports have been issued. Tank farm reports for the S, SX, U, TY, TX, AX, BY, BX, and C Tank Farms are referenced as DOE (1998d, 1996, 1997b, 1998a, 1997c, 1997d, 1997a, 1998c, 1998b), respectively. References for the individual tank summary data reports and other project documentation are provided in the tank farm reports.

Findings by Tank Farm

SX Tank Farm. The SX Tank Farm was the first tank farm for which the geophysical logging was completed and for which visualizations of the contamination were created. Ten of fifteen tanks in this tank farm are suspected of having leaked. Some of the tanks are known to have leaked many tens of thousands of gallons of high-level waste. The SX Tank Farm has released more contamination to the vadose zone than any other tank farm. As a result, contaminant plumes consisting primarily of ^{137}Cs were identified in the vadose zone (see Figure 4-22) more than 38 m (125 ft) in depth and more than 30 m (100 ft) from the suspected leak sources.
A particularly deep ^{137}Cs plume is associated with commingled contamination attributed to leaks from tanks SX-108, SX-109, SX-111, SX-112, and SX-115.

Figure 4-22. Summary of SX Tank Farm Gamma Logging Results.

NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

The SX tanks contained waste from the reduction oxidation REDOX process, which was about a factor of 30 times more highly concentrated in fission products than the waste resulting from the bismuth-phosphate process (T Plant and B Plant) or from the tributyl-phosphate process (U Plant). As a result, ^{137}Cs is much more highly concentrated, and it was the dominant gamma-emitting radionuclide identified in the vadose zone. The high ^{137}Cs levels within the tanks cause the environmental contamination found here to differ considerably from the contamination plumes observed at the other tank farms.

The existence of deep ^{137}Cs contamination (>38 m [>125 ft]) was initially questioned and thought to be the result of contamination dragdown during drilling or from migration down the boreholes. To resolve this issue, two additional boreholes were drilled through one of the main contamination plumes. Data acquired from the new boreholes quantified the amount of contamination carrydown during drilling, and confirmed that the ^{137}Cs is actually in the formation and is not primarily the result of contamination dragdown.

The amount of contamination dragdown that occurred during the drilling of one of the new boreholes hastened the development and implementation of a gamma-ray spectrum shape factor analysis method. This analytical method is now routinely used along with other information to help interpret the potential for borehole contamination conditions.

In conjunction with the baseline characterization at the SX Tank Farm, Hanford Site groundwater hydrologists and Washington State Department of Ecology (Ecology) personnel reexamined groundwater sampling data and determined that ^{99}Tc in the groundwater originated

from the tanks. This was the first confirmation that tank waste from one of the tank farms had impacted groundwater.

The geostatistical analysis completed during development of the SX Tank Farm visualizations showed a poor spatial correlation for ^{137}Cs, indicating that ^{137}Cs plumes are likely discontinuous and thus difficult to detect and define. This high spatial variability of ^{137}Cs relative to other radionuclides indicates that closely spaced borehole placement would be required to properly define specific ^{137}Cs plumes, and even with the very high density of boreholes in the SX Tank Farm, the current number of boreholes is inadequate to quantify the ^{137}Cs contamination in the subsurface to a degree of confidence necessary to support mass balance calculations.

The second borehole (41-09-39) drilled to confirm the presence of ^{137}Cs deep in the vadose zone was placed about 1.5 m (5 ft) from an existing borehole (41-09-04). A comparison of the activity profiles of the two boreholes showed a good correlation with some differences in the profiles, indicating that the ^{137}Cs profiles are correlatable at least at 1.5-m (5-ft) spacings. Variograms from other tank farms such as that shown in Figure 4-23 (BX Tank Farm) suggest the range of spatial correlation may only be about 6 m (20 ft). A more extensive geostatistical structural analysis is required to quantify the ^{137}Cs distribution at the SX Tank Farm.

Because of the relatively large number of tank leaks in the SX Tank Farm, the commingling of contamination plumes, and the high spatial variability of ^{137}Cs in the vadose zone, it is very difficult to determine the exact sources of the plumes.

Figure 4-23. BX Tank Farm Variogram.

The unanticipated depth and extent of the ^{137}Cs contamination detected during the baseline characterization at the SX Tank Farm have raised questions regarding exactly how deep the ^{137}Cs has migrated into the vadose zone, and have also raised questions about the geochemistry of cesium and how a radionuclide that was previously thought not to migrate has reached depths of 38 m (125 ft) in such high concentrations. On the other hand, the high spatial variability of the ^{137}Cs distribution suggests that deep migration should not occur.

Because ^{137}Cs has migrated to such a great depth, questions are raised as to the location of major plumes of other more mobile radionuclides with significantly higher risk (i.e., ^{99}Tc). Analysis of groundwater data established that ^{99}Tc has reached the groundwater. The SX Tank Farm vadose zone work essentially disproved some long-held assumptions that the contamination from the tanks did not migrate and therefore was not a significant environmental risk.

The future focus of characterization should now be to identify where in the vadose zone mobile radionuclides may be found.

A reevaluation of tank chemistry and vadose zone geochemistry transport mechanisms is needed to explain the observations. Much more vadose zone characterization work is required at the SX Tank Farm.

BY Tank Farm. Data acquired at the BY Tank Farm showed relatively extensive and continuous ^{60}Co plumes, some of which are shown in Figure 4-24. ^{60}Co was detected in all but a few of the boreholes, which is not surprising, because the BY tanks were used for in-tank ferrocyanide scavenging operations. The ^{60}Co has been shown to form a chemical complex with ferrocyanide, increasing the mobility of an element that was already relatively mobile. However, because ^{60}Co has a short (5-year) half-life, it does not pose a serious long-term health risk.

Correlation of the old gross gamma data with the spectral data showed that ^{60}Co was an indicator of tank leaks in the BY Tank Farm under the previous gross gamma monitoring program. ^{60}Co caused the activity first detected at the wells from a tank leak.

Because ^{60}Co has a higher degree of spatial correlation than ^{137}Cs, plumes can be detected with sparse boreholes, and it is easily correlated between boreholes. The continuity of ^{60}Co plumes made it easier to identify probable contamination sources.

Cobalt-60 concentrations up to about 2 pCi/g were detected as deep as the bottoms of the boreholes at 30 m (100 ft) around tanks BY-103, BY-105, BY-107, and BY-108, as shown in Figure 4-24. Compared to ^{137}Cs, this is not a high concentration; but for ^{60}Co, it is quite significant to find 2 pCi/g at the bottom of the boreholes. This high level is indicative of a ^{60}Co plume. Therefore, the total depth extent of the ^{60}Co is not yet known at the BY Tank Farm. It was previously known that ^{60}Co is present in the groundwater in the area, and the BY Cribs located just north of the BY Tank Farm are known to be a source of the contamination. It is not known if the BY Tank Farm has also contributed to the groundwater contamination.

Figure 4-24. Summary of BY Tank Farm Gamma Logging Results.

NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

In general, the occurrence of ^{60}Co in the subsurface is not associated with dragdown during drilling at the BY Tank Farm, because it is often detected at depth with no source farther up in the borehole and because it correlates well between boreholes, indicating that it is present as continuous subsurface plumes.

The distribution of ^{60}Co at the BY Tank Farm will probably prove to be a good indicator of the distribution of some of the higher risk, nongamma-emitting radionuclides once correlations are made between the gamma emitters and other radionuclides such as ^{99}Tc.

A ^{137}Cs plume at concentrations greater than 10,000 pCi/g is associated with a leak from tank BY-103, and ^{137}Cs is identified as somewhat isolated plumes elsewhere in the tank farm. The amount of ^{137}Cs contamination dragdown that has occurred in these boreholes has not been determined for this tank farm, and it is suspected that much of the low-level ^{137}Cs contamination shown at the lowest elevation in the visualizations is actually windblown particulate contamination that fell into the monitoring boreholes. Because these contamination data were not removed from the database that was used to generate the visualizations, the visualizations show false plumes in this instance.

Tank BY-111 may have been the source of a relatively low-volume leak; however, this tank is not identified as an assumed leaker. A discontinuous region of ^{60}Co identified on the west side of BY-111 may have originated from the tank.

Questions remain as to the location of some of the more mobile and higher risk radionuclides that leaked from the tanks. In addition, it is not known how deep some of the ^{60}Co and ^{137}Cs plumes have migrated because they were detected at the bottom of some boreholes, and the

contribution of contamination dragdown during drilling is thought to be minimal. Also, it is not established what or if there has been a contribution of radionuclide contamination to the groundwater from the tanks.

U Tank Farm. The baseline characterization of the U Tank Farm revealed a region of very high ^{137}Cs contamination (>10,000 pCi/g) defined by the log from borehole 60-12-01. This contamination undoubtedly originated from a leak in tank U-112, which is designated as an assumed leaker. The amount of contamination dragdown that has occurred is not known, because shape-factor analysis has not yet been performed on the log data from this tank farm. It is possible that some or all of the contamination from 30 m (100 ft) to total depth of the borehole at 37 m (120 ft) was carried down when the hole was drilled. As with the SX Tank Farm, the ^{137}Cs contamination shows a relatively poor spatial correlation, and because there are no other boreholes in the immediate vicinity of borehole 60-12-01, there is no way to confirm that the plume occurs as deep contamination in the vadose zone.

Other areas of ^{137}Cs contamination are shown in Figure 4-25. The surface contamination, some of which may be the result of dragdown, is extensive across the tank farm and extends to varying depths.

Another relatively large area of contamination was detected deeper and throughout much of the tank farm as low-level contamination shown in Figure 4-25 between elevations of 152 and 165 m (500 and 540 ft). Some of this contamination may also have been the result of dragdown,

Figure 4-25. Summary of U Tank Farm Gamma Logging Results.

NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

and the visualization exaggerates the extent of the plumes. However, it is apparent that much of the contamination is actually within the formation, as shown by the log of borehole 60-09-10 (Figure 4-26). This log shows almost no contamination near the ground surface or near the base of the tanks (12-m [40-ft] depth), yet a plume of contamination at levels up to 1.5 pCi/g is identified from 26 to 38 m (85 to 125 ft). This deep contamination was not dragged down during drilling because there is no source higher up in the borehole. Therefore, it is probable that this contamination represents a subsurface plume. Questions are now raised as to the depth of migration of the ^{137}Cs plume in this region of the tank farm.

Figure 4-26. Cesium-137 Contamination Levels in Borehole 60-09-10.

Another significant plume shown in Figure 4-25 is the uranium contamination below tanks U-104 and U-107. This plume covers a diameter of about 61 m (200 ft), but is only as deep as 30 m (100 ft). A larger horizontal extent compared to the vertical extent is not unexpected for this relatively mobile radionuclide. The total depth extent of this plume is established by the log data, and contamination dragdown is not suspected to have occurred in the boreholes defining this plume. Correlations of the distribution of uranium with other radionuclides can be accomplished with this plume, only in a more comprehensive characterization.

Historical groundwater monitoring data from wells surrounding the U Tank Farm have shown low concentrations of uranium and ^{99}Tc in the groundwater. The potential contributions of contamination from tank leaks to the groundwater are unknown at this time, but cannot be

discounted. It is suspected, but has not been established, that the source of the groundwater contamination is the adjacent U-14 Ditch.

The primary areas of concern for future investigations at the U Tank Farm relate to determining the true depth extent and distribution of ^{137}Cs contamination shown at the base of the visualization and the contribution of dragdown during drilling in that area and, of course, to determining the source of the groundwater contamination.

TX Tank Farm. The TX Tank Farm is the largest of all tank farms at the Hanford Site, with 18 SSTs, 8 of which are designated as assumed leakers. The baseline characterization of the TX Tank Farm identified ^{137}Cs, ^{60}Co, ^{154}Eu, and processed uranium contaminant plumes. Of greatest interest are the ^{60}Co and ^{154}Eu plumes in the southern portion of the tank farm.

Both the ^{60}Co and ^{154}Eu plumes appear to have originated from the south side of tank TX-107 and extend southward beyond tank TX-103 (Figure 4-27). The ^{60}Co plume is more extensive than the ^{154}Eu plume and extends to the bottom of the boreholes immediately south of tank TX-107, making it impossible to determine the depth of the ^{60}Co contamination.

Historical gross gamma log data indicate the ^{60}Co contamination continued to exhibit horizontal migration for a period of at least 9 years after the leak is suspected to have occurred. The mechanism for the continued migration is not known; however, it is possible that chemical complexants may be involved, although based on the performance of ^{60}Co at other tank farms, it is not certain that ^{60}Co necessarily must be in a complexant form to be mobile.

Three subsurface ^{137}Cs contamination plumes were identified in the TX Tank Farm that are related to tank leaks. These plumes are located in the northern half of the tank farm and are visible in Figure 4-27 just below tanks TX-109, TX-113, and TX-116. The migration of ^{137}Cs appears to have been controlled by the contact between the tank farm excavation backfill material and the undisturbed formation, indicating that the base of the tank farm excavation acted as a spreading surface for the contamination.

In addition to the three ^{137}Cs plumes noted previously, a widespread ^{137}Cs plume is shown in Figure 4-27 at an elevation of about 175 m (573 ft). It is suspected that the low-level ^{137}Cs contamination shown at these elevations is actually windblown particulate contamination that fell into the monitoring boreholes. Because these contamination data were not removed from the database that was used to generate the visualizations, the visualizations show false plumes in this instance.

Two uranium plumes were identified in the southern portion of the tank farm. One plume is located around tanks TX-101 and TX-105, and the other is located around tank TX-104. The processed uranium plume beneath tanks TX-101 and TX-105 is the most extensive of the two plumes and extends to a depth of about 24 m (80 ft). The maximum depth extent of the uranium plumes beneath tank TX-104 is about 30 m (100 ft).

Figure 4-27. Summary of TX Tank Farm Gamma Logging Results.

NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

Future characterization at the TX Tank Farm should focus on determining the total depth extent of the ^{60}Co associated with the TX-107 tank leak. Future monitoring of the ^{60}Co plume is recommended to assess the stability of that contamination.

TY Tank Farm. The TY Tank Farm data were the first data set to be analyzed using shape-factor analysis methods. For any regions where shape-factor analysis or the associated data correlation and interpretation indicated that the contamination was not distributed in the formation, the contamination data were removed from the visualization data set prior to preparation of the visualizations. This improved the accuracy of the visualizations. A visualization of the contamination at the TY Tank Farm is shown in Figure 4-28.

Plumes of ^{137}Cs and ^{60}Co were identified at the TY Tank Farm. The largest ^{137}Cs plumes were detected near the ground surface and resulted from surface spills.

Five of the six TY Farm tanks are designated as assumed leakers, and ^{137}Cs contamination plumes attributed to leaks from the tanks were identified at the base of each tank. In addition, a relatively small plume was identified in a single borehole adjacent to tank TY-102, showing about 4 m (12 ft) of ^{137}Cs contamination at the base of the tank with concentrations up to 80 pCi/g. Because this plume is located on the north side of tank TY-102, away from the other tanks, this contamination was attributed to a leak from the tank. Tank TY-102 is the only tank in the farm that is not designated as a leaker.

Figure 4-28. Summary of TY Tank Farm Gamma Logging Results.

Deep ^{60}Co plumes were identified on the south side of the tank farm. These plumes originated from either tank TY-105 or tank TY-106, or both. As with the ^{60}Co plumes identified at other tank farms, the TY Tank Farm ^{60}Co plumes showed relatively high spatial correlation; they were low in concentration relative to the ^{137}Cs plumes, and they were detected much deeper than the ^{137}Cs plumes. There is virtually no possibility that contamination dragdown caused these plumes, because no high-concentration zones of ^{60}Co exist in the upper portions of the boreholes, which makes it impossible for the contamination to have been dragged down. Data acquired from several boreholes showed continuous ^{60}Co plumes at the bottom of the boreholes, indicating the total depth extent of ^{60}Co migration has not been defined and that ^{60}Co may be present beyond the bottom of the boreholes. This deep ^{60}Co is below the Plio-Pleistocene unit.

A plume of concern is shown in Figure 1-28 in the southwest corner of the tank farm at an elevation of 140 m (460 ft). This plume is defined by the data from a single borehole (52-06-07). The log from this borehole is presented in Figure 1-29. This plume consists of a layer of low concentrations of ^{60}Co just above the groundwater in the capillary fringe along with what would normally be considered “trace” amounts of ^{137}Cs. There is essentially no contamination in the upper portion of the borehole, including the region at the ground surface, so it is probable that this contamination was transported to the location of the borehole by migration through the groundwater regime. However, the borehole may also have been contaminated by some groundwater sampling equipment or particulate matter that was blown into the borehole.

Figure 4-29. Cesium-137 and Cobalt-60 Contamination Levels in Borehole 52-06-07.

The significance of the contamination in the groundwater is that it suggests the groundwater has been impacted. The exact source of the contamination remains unknown, but there are no crib sources in the immediate vicinity of the borehole. The leaks from the tanks on the south side of the tank farm (TY-105 and TY-106), which are the primary sources of the deep cobalt contamination, are most likely the source of this contamination in the groundwater. Future investigation is required to determine the total depth extent of the contamination on the south side of the tank farm and to determine if that contamination is actually in the formation and the groundwater.

S Tank Farm. The S Tank Farm data showed a relatively clean vadose zone, as only one tank in this farm (S-104) is known to have leaked. The contamination plume from tank S-104 is shown in Figure 1-30.

Like the SX Tank Farm, ^{137}Cs was the principal gamma-emitting radionuclide contaminant identified at the S Tank Farm because it too was used to store REDOX wastes. Some surface contamination is present, but compared to other tank farms, this surface contamination is limited.

Figure 4-30. Summary of S Tank Farm Gamma Logging Results.

The S-104 plume shows contamination down to about 30 m (100 ft), the depth extent of the monitoring boreholes. The total depth of the plume has not been established, but there is evidence from the decrease in concentration in the gamma-ray log that the contamination is not much deeper than 30 m (100 ft). The leak volume estimate is 90,850 L (24,000 gal) and, although an extensive correlation between leak volumes and contaminant depth extent has not been made, the S-104 contamination depth extent is relatively consistent with that from other tank leaks.

Because the plume from the S-104 tank leak is relatively confined and the leak volume is well known, this tank leak would provide a good analogous plume for studying the geochemistry, the contaminant distributions, and the temporal changes associated with a REDOX waste leak.

AX Tank Farm. Cesiuum-137 is the main contaminant detected in the vadose zone at the AX Tank Farm. A plume was detected in the northern region of the tank farm between tanks AX-101 and AX-103 (see Figure 1-31), but it was relatively limited in extent and concentration. The contamination interval is about 30 m (100 ft) thick and is attributed to leakage from a failed piping coupling at the surface. Both tanks AX-101 and AX-103 are designated sound.

Tanks AX-102 and AX-104 are designated leakers. Historical records of gross gamma logging leak detection data indicate that elevated gamma activity was detected in monitoring boreholes for both of these tanks, but that activity quickly decayed away. No significant subsurface contamination indicative of a tank leak was detected with the spectral gamma logging around these tanks. However, because there are no major apparent lithologic features beneath the AX Tank Farm that impede vertical migration, the main plumes of contamination that may have leaked from these tanks could have migrated downward and may have never reached the lateral extent necessary to be intersected by the monitoring boreholes.

Figure 4-31. Summary of AX Tank Farm Gamma Logging Results.

Cesium-137 contamination is present over 90% of the ground surface defined by the areal extent of the vadose monitoring borehole locations. At a depth of 6 m (20 ft), the contamination was only present over about 25% of this area. The highest near-surface ^{137}Cs concentrations, which are greater than 5,000 pCi/g, are north of tanks AX-101 and AX-103 and resulted from a piping leak. Minor occurrences of ^{60}Co, ^{154}Eu, and ^{125}Sb were detected near the ground surface, along with the ^{137}Cs. This contamination originated from surface spills and/or piping leaks.

There is no evidence that waste from tanks in the AX Tank Farm reached and contaminated groundwater beneath the tank farm.

Future vadose zone investigations at the AX Tank Farm should focus on determining if significant contamination leaked from tanks AX-102 and AX-104 and if that contamination can be found beneath the tanks.

BX Tank Farm. Extensive plumes of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, and ^{154}Eu occur adjacent to and east of tanks BX-101 and BX-102, the tanks from which the waste originated (see Figure 1-32). These plumes range in thickness from 15 to 24 m (50 to 80 ft), and the contaminants have migrated laterally eastward more than 30 m (100) ft from these tanks (the eastern extent of the vadose zone monitoring boreholes). The contaminants from these two tanks have commingled to create a complex distribution. There has been substantial segregation of the individual radionuclides as they migrated through the vadose zone.

Figure 4-32. Summary of BX Tank Farm Gamma Logging Results.

The extent of these plumes is not defined by the areal distribution and depths of the vadose zone monitoring boreholes. To the east of tank BX-102, the boreholes are 46 m (150 ft) deep and several contaminants are present at the bottoms of the boreholes, preventing determination of the total depth extent of the plumes. To the west of tank BX-102, the boreholes are only 30 m (100 ft) deep and have not intercepted contamination, but the possibility exists that there are deeper plumes in this area.

A laterally extensive plume of uranium can be traced from tank BX-102 downward and to the northeast, where it is identified in a groundwater monitoring well both within the groundwater and as a contamination plume within the capillary fringe.

Data acquired from one monitoring borehole adjacent to tank BX-102 show concentrations of ^{137}Cs through most of the borehole that are greater than the saturation limit of the spectral gamma logging system. This borehole extends down to the groundwater (to a depth of approximately 76 m [250 ft]). It is suspected that much of this contamination was carried down the borehole during drilling, but there are no other deep boreholes in the immediate area that can be used to evaluate if the contamination is in the formation or a result of dragdown. Shape-factor analysis could not be used to assess the radial distribution of contamination in this borehole because of the high activity.

Tank BX-106 is presently designated as a sound tank, but an isolated plume of ^{137}Cs, ^{235}U, and ^{238}U contamination was identified on the south side of the tank at a depth of 12 m (40 ft), which is the depth of the tank base. The contamination interval, which is about 5 m (15 ft) thick, was detected in borehole 21-06-05. The presence of this contamination indicates the tank leaked, and

because contamination was not detected in adjacent boreholes at this depth, borehole 21-06-05 is very close to the leak source. Also, because the plume is very limited in extent and there has not been a significant segregation of the uranium from the cesium, it is likely that the contaminants have not migrated far and the leak volume is not large.

Cesium-137 contamination was detected on the south side of tank BX-107 throughout the 30-m (100-ft) length of borehole 21-07-06. The source of this contamination may be a near-surface pipeline leak, or leakage from tank BX-107 itself. This tank is presently designated as sound.

Cesium-137 and ^{60}Co plumes were also detected below tanks BX-108, BX-110, and BX-111, all of which are designated leakers.

Cesium-137 contamination was detected over 90% of the near-surface region of the tank farm as defined by the monitoring borehole locations. At a depth of 5 m (15 ft) below the ground surface, only about 20% of the area is contaminated with ^{137}Cs. The highest ^{137}Cs concentrations of about 100 pCi/g were detected between tanks BX-107 and BX-110, suggesting a spill or pipeline leak occurred in this region.

Contamination of groundwater beneath the BX Tank Farm has been identified in groundwater monitoring wells located east and west of the tank farm. The source(s) of the contamination in the eastern well is postulated to be contamination originating from tank BX-102, as well as contamination from nearby crib facilities. Data acquired from two groundwater monitoring wells on the west side of the tank farm are also providing evidence of a dynamic condition with increasing ^{99}Tc values.

Future characterization work should focus on determining the depth and areal distribution of the uranium and ^{137}Cs plumes from the BX-102 tank leak. This tank leak can be considered to be an example of a plume from the original bismuth phosphate process and should be studied to understand the geochemistry and soil/waste interactions.

C Tank Farm. Significant ^{137}Cs contamination (and, to a lesser extent, ^{60}Co contamination) is present in the vadose zone at the C Tank Farm as shown in Figure 1-33. The majority of the contamination detected during the baseline characterization cannot be directly associated with either tank leaks or leaks from tank farm ancillary piping or equipment. The contamination, as measured with the spectral gamma-ray logging systems, appears to indicate that tanks presently designated sound, such as C-108 and C-109, may have leaked. Conversely, the data indicate there is not much contamination surrounding tanks that are designated leakers, such as C-110 and C-111. The absence of contamination in boreholes surrounding some of the leakers may indicate the lateral extent of migration of leakage from these tanks did not reach the region of the vadose zone penetrated by the monitoring boreholes.

Figure 4-33. Summary of C Tank Farm Gamma Logging Results.

The source(s) of the ^{137}Cs contamination below tanks C-104, C-105, and C-106, which are all designated sound tanks, is uncertain; however, a known source of contamination is a leak in the cascade line between tanks C-104 and C-105. Other possible sources include the extensive surface contamination that originated from spills at an adjacent waste loadout facility and the subsequent migration of contamination down along the domes of the tanks, or leakage from tank C-105 itself. Historical information regarding operations at these three tanks did not provide positive indication as to the source of this contamination.

The ^{137}Cs contamination in the vicinity of tanks C-104 and C-105 also shows a very high degree of spatial variability, but because there is a high density of boreholes in this area, the contamination is correlatable. This region would be a good area to study and quantify the spatial variability of ^{137}Cs in the vadose zone and to understand the ^{137}Cs geochemistry.

Extensive ^{137}Cs and ^{60}Co contamination was detected beneath tanks C-108 and C-109, both of which are presently designated sound tanks. This contamination may have resulted from leakage from either or both of these tanks, from leakage from the cascade line between the tanks, or from leakage from a source above the tank(s) that migrated over the dome and downward along the tank sides and spread laterally at the base of the tank farm excavation backfill. Some of the deeper ^{60}Co beneath tank C-108 may have originated from leakage from a nearby tank such as tank C-105. Regardless, positive determination of the source of this contamination could not be determined, and additional investigation into the source of this contamination is required.

Tanks C-201, C-202, C-203, and C-204, which are estimated to have leaked a total of about 6,624 L (1,750 gal) of waste, do not have monitoring boreholes; therefore, the vadose zone surrounding these tanks could not be characterized during this initial investigation. However, the contribution of these tanks to the vadose zone contamination at the C Tank Farm is estimated to be small.

Evaluation of groundwater data collected from monitoring wells surrounding the C Tank Farm indicates the leakage from tanks has not reached groundwater. Because a majority of the tank monitoring boreholes are only 30 to 37 m (100 to 120 ft) deep and groundwater is at a depth of about 76 m (250 ft), the lower portion of the vadose zone is uncharacterized and the potential for C Tank Farm waste to impact groundwater beneath the tank farm is unknown.

B Tank Farm. The boreholes in the B Tank Farm are currently being logged, and data are not yet available for this tank farm.

T Tank Farm. Logging operations at the T Tank Farm are almost complete, and tank summary data reports are being prepared.

A Tank Farm. Logging operations at the A Tank Farm are complete, and tank summary data reports are currently being prepared.

Summary and Conclusions

Characterization of the vadose zone is being accomplished by measuring the gamma-ray-emitting radionuclide concentrations in the sediment around the tanks, creating a database of the contamination, interpreting the data, and creating visualizations of the contamination.

The limitations in visualizations produced by the project have been identified. These limitations are present because only a limited geostatistical structural analysis is possible at this time and because of an inherent problem of contamination dragdown during the drilling of the monitoring boreholes. Spectrum shape-factor analysis methods were developed to interpret some of the borehole contamination conditions.

The SX Tank Farm was the first tank farm completed, and it has the largest volume of leakage of any other tank farm. In addition, this tank farm showed the largest and the deepest distribution of ^{137}Cs of any of the tanks farms completed to date. The total depth extent of contamination for this tank farm is not known, but it is evident that tank waste has impacted groundwater.

In all of the tank farms, the gamma-emitting radionuclide present in the vadose zone with the largest distribution and in the greatest quantity by far is ^{137}Cs. The ^{137}Cs plumes show a high degree of spatial variability, and it is often difficult to correlate the ^{137}Cs concentration data between boreholes. The discontinuity in the plumes often makes it difficult to sort out the contamination sources and properly define the extent of contamination.

Cobalt-60 was the next most abundant gamma-emitting radionuclide. It has a lower spatial variability than ^{137}Cs and therefore shows a much better borehole-borehole correlation. Plumes of ^{60}Co have migrated farther than ^{137}Cs and show much more uniform distributions.

At some tank farms such as at the SX or the BX Tank Farms, contamination was detected much deeper and more spatially extensive than expected. Several tank farms showed evidence of groundwater contamination, either direct evidence such as on the south side of the TY Tank Farm and from the BX-102 tank leak, or circumstantial evidence such as groundwater contamination at the SX Tank Farm or U Tank Farm.

Questions remain about the total depth of contaminants in the vadose zone at the AX, BX, BY, SX, TY, and U Tank Farms because significant contamination was identified as continuous plumes at the bottoms of some of the boreholes, indicating that the total depth of contamination has not been reached by the boreholes.

The most significant contamination plumes identified are associated with a leak from tank BX-102. High concentrations of ^{137}Cs (several thousand picocuries per gram) were identified from the base of the tank all the way down to the groundwater, although it is highly uncertain how much contamination dragdown has occurred and whether the contamination is actually in the formation. This tank leak resulted in multiple radionuclide plumes. Uranium from this tank appears to have migrated from the leak source down and into the groundwater at a nearby groundwater well, although knowledge of the total depth of the uranium in the vadose zone is limited to the total depth of the boreholes (46 m [150 ft[).

The work demonstrates a need for geochemical studies that can explain some of the observations of contamination deep in the vadose zone. Considering the depth and extent of some of the relatively immobile contaminants that were measured under this program, a great concern has been raised as to the distribution of the more mobile radionuclides such as ^{99}Tc, tritium, and ^{129}I that cannot be measured with gamma-ray detection systems. This concern will be addressed in a more comprehensive vadose zone characterization program.

4.2.2.3 Numerical Modeling. Numerical modeling has been used to assess contaminant migration rates in the vadose zone at the Hanford Site. Although all numerical simulation methods have limitations, numerical codes such as VAM3D (Huyakorn and Panday 1994), PORFLOW, and STOMP (White and Oostrom 1996, 1997; Nichols et al. 1997) have been helpful in identifying key and controlling physical processes affecting transport of contaminants under waste disposal sites at the Hanford Site. For example, a three-dimensional model was used to evaluate leak migration rates as a function of variable recharge, fluid densities (i.e., salt brines), moisture changes and moisture-dependent anisotropy, multiple sloping layers with variable hydraulic properties, funnel flow, variable chemical distribution coefficients, and movement of contaminants down boreholes (Ward et al. 1997a). Other tank leak simulations are documented in Smoot and Sagar (1990), Smoot et al. (1989), and Jacobs (1998).

Other models have been used for water balance calculations to support surface barrier design and to assess the impacts of gravel surfaces on recharge rates (Fayer and Jones 1990; Smoot et al. 1990; Fayer et al. 1992). In addition, numerical codes have been used in the analysis of cumulative dose effects from radionuclide migration of low-level wastes via groundwater pathways (Kincaid et al. 1998), of tank waste remediation strategies for solid waste burial grounds (Wood et al. 1996), in the performance assessment of ILAW (Mann et al. 1998), and evaluations of tank waste retrieval and closure strategies (Jacobs 1998). Current efforts are under way to develop a reactive-transport model that can address impacts of extreme chemistry (from tank leaks) on the hydraulic properties (e.g., calculate the effects of chemical precipitation on hydraulic conductivity of Hanford Site sediments). The reactive-transport modeling effort is designed to address coupled processes of chemical, heat, and water flow in both liquid and vapor phases (Yabusaki and White 1998).

The past approach has been to use numerical models in an ad hoc way, on a site-specific basis, to evaluate problems and suggest solutions. With the current focus on vadose zone contamination, a more systematic modeling approach is needed that integrates the vadose zone data-gathering effort with consistent interpretations as conceptual models are developed and tested. Additionally, improved models are needed that incorporate and depict primary controlling physical and chemical processes in a realistic manner or so that their complex and interactive effects can be appropriately considered. It is important that consensus agreement be reached on the numerical models applied to understand and predict vadose zone transport events. Numerical models are key analytical tools needed to develop a complete picture of vadose zone hydrology and contaminant transport at the Hanford Site and that their utility and reliability will improve as understanding of the processes controlling migration of contaminants in the Hanford Site vadose zone is enhanced.

Field experiments will be performed at the Hanford Site under controlled conditions, at well-characterized, clean sites, to test conceptual and numerical models of flow and transport in heterogeneous systems. The emphasis will be on evaluating fluid phase transport by gaseous phase transport will also be considered. Key geohydrologic, chemical, and biologic processes that control plume migration in the vadose zone will be evaluated. Research will include investigations of the impact of lithological features, such as sediment layering, clastic dikes, and fractures on the flow regime. Field tests, with controlled source terms and boundary conditions, will be conducted to improve model testing and rigor and provide enhanced understanding of the processes that affect distribution, transport, and attenuation of contaminants in the Hanford Site vadose zone.

4.3 GROUNDWATER

4.3.1 Scope

The Groundwater technical element provides the information, capabilities, and understanding necessary to perform technically sound assessments of the impacts of Hanford Site operations on the groundwater resource. The Groundwater technical element encompasses the characterization and modeling of the saturated zone environment and contaminants present in the saturated zone.

The saturated zone includes the capillary fringe, the unconfined aquifer, aquitards, and confined aquifers. Major elements of the technical element include the following:

1. Evaluation of the distribution of contamination within the saturated sediments.

2. Assessment of the controls of the saturated zone hydrology, geology, geochemistry, and microbiology on the flow and transport of contamination.

3. Development and use of predictive models to credibly depict the flow and transport of contamination through the saturated zone.

The Groundwater technical element consists of a combination of data management, field measurement, and modeling capabilities. The technical element provides information and data that are used in performing risk assessments. Hanford Site groundwater is accessible to the environment at the Columbia River and in water-supply wells and is a pathway for contaminant transport to the Columbia River.

The technical element must provide an accurate understanding of current conditions and the ability to assess potential future conditions, near- and long-term. In addition, the evaluation must allow for the differentiation between contaminant contributions from the Hanford Site and other sources, natural background, and/or anthropogenic.

4.3.2 Current State of Knowledge

The conceptual model of the Hanford Site unconfined aquifer system was developed from information on the hydrogeologic structure of the aquifer, spatial distributions of hydraulic and transport properties, aquifer boundary conditions, recharge and discharge, and distribution and movement of contaminants. Most information on the groundwater flow system comes from wells. Geologic information is obtained from descriptions of drill cuttings or core samples, and from geophysical logging of wells. Groundwater flow direction and gradient are inferred from water levels measured in wells. Groundwater chemistry and contaminant distributions are determined from water samples taken from wells. The greatest amount of information is available for the shallower portions (less than 10 m below the water table) of the unconfined aquifer system. Fewer wells penetrate the deeper part of the unconfined aquifer system or the basalt confined aquifers. However, the shallower unconfined aquifer is the most likely to be impacted by contaminants migrating through the vadose zone.

4.3.3 Hydrogeologic Units

The lithofacies described by Lindsey (1995) have been regrouped into nine hydrogeologic units based on similarity in expected groundwater flow properties. Flow properties generally correlate to texture, sorting, and degree of cementation. Other geologic factors such as depositional environment, lithologic composition, and time of deposition were not considered in defining hydrogeologic units for the model. Therefore, the grouping of lithofacies was similar but not identical to that of Lindsey (1995). Hydrogeologic units defined for the conceptual model were designated by numbers. A graphical comparison of the groundwater conceptual model units with

Lindsey's stratigraphic column is shown in Figure 4-34. Odd-numbered units are predominantly coarse-grained sediments. Even-numbered units are predominantly fine-grained sediments with low permeability.

The Hanford formation, combined with the pre-Missoula gravel deposits, was designated as model Unit 1. Units 2 and 3 correspond to the early Palouse soil and the Plio-Pleistocene unit, respectively. The predominantly mud facies of Lindsey's upper Ringold was designated as Unit 4. However, a difference in the model units is that the lower, predominantly sand portion of Lindsey's upper Ringold was grouped with Unit 5, which also includes Lindsey's Ringold gravel Units E and C. Part of Lindsey's lower mud unit was designated as Unit 6. However, sandy portions of Lindsey's lower mud unit were assigned to Unit 7, which also includes Lindsey's gravel Units B and D. Portions of the lower mud that occur below Unit 7 were designated as Unit 8. Gravels of Lindsey's Unit A were designated as Unit 9.

Figure 4-35 shows the distribution of wells used to define hydrogeologic structure for the groundwater conceptual model. Figures 4-36, 4-37, and 4-38 show cross-sections of the Hanford Site delineating the conceptual model hydrogeologic units and the 1997 water table. Cross-section locations are shown in Figure 4-35. The water table lies within the Hanford formation over most of the eastern and northern parts of the Hanford Site. The Hanford formation lies entirely above the water table in the western part of the Hanford Site and in some other localized areas. Figure 4-39 is a map showing which hydrogeologic unit contains the 1997 water table over the Hanford Site.

4.3.3.1 Hydraulic and Transport Properties. To predict groundwater flow, the distribution of hydraulic properties, including both horizontal and vertical hydraulic conductivity, storativity, and specific yield, were needed for each hydrogeologic unit defined in the model. In addition, to simulate movement of contaminant plumes, transport properties including contaminant-specific K_ds, bulk density, effective porosity, and longitudinal and transverse dispersivities are needed. Hydraulic and transport properties are documented in DOE (1988a), Graham et al. (1981), Thorne and Newcomer (1992), Connelly et al. (1992a, 1992b), Thorne et al. (1993, 1994), Wurstner (1995), Cole et al. (1997), and other project-specific reports.

Transmissivity (the product of hydraulic conductivity and aquifer thickness) and storage information for the unconfined aquifer system has been obtained primarily from aquifer pumping tests and slug tests conduced at wells. Hydraulic conductivity has also been determined from laboratory tests of sediment samples. Values determined from aquifer pumping tests and slug-interference tests (Spane 1993; Spane and Thorne 1995) are considered to be more reliable than single-well slug tests or laboratory measurements. Transmissivity values from these types of tests were applied to an inverse flow model to develop a transmissivity distribution for the Hanford Site (Jacobson and Freshley 1990; Wurstner et al. 1995, Cole et al. 1997). Hydraulic conditions for 1979 were used in the inverse calibration because measured hydraulic heads were relatively stable at that time. Details concerning the updated calibration of the two-dimensional model are provided in Cole et al. (1997). Figure 4-40 shows the distribution of transmissivity data from aquifer pumping tests and slug-interference tests. Figure 4-41 shows the distribution of transmissivity determined from inverse flow modeling. Aquifer transmissivity is relatively high in the area between Gable Mountain and Gable Butte, and in the central part of the Hanford

Figure 4-34. Comparison of Hanford Conceptual Model Hydrostratigraphic Units with Stratigraphy.

Figure 4-35. Distribution of Wells Used to Define Hydrogeologic Structure and Cross-Section Locations.

Figure 4-36. East-West Cross-Section (A-A) of Hydrogeologic Units of the Hanford Site.

Figure 4-37. North-South Cross-Section (B-B) of Hydrogeologic Units Along the Eastern Portion of the Hanford Site.

Figure 4-38. North-South Cross-Section (C-C) of Hydrogeologic Units Through the Central Portion of the Hanford Site.

Figure 4-39. Hydrogeologic Units Intersected by Water Table (1997).

Figure 4-40. Areal Distribution of Transmissivity Data.

Figure 4-41. Transmissivity Distribution from Model Calibration.

Site. Coarse-grained Hanford formation sediments with relatively high hydraulic conductivity are present below the water table in these areas, and the aquifer is relatively thick in the central part of the site.

Figure 4-42 shows the range of hydraulic conductivity values calculated by dividing the measured transmissivity by the aquifer thickness. The areal distribution of hydraulic conductivity for the uppermost saturated unit across the Hanford Site is shown in Figure 4-43.

Hydraulic conductivity of the Hanford formation is generally an order of magnitude greater than the hydraulic conductivity of the Ringold Formation. However, measured hydraulic conductivity of both of these units varies laterally by more than two orders of magnitude. This is a result of aquifer heterogeneity. The aquifer also displays vertical anisotropy. Results of a few multiple-well aquifer tests suggest that the ratio of vertical to horizontal hydraulic conductivity is in the range of 0.01 to 0.1. Because Hanford formation sediments are so much more permeable than Ringold sediments, the Hanford formation tends to dominate groundwater flow where the water table is in the Hanford formation.

Less reliable data are available on aquifer storage properties because they are difficult to measure accurately. Only multiple-well aquifer tests provide valid estimates, and these are affected by nonideal aquifer conditions and well configuration (Spane 1993). Measured aquifer storage properties are documented in Wurstner et al. (1995). Specific yield was estimated to range from 0.1 to 0.3 for the Hanford formation and from 0.05 to 0.2 for Ringold Formation gravel units. Storativity was estimated to range from 0.0001 to 0.0005 for the Hanford formation and from 0.0001 to 0.001 for Ringold Formation gravels.

Wurstner et al. (1995) and Cole et al. (1997) provide information on transport properties used in past modeling studies at the Hanford Site. Transport parameters, including effective porosity and longitudinal and transverse dispersivities, are also needed for transport simulations. Effective porosity was set equal to specific yield for the unconfined aquifer (e.g., 0.1 for the Ringold Formation and 0.25 for the Hanford formation). Dispersivity is theoretically expected to have an asymptotic value that can be related to the scale of uncharacterized aquifer heterogeneity (Farmer 1986). In contaminant transport simulations, large values of dispersivity result in lower peak concentration estimates, but give rise to earlier first arrival times that can increase arrival concentrations of radionuclides with short half-lives. For the Composite Analysis (Kincaid et al. 1998), a longitudinal dispersivity of 95 m and a transverse dispersivity of 20 m were selected. Dispersivity and the basis for this selection is discussed in detail in Kincaid et al. (1998). Distribution coefficients for various contaminants in the Hanford Site unconfined aquifer system have been determined from laboratory tests and from the literature. These quantities are affected by water chemistry, grain size, and mineralogy. The selection of K_ds and bulk densities for application in model is discussed in detail in Cole et al. (1997) and Kincaid et al. (1998).

Aquifer Boundaries. Peripheral boundaries for the Hanford Site unconfined aquifer system are formed by the Columbia River on the north and east and by basalt ridges and the Yakima River on the south and west. At the Cold Creek and Dry Creek Valleys, the unconfined aquifer extends westward beyond the boundary of the Hanford Site. The Columbia River

Figure 4-42. Range of Hydraulic Conductivities.

Figure 4-43. Hydraulic Conductivity Distribution in the Uppermost Hydrogeologic Units of the 3-Dimensional Model.

represents a point of regional discharge for the unconfined aquifer. The amount of groundwater discharging to the river is a function of local hydraulic gradient between groundwater elevation alongside and beneath the river. This hydraulic gradient is highly variable because the river stage is affected by seasonal variations in precipitation and runoff in other regions of the river drainage system. The river stage is also impacted by weekly and daily changes in river flows caused by dam operations. Because the stage elevation of the Yakima River is higher than the water table in the adjacent aquifer, it represents a potential source of recharge in the southern part of the Hanford Site.

The basalt underlying the unconfined aquifer sediments represents a lower boundary to the unconfined aquifer system. The potential for interflow (recharge and discharge) between the basalt confined aquifer system and the unconfined aquifer system is largely unquantified, but is postulated to be small relative to the other flow components estimated for the unconfined aquifer system.

4.3.3.2 Aquifer Recharge and Groundwater Flow Dynamics. Groundwater in the unconfined aquifer generally moves from recharge areas along the western boundary of the site eastward and northward toward the Columbia River, which is a discharge location for the aquifer. However, this flow pattern has been altered locally by the formation of groundwater mounds resulting from wastewater discharge. The direction of groundwater flow is inferred from measurements of hydraulic head in wells. A sitewide network of wells is measured annually for this purpose, and some wells are measured more frequently to track water level fluctuations or to monitor groundwater flow around critical facilities. The water table elevation is mapped and reported in the annual *Hanford Site Groundwater Report* (e.g., Hartman and Dresel 1998). Figure 4-44 shows a contour map of water table elevations for the unconfined aquifer for 1997. Figure 4-45 shows water table elevations for the upper basalt confined aquifer for 1997.

Natural recharge occurs from infiltration of runoff from elevated regions west of the Hanford Site and infiltration of precipitation falling across the Hanford Site. Other potential sources of natural recharge are the Yakima River and the basalt confined aquifer system. Recharge from the western boundary of the Hanford Site enters primarily from the Cold Creek and Dry Creek drainages. These are ephemeral streams on the Hanford Site. Estimates of combined recharge from the Cold Creek and Dry Creek Valleys have ranged from 0.10 to 0.34 m^3/sec (Law et al. 1986).

Recharge from precipitation across the Hanford Site is highly variable both spatially and temporally, ranging from near zero to more than 100 mm/yr depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). A natural recharge map (Figure 4-46) was developed by Fayer and Walters (1995) based on distributions of soil and vegetation types. The average recharge from precipitation across the Hanford Site (901 km [560 mi]) was estimated as 0.27 m^3/sec (0.59 mm/yr).

The total volume of recharge from the Yakima River is not well known. However, low-permeability sediments adjacent to the Yakima River appear to limit leakage into the aquifer. Comparison of Yakima River stage and water levels in an adjacent well showed little correlation (Wurstner et al. 1995).

Figure 4-44. Water Table Map (June 1997) of the Hanford Site and Outlying Areas.

Figure 4-45. Potentiometric Map of Upper Basalt Confined Aquifer System (June 1997).

Figure 4-46. Estimated Recharge from Precipitation and Irrigation.

Another potential source of recharge (or discharge) for the unconfined aquifer system is interaquifer communication with the upper basalt confined aquifers. The volume and distribution of water movement between the aquifer systems has not been quantified. Over most of the site, the amount of interflow is thought to be small because of the low hydraulic conductivity of the basalt separating the two aquifer systems. However, areas of increased vertical communication have been previously identified in the Gable Mountain and Gable Butte area on the basis of chemistry data (Graham et al. 1984; Jensen 1987). The increased communication in the area results from erosional channels that penetrate in the upper basalt confining layer. Hydraulic head data for the uppermost confined basalt aquifer also indicate the potential for water to discharge from this aquifer upward into the unconfined system in the northeastern part of the Hanford Site (Spane and Webber 1995).

Since the start of Hanford Site operations in the mid-1940s, artificial recharge from wastewater disposal facilities has been greater than the estimated recharge from natural sources. Sources and volumes of artificial recharge are summarized in Wurstner et al. (1995). Figure 4-47 graphically shows volumes of wastewater discharged in different areas of the Hanford Site since 1945. The disposal of large volumes of wastewater to the ground has caused an increase in the water table elevation over most of the Hanford Site and the formation of groundwater mounds beneath major wastewater disposal facilities. However, during the past 5 years, all production activities on the Hanford Site have been curtailed, resulting in a decrease in wastewater disposal and decreases in water table elevation over much of the Hanford Site. Figure 4-48 shows the change in water table elevations between 1944 and 1979, when the water table was near its peak level. Figure 4-49 shows the change in table elevations between 1979 and 1995.

4.3.3.3 Groundwater Contaminant Distributions. Groundwater conditions and recent activities are summarized annually in the *Hanford Site Groundwater Monitoring Report* (Hartman and Dresel 1998). Information about groundwater contamination is also included in the annual *Hanford Site Environmental Report* (Dirkes and Hanf 1997). This report integrates the results of monitoring, remediation, and groundwater investigations by all Hanford Site contractors.

Groundwater quality is monitored in more than 700 wells annually. Unconfined aquifer and basalt confined aquifer monitoring wells sampled in 1997 are shown in Figures 4-50 and 4-51, respectively. The most widespread contaminant plumes are tritium, nitrate, and ^{129}I. Smaller plumes of chromium, fluoride, organic contaminants (carbon tetrachloride, chloroform, trichloroethylene, and cis-1,2-dichloroethylene), ^{14}C, ^{90}Sr, ^{99}Tc, ^{137}Cs, uranium, and plutonium also are present at levels above drinking water standards. The distribution of radionuclide contamination is shown in Figure 4-52, and the distribution of chemical contaminants in Figure 4-53. The tritium plumes are shown in Figure 4-54 between 1964 and 1988. This plume provides insight into characteristics of the groundwater flow.

The vertical distribution of contaminants in the unconfined aquifer has been studied in a limited number of wells, and contaminant concentrations generally are highest near the water table and decrease with depth. The vertical extent of contamination is least well characterized in the source areas where groundwater mounding and possible density-driven flow may have moved

Figure 4-47. Annual Summary of Volume of Water and Wastewater Discharged to Ground at Hanford Site and City of Richland.

Figure 4-48. Rise of Water Table Elevations from 1944-1979.

Figure 4-49. Decline of Water Table Elevations from 1979-1995.

Figure 4-50. Location of Unconfined Aquifer Wells Sampled in FY 1997.

Figure 4-51. Location of Confined Aquifer Wells Sampled in FY 1997.

Figure 4-52. Distribution of Major Radionuclides in the Unconfined Aquifer.

Figure 4-53. Distribution of Major Hazardous Chemicals in the Unconfined Aquifer.

Figure 4-54. Tritium Plumes: 1964 Through 1988.

contaminants deeper in the aquifer. In certain locations, open boreholes may have provided a conduit for downward contaminant migration. Wells completed in the basalt confined aquifer are also sampled, although the number of these wells is limited. Tritium, cyanide, ^{60}Co, and nitrate have been detected in some of the confined aquifer wells.

The mobility of contaminants in the aquifer is currently estimated from sorption K_ds. K_ds have been estimated by laboratory testing for most of the contaminants found in the groundwater at the Hanford Site (Kincaid et al. 1998). The chemical form, or species, of contaminants also affects mobility. For example, chromate (Cr+6) is much more mobile and more hazardous than Cr+3. Studies in the 100 Areas have shown that most of the chromium in groundwater and discharging to the river is Cr+6. Oxidizing conditions appear to be present in the upper part of the unconfined aquifer, but conditions may be somewhat more reducing deeper in the aquifer. The natural groundwater composition is predominantly calcium bicarbonate-sulfate with slightly alkaline pH and low amounts of dissolved organic matter. The dominant complexing agents for contaminants are carbonate and sulfate, although study of the influence of natural organic and co-disposed manmade organic ligands merits further study. Contaminant transport may also be influenced by colloidal transport of sorbed constituents. The most recent compilation of K_ds for application on Hanford Site problems was done as part of the composite analysis (Kincaid et al. 1998).

100 Areas Hydrology

The hydrology of the 100 Areas is unique because of their location adjacent to the Columbia River. The water table ranges in depth from near 0 m at the river edge to 30 m. The groundwater flow direction is generally toward the Columbia River. However, during high river stage, the flow direction may reverse immediately adjacent to the river. The unconfined aquifer in the 100 Areas is composed of either the Ringold Unit E gravels or a combination of the Unit E gravels and the Hanford formation. As shown in Figure 4-39, there are two large areas where the water table is within the Ringold Formation (Lindsey 1992) and the Hanford formation is unsaturated. In the 100-H and 100-F Areas, the Ringold Unit E gravels are missing and the Hanford formation lies directly over the fine-grained Ringold lower mud unit. In most of the 100 Areas, the lower Ringold mud forms an aquitard and the Ringold gravels below the mud are locally confined. Additional information on the hydrology of the 100 Areas is available in Hartman and Peterson (1992) and Peterson et al. (1996).

200 Areas Hydrology

In the 200 West Area, the water table occurs almost entirely in the Ringold Unit E gravels, while in the 200 East Area, it occurs primarily in the Hanford formation and in the Ringold Unit A gravels. Along the southern edge of the 200 East Area, the water table is in the Ringold Unit E gravels. The upper Ringold facies were eroded in most of the 200 East Area by the Missoula floods, which subsequently deposited Hanford Site gravels and sands on what was left of the Ringold Formation. Because the Hanford formation sand and gravel deposits are much more permeable than the Ringold gravels, the water table is relatively flat in the 200 East Area, but groundwater flow velocities are higher. On the north side of the 200 East Area, there is evidence

of erosional channels that may allow communication between the unconfined and uppermost basalt confined aquifer (Graham et al. 1984; Jensen 1987).

The hydrology of the 200 Areas has been strongly influenced by the discharge of large quantities of wastewater to the ground over a 50-year period. Those discharges have caused elevated water levels across much of the Hanford Site, resulting in a large groundwater mound beneath the former U Pond in the 200 West Area and a smaller mound beneath the former B Pond, east of the 200 East Area. Water table changes beneath 200 West Area have been greatest because of the lower transmissivity of the aquifer in this area. Discharges of water to the ground have been greatly reduced, and corresponding decreases in the elevation of the water table have been measured. Water levels in 200 West Area have also been affected by pump-and-treat operations associated with 200-ZP-1 remedial actions. Figure 4-55 shows cones of depression and a water table mound associated with this activity. The decline in part of the 200 West Area has been more than 7 m (Hartman and Dresel 1998). Water levels are expected to continue to decrease as the unconfined groundwater system reaches equilibrium with the new level of artificial recharge (Wurstner and Freshley 1994).

300 Area Hydrology

The unconfined aquifer water table in the 300 Area is generally found in the Ringold Formation at a depth of 9 to 19 m below ground surface. Fluctuations in the river level strongly affect the groundwater levels and flow in the 300 Area, just as they do in the 100 Areas. Groundwater flows from the northwest, west, and even the southwest to discharge into the Columbia River near the 300 Area. Schalla et al. (1988) and Swanson (1992) have provided more detailed information on the hydrogeology of the 300 Area.

1100 Area and North Richland Hydrology

The groundwater in the southeastern portion of the Hanford Site is less impacted by Hanford Site operations than by offsite activities. In addition to natural recharge, artificial recharge is associated with the North Richland recharge basins (used to store Columbia River water for Richland water use) south of the 1100 Area, and irrigated farming near the Richland North Area and west and southwest of the 1100 Area. Although pumping to obtain water also occurs from the unconfined aquifer in these areas, there is a mound in the water table beneath the Richland city system of recharge basins. The Richland city recharge basins are used primarily as a backup system between January and March each year when the filtration plant is closed for maintenance, and during the summer months to augment the city's river water supply. The water level also rose from December 1990 and December 1991 in the area of the Lamb Weston Potato Processing Plant, which uses large amounts of water and, except for plant maintenance during July, operates year-round. The water table in the 1100 Area also seems to reflect irrigation cycles connected with agriculture (Liikala et al. 1994).

4.3.3.4 The geologic history and hydrogeologic setting of the Hanford Site is described in the annual *Hanford Site Groundwater Report* (Hartman and Dresel 1998). Summaries of site-wide hydrogeologic conditions are also available in Newcomb et al. (1972), Law et al. (1996), and Wurstner et al. (1995). Studies focused on the unconfined aquifer system in the vicinity of the

Figure 4-55. Influence of 200-ZP-1 Remedial Action Pump and Treat Upon Water Table Elevations.

200 Areas are provided in Graham et al. (1981), Lindsey et al. (1991, 1992), and Connelly et al. (1992a, 1992b). Confined aquifers within the Columbia River Basalts were extensively studied from 1977 to 1987 as part of the Basalt Waste Isolation Project. Detailed descriptions of these studies are available in DOE (1988a).

Modeling. A three-dimensional groundwater flow and transport model has been developed over the past 10 years for the Hanford Groundwater Project. This model uses the Coupled, Fluid, Energy, and Solute Transport (CFEST) code (Gupta et al. 1997). Initial development of the model is described in Wurstner et al. (1995). The model was recently used to simulate future site-wide transport of selected contaminant plumes in the unconfined aquifer system (Cole et al. 1997) and to support the Composite Analysis (Kincaid et al. 1998) with simulation of transport from all radionuclide sources on the Hanford Site. A recent multi-year modeling effort conducted to support development of the *Hanford Sitewide Groundwater Remediation Strategy* (DOE-RL 1995c) was completed during fiscal year (FY) 1996 and was described in Chiaramonte et al. (1996).

Other models have been used recently to simulate groundwater flow conditions for specific projects at a local scale. A model was applied to assess the interaction between the unconfined aquifer and the Columbia River in the vicinity of the 100-N Area. The objective of this model was to better understand the release of ^{90}Sr from the aquifer into the Columbia River. Other models were used in the design and evaluation of pump-and-treat activities aimed at remediation of contaminated groundwater in the 200 West Area. These models were used to delineate capture and injection zones for the extraction and injection wells, respectively, and to estimate the area affected by the pump-and-treat operations at different times.

4.4 COLUMBIA RIVER

Technical scope associated with the Columbia River ecosystem extends from reference locations upstream of the Hanford Site to downstream locations appropriate for specific aspects of the system assessment. Environments of interest include the riparian zone, near-river groundwater, the hyporheic zone, and the Columbia River water column. Within each, a wide variety of information is needed to define physical, chemical, and biological characteristics.

The scope of this technical element starts with the zone in which groundwater from the Hanford Site meets the Columbia River. Key topics in this zone include mixing, geochemical conditions, preferential pathways, and biological activity. Credible conceptual and numerical models for processes occurring in this zone are crucial to (1) identify impacts to the river's ecosystem, and (2) quantify risks to aquatic and human receptors. This zone encompasses near-river groundwater and infiltrated river water (bank storage), and the hyporheos (sediment pore water and biota immediately beneath the free-flowing stream).

Once in the Columbia River, Hanford Site groundwater and any entrained contamination co-mingle with river water and disperse to a wide array of potential receptors. The scope of this technical element relates to information needs associated with the fate and transport of contamination within this river environment. These include the contaminant characteristics (type, nature, concentration, decay/attenuation qualities), physical movement in the dynamic

flow of the river, and bioavailability. Interaction with the suspended load of the river, and with biological systems, is key to anticipating the fate of contaminants. Erosion and deposition patterns for the river are major topics for understanding where potential contaminant sinks are located, and where sensitive species and humans are at greatest potential threat of exposure. Understanding how the channel morphology and its distribution of sediments evolve (with time) is key to anticipating future conditions.

The Columbia River technical element scope includes the capability to provide information necessary to accurately and credibly assess of risk posed by Hanford Site contaminants to aquatic, terrestrial, and human receptors in the river environment. Key information needs include identifying (1) locations where contaminants enter a pathway to receptors; (2) various habitats in the river environment; (3) contaminant-sensitive receptors; and (4) exposure pathways to habitats and receptors.

An understanding of contaminant bioavailability is crucial for assessing potential impacts and risk, and contaminant-transfer coefficients and bioaccumulation rates are needed for contaminant/species combinations of interest. The capability to differentiate Hanford-derived contamination from other sources is a part of this effort, as is analysis of the potential cultural consequences that may result from impacts to the natural resources of the river environment. The assessment of risk considers near-term conditions, as well as conditions extending far into the future.

4.4.1 Current State of Knowledge

To understand the current status of the Columbia River environment and the impacts of Hanford Site operations on this environment, one must have a general understanding of the environmental setting and historical environmental assessment activities conducted at the Hanford Site during the past 54 years. Brief discussions are provided below to provide this information. In addition, the current environmental conditions of the Columbia River are summarized.

4.4.1.1 Environmental Setting. The Columbia River is the primary surface-water feature associated with the Hanford Site. Other surface water bodies bordering or onsite include springs, streams, West Lake, and a number of artificial ponds and ditches. Onsite sources of recharge to these surface water bodies include precipitation, overland flow, groundwater, and direct discharge of water from Hanford Site facilities (Neitzel 1997; Dirkes and Hanf 1996; Cushing 1995; Becker 1990).

Columbia River

The Columbia River is the second largest river (measuring total flow) in the continental United States and is the dominant surface water body on the Hanford Site. Originating in the mountains of eastern British Columbia, Canada, the Columbia River flows south through a gap in the Saddle Mountains, then turns east near Priest Rapids Dam and flows into the northern portion of the Hanford Site. The Hanford Reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula (created by McNary Dam), near the City of Richland, and is currently under consideration for designation as a National Wild and Scenic River. No tributaries enter the

Columbia in the Hanford Reach. The bank along the eastern shore of the Hanford Reach in places rises over 150 m above the surface of the Columbia River, forming the White Bluffs. In total, the water level of the Columbia River drops about 20 m along its path through the Hanford Site.

The flow of water in the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Hanford Site. Priest Rapids Dam is the nearest dam upstream of the Hanford Site, and McNary Dam is the nearest downstream. Flows through the Hanford Reach fluctuate significantly and are controlled primarily by operations at Priest Rapids Dam. Annual flows below Priest Rapids Dam over the last 77 years have averaged nearly 3,360 m^3/sec (Wiggins et al. 1995). Daily average flows ranged from 1,152 to 7,787 m^3/sec. Monthly mean flows typically peak from April through June during spring runoff from melting snow in the upriver watershed. River flow is lowest from September through October.

As a result of fluctuations in discharges, the depth of the Columbia River varies significantly over time. River stage may change along the Hanford Reach by up to 3 m within a few hours (Dresel et al. 1995). Seasonal changes of about the same magnitude are also observed. River-stage fluctuations measured at the 300 Area are only about half the magnitude of those measured near the 100 Areas because of the effect of the pool behind McNary Dam (Campbell et al. 1993). The width of the Columbia River varies from approximately 300 m to 1,000 m within the Hanford Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of large-scale flooding recurring in the Hanford Reach has been reduced by the presence of dams upstream of the Hanford Site.

Three tributaries join the Columbia River between the Hanford Site and McNary Dam: the Yakima River at river mile 335, the Snake River at river mile 324, and the Walla Walla River at river mile 315. The mean annual discharge of the Yakima River a few miles upstream of the confluence with the Columbia River at Kiona, Washington, was approximately 70 m^3/sec from 1990 to 1994 (Wiggins et al. 1995). The Snake River mean annual discharge as measured at Ice Harbor Dam, just upstream of the confluence with the Columbia River, is approximately 1,600 m^3/sec. The mean annual discharge of the Walla Walla River, measured before entering the Columbia River, is approximately 15 m^3/sec.

Since McNary Dam was completed in 1953, a significant part of the Columbia River's sediment load has been trapped behind the dam (Robertson et al. 1973). However, as is true of the other Columbia River dams, some of the trapped sediment is resuspended and transported downstream by seasonal high discharges. As expected, much of this material is redeposited behind dams located further downstream. The primary contributor of suspended sediment to the Columbia River is the Snake River (Whetten et al. 1969), but the Yakima and Walla Walla Rivers are also significant sources. Sediment contributions from these sources are highly seasonal. Sedimentation rates at certain sites behind McNary Dam have been assumed to be as high as 30 cm/yr (Robertson et al. 1973). Subsequent studies by Beasley et al. (1986) reported sedimentation rates above McNary Dam to average 7 ($\pm$3) cm/yr along the Oregon shore, 4 ($\pm$2) cm/yr at midchannel, and 2 ($\pm$1) cm/yr near the Washington shore.

Sediment accumulates faster on the Oregon shore than the Washington shore because sediment input from the Snake and Walla Walla Rivers is constrained to the near shore (Oregon side). Based on visual observations from past sediment-monitoring samples taken for the Hanford Sitewide Surface Environmental Surveillance Project (SESP), the top 1 to 5 cm of the bed sediment at Priest Rapids Dam is dominated by coarse-to-fine sands and silts. By contrast, cobble, coarse, and fine sand bed sediment was found at sampling locations along the Hanford Site, and silt and clay sediment was observed at the McNary Dam sampling site (Blanton et al. 1995).

Water from the Columbia River, both upstream and downstream from the Hanford Site, is used extensively for crop irrigation. River water is a source of onsite drinking water and industrial cooling water for facilities, and is also used by communities downstream from the Hanford Site. In addition, the Hanford Reach is used for a variety of recreational activities, including hunting, fishing, boating, water-skiing, and swimming.

Columbia River Seeps

Seepage of groundwater into the Columbia River has been known to occur for many years. Riverbank springs, defined as groundwater discharge zones located above the water level of the Columbia River, were documented along the Hanford Reach long before Hanford Site operations began (Jenkins 1922). McCormack and Carlisle (1984) walked the 66-km stretch of the Hanford Reach shoreline of the Columbia River in 1983 and identified 115 springs. They reported that the predominant areas of groundwater discharge at that time were near the 100-N Area, the old Hanford Townsite, and the 300 Area. The predominance of springs in the 100-N Area is no longer valid because of declining water-table elevations in response to a decrease in liquid waste discharges to the ground (Dirkes and Hanf 1996). Select springs in the 100-B, 100-D, 100-H, 100-K, and 100-N Areas, the old Hanford Townsite, and the 300 Area have been sampled routinely since 1984.

The presence of springs along the shoreline depends on the height of the water level of the Columbia River. Dresel et al. (1994) reported that groundwater levels in the 100 and 300 Areas were heavily influenced by fluctuations in river stage from operations at Priest Rapids Dam. Water flows into the aquifer (that is, bank storage) as the river stage rises, and water flows from the aquifer as the river stage falls. Following an extended period of low river discharge, groundwater discharge zones located above the water level of the Columbia River may cease to exist once the level of the groundwater comes into equilibrium with the level of the river. Thus, springs are most readily identified immediately following a decline in river stage.

Bank storage of river water also affects the concentration of contaminants in the spring water. When river stage is high, river water flows into the aquifer and overlays or mixes with groundwater. Typically, this inland flow of river water is restricted to within several hundred feet of the shoreline (McMahon and Peterson 1992). Spring discharge that immediately follows a river stage decline generally consists of river water or a river water and groundwater mix. The percent contribution of groundwater to spring discharge increases over time. Because of the effect of bank storage on groundwater discharge and contaminant concentration, it is difficult to

estimate the volume of contaminated groundwater (and therefore flux of contaminant) that is discharged to the Columbia River within the Hanford Reach.

Ecology

The Columbia River and its Hanford Reach are the dominant aquatic ecosystem on the Hanford Site. The Columbia River is a complex ecosystem because of its size, number of alterations (e.g., dams), biotic diversity, and size and diversity of its drainage basin. The Hanford Reach comprises the last unimpounded portion of the Columbia River in the United States above Bonneville Dam. The Hanford Reach supports diverse plant, fish, and wildlife species that are locally abundant. The ecology of the aquatic and riparian systems within the study area has been studied extensively in the last 50 years, largely because of concerns about hydropower and reactor construction and operation.

Several habitats on the Hanford Site could be considered wetlands, but the largest and most important is the riparian zone bordering the Columbia River. Riparian areas include sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River flood plain. The extent of this zone in the Hanford Reach varies, but includes extensive stands of willows, grasses, various aquatic macrophytes, and other plants. Fitzner and Gray (1991) listed 39 species of mammals known to occur on the Hanford Site. Brandt et al. (1993) identified 24 as occurring within the riparian zone of the Columbia River. Weiss and Mitchell (1992) identified 103 bird species associated with the riparian community of the Hanford Reach. These include species that use the area only during winter (e.g., American widgeon, bald eagle), only during summer (e.g., cliff swallow, Forster's tern,), or year-round (e.g., barn owl, mallard). Principal herbivorous species include Canada geese and mallards. Amphibians and reptiles are also known to exist in the riparian zone of the Hanford Reach.

Aquatic vegetation is composed of three general groups: phytoplankton, periphyton, and macrophytes. Diatoms dominate the Columbia River algae. Periphyton develops on suitable substrate where light is sufficient for photosynthesis. Diatoms also predominate among this group. Macrophytes are sparse outside of McNary Pool and slackwater areas because they require relatively low flow and a sediment substrate in which to root. Zooplankton is generally sparse in the study area. Benthic invertebrates (invertebrate species associated with the substrate rather than the water column) include all major fresh-water benthic taxonomic groups (Brandt et al. 1993). The invertebrate fauna is dominated by insect larvae. A total of 44 species of fish are known to occur in the Hanford Reach (Cushing 1995; Gray and Dauble 1977). Chinook, coho, sockeye salmon, and steelhead trout use the Hanford Reach as a migration corridor to and from upstream spawning areas (Dauble and Watson 1990). The Hanford Reach supports the only major spawning habitat for the upriver bright race of fall chinook salmon within the main stem of the Columbia River. No plants or mammals on the federal list of threatened and endangered wildlife and plant species are known to occur on the Hanford Site. However, three bird species on the federal list have been recorded on the Hanford Site. Table 4-4 shows threatened and endangered species on federal and state lists that have been recorded on the Hanford Site and thereby occur within that portion of the study area.

Table 4-4. Threatened (T) and Endangered (E) Species Occurring or Possibly Occurring within the Hanford Site.

Common Name	Federal	State
Plants		
Columbia milkvetch		T
Columbia yellowcress		E
Dwarf evening primrose		T
Hoover's desert parsley		T
Birds		
Aleutian Canada goose[a]	T	E
American white pelican		E
Bald eagle	T	T
Ferruginous hawk		T
Peregrine falcon[a]	E	E
Sandhill crane[a]		E

[a] Incidental occurrence.

The bald eagle is one of six threatened or endangered birds at the Hanford Site. The bald eagle is a regular winter resident and forages on dead salmon and waterfowl, but has not yet been observed to nest successfully on the Hanford Reach. Access controls are in place along the river at certain times of the year to prevent the disturbance of eagles. The Washington State Bald Eagle Protection Rules were issued in 1986, and DOE prepared a site management plan to mitigate eagle disturbance (Fitzner and Weiss 1994). The American white pelican and ferruginous hawk are listed by the State of Washington as endangered and threatened, respectively. In addition, the Aleutian Canada goose, peregrine falcon, and sandhill crane occur, incidentally, at the Hanford Site, and are listed as threatened or endangered.

Eight species of plants listed as threatened or endangered by the State of Washington are found on the Hanford Site. Only Columbia milkvetch and Columbia yellowcress are associated with the Columbia River. Milkvetch occurs on dry-land benches along the Columbia River near Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Hanford Reach. Northern wormwood is another plant listed by the state as an endangered species and is known to occur near the town of Beverly, upstream of Priest Rapids Dam. The shoreline of the Columbia River, across from the 100 Areas, could provide a suitable habitat for northern wormwood, but it has not been observed in the area.

Steelhead trout (upper Columbia River ESU) are listed as endangered and are known to be present in the Hanford Reach of the Columbia River.

4.4.1.2 Current Environmental Conditions. Currently, there are several different Hanford-related programs and projects working on various aspects of the river evaluation defined in the previous section. In addition, several agencies outside of the Hanford Site domain

are conducting related studies. These agencies include Ecology and the Washington State Department of Health (DOH), U.S. Army Corps of Engineers, U.S. Geologic Survey, Federal and State Fish and Wildlife Service, U.S. Environmental Protection Agency (EPA), and the Bonneville Power Administration. The activities performed by the various entities are defined by organization and project-specific objectives. Efforts have been made to coordinate the activities of these organizations.

Columbia River Environment

The Columbia River near the Hanford Site is monitored primarily through the SESP, according to the *Environmental Monitoring Plan (EMP) U.S. Department of Energy, Richland Operations Office* (DOE-RL 1997b). Additional Columbia River monitoring is conducted by the Hanford Site Near-Facility Environmental Monitoring Program, which collects riverbank spring water samples and measures external radiation at the 100-N Area shoreline (Perkins et al. 1997).

The current environmental status of the Columbia River is evaluated and documented on a yearly basis through the Hanford Site Environmental Report (PNL-7930; Woodruff and Hanf 1992; PNL-8682; PNL-9823; PNL-10574; PNNL-11139; PNNL-11472). The *Columbia River Comprehensive Impact Assessment* study (DOE-RL 1998b), non-DOE agency reports (WA 1993; Paris 1994; Wells 1994; Danielson and Jaquish 1996; Wiggins et al. 1996), and other Hanford Site contractor reports (Dirkes 1990; Dirkes 1993; Poston 1994; Poston and Cooper 1994; Hope and Peterson 1996a; Hope and Peterson 1996b) provide valuable information on the status of the Columbia River.

Columbia River Water. The Columbia River was one of the primary environmental exposure pathways to the public from 1990 through 1996. Radiological and chemical contaminants entered the river along the Hanford Reach primarily through seepage of contaminated groundwater. Environmental samples were collected from the river at various locations during this period to determine compliance with applicable standards. Water sampling locations used in 1997 are illustrated in Figure 4-56.

Although radionuclides associated with Hanford Site operations continue to be identified routinely in Columbia River water during this time period, concentrations remained extremely low at all locations and were well below standards. The concentrations of tritium (Figure 4-57), ^{129}I (Figure 4-58) and, for some years, uranium (Figure 4-59) were significantly higher (5% significance level) at the Richland water supply pumphouse (downstream from the Hanford Site) than at Priest Rapids Dam (upstream from the Hanford Site), indicating contributions from the Hanford Site. Transect sampling (concentration profiles across the river) revealed elevated tritium concentrations along the Benton County shoreline near the 100-N Area, old Hanford Townsite, 300 Area, and the Richland pumphouse (Figure 4-59). Total uranium concentrations were elevated along the Benton and Franklin County shorelines near the 300 Area and Richland pumphouse (Figure 4-60). The highest total uranium concentration was measured near the Franklin County shoreline of the Richland pumphouse transect and likely resulted from groundwater seepage and irrigation return canals east of the river.

Figure 4-56. Water and Sediment Sampling Locations for the Columbia River Used in 1997.

Figure 4-57. Annual Average Tritium Concentrations (±2 Standard Error of the Mean) in Columbia River Water, 1992 Through 1997.

Figure 4-58. Annual Average I-129 Concentrations (±2 Standard Error of the Mean) in Columbia River Water, 1992 Through 1997.

Figure 4-59. Annual Average Uranium Concentrations (±2 Standard Error of the Mean) in Columbia River Water, 1992 Through 1997.

Figure 4-60. Tritium Concentrations in Water Samples from Columbia River Transects, August 1997.

Several metals and anions were detected upstream and downstream of the Hanford Site. Nitrate concentrations were elevated along the Franklin County shoreline of the old Hanford Townsite, the 300 Area, and Richland pumphouse transects, and likely resulted from groundwater seepage associated with extensive irrigation north and east of the Columbia River. Most metal and anion concentrations measured in Columbia River water collected during this time period were less than Washington State ambient surface water quality criteria levels for acute toxicity, except for silver and cadmium that exceeded the standards for a few samples. In September 1996, transect samples at Vernita Bridge, 100-F Area, and the Richland pumphouse for ultra-trace levels of mercury were all below 1 part per trillion (Bisping 1997b). The chronic toxicity levels for lead and selenium were occasionally exceeded in Columbia River transect samples. Volatile organic compounds (trichloroethylene, chloroform, and toluene) were occasionally detected in Columbia River water samples.

Since 1986, under the National Stream Quality Accounting Network program, the U.S. Geological Survey has collected water samples along transects of the Columbia River at the Vernita Bridge and the Richland pumphouse. Physical measurements and chemical analyses are performed on the samples. Results are reported annually by the U.S. Geological Survey (Wiggins et al. 1996). Applicable standards for a Washington State Class A-designated surface-water body were reached. From 1990 through 1996, there was no indication of any deterioration of water quality resulting from Hanford Site operations.

Columbia River and Riverbank Spring Sediment. Sediment in the Columbia River contains low levels of radionuclides and nonradioactive metals of Hanford Site origin, as well as radionuclides from worldwide fallout (Woodruff et al. 1992; Beasley et al. 1981; Robertson and Fix 1977). Results of sediment investigations indicate that the predominance of radionuclides in river sediments downstream of Hanford result from worldwide fallout and do not generally result from past or present Hanford Site operations (Beasley et al. 1981, Beasley 1984). Samples of Columbia River surface sediments were collected from permanently flooded monitoring sites above McNary Dam (downstream of the Hanford Site), Priest Rapids Dam (upstream of the Hanford Site), and along the Hanford Reach (Dirkes and Hanf 1997) (Figure 4-61). Strontium-90 was the only radionuclide to exhibit consistently higher median concentrations at McNary Dam compared to the other location. The median concentration of ^{60}Co was highest in sediment collected along the Hanford Reach. Sediment samples were also collected from riverbank springs. The concentrations of radionuclides in sediment collected from riverbank springs were similar at all locations and were comparable to sediment collected behind Priest Rapids Dam. Detectable concentrations of most metals were found in all Columbia River sediment samples, except silver, which was below the detection limit for all samples. Median concentrations of most metals were highest in McNary Dam sediments. The highest median concentration of chromium was found in riverbank spring sediment.

Columbia River Shoreline Springs. Currently, reasonably comprehensive coverage of contaminant conditions along the south (or “right”) shoreline of the Columbia River is available. Data from near-river monitoring wells at the reactor areas have accumulated for many years, including from as far back as the reactor operating years. Samples of riverbank seepage have been routinely collected and analyzed since the mid-1980s. Some data also exist in reports of

Figure 4-61. Minimum, Median, and Maximum Concentrations of Selected Radionuclides Measured in Columbia River Sediments, 1992 Through 1997.

specialized sampling conducted during the operating years, although these data are not readily available to analysts, and they must be retrieved from the old reports. Current data sets and interpretations provide a reasonably accurate and comprehensive picture array of opportunities to obtain observational data.

All radiological contaminant concentrations measured in riverbank spring water were less than DOE Derived Concentration Guides. However, tritium concentrations in the 100-B Area and old Hanford Townsite riverbank springs exceeded the Washington State ambient surface water quality criteria levels. There are currently no ambient surface water quality criteria levels directly applicable to uranium. However, total uranium exceeded the Hanford Site-specific proposed EPA drinking water standard in the 300 Area riverbank spring. All other radionuclides were below the Washington State ambient surface water criteria.

Nonradiological contaminants measured in riverbank springs were below Washington State ambient surface water acute toxicity levels, except copper in the 100-F Area and 300 Area springs; cadmium in the 100-F Area spring; and chromium (IV) in 100-B Area, 100-D Area, and 100-F Area springs. The Washington State ambient surface water chronic toxicity level of cadmium, chromium, zinc, and selenium were exceeded at some locations. Nitrate concentrations were the highest in the 100-D Area and the old Hanford Townsite springs. Concentrations of volatile organic compounds were similar to previous years with most compounds below the detection limits. Chloroform (100-B and 100-D Areas), trichloroethylene (100-B), and tetrahydrofuran (100-B) were occasionally detected (Peterson and Johnson 1992, Peterson et al. 1998).

Irrigation Water. Irrigation water from the Riverview canal was sampled to determine radionuclide concentrations. Radionuclide concentrations in offsite irrigation water were below DOE Derived Concentration Guides and ambient surface water quality criteria levels, and were similar to those observed in the Columbia River.

Aquatic Biota. For fish samples collected from 1990 through 1996, ^{90}Sr was detected in Columbia River bass and carp at concentrations slightly exceeding those found in fish collected upstream of the Hanford Site in the Priest Rapids reservoir. Cesium-137 has occasionally been detected in bass from the Hanford Reach. Results for aquatic biota sampling for 1997 are summarized in Dikes and Hanf (1998). The concentrations of radionuclides measured in Hanford Site fish indicate accumulation of small amounts of radionuclides; however, it is likely that these radionuclides were from atmospheric fallout, as well as the Hanford Site.

Shoreline Vegetation. Shoreline vegetation was sampled from 1990 to 1992 along areas of the Hanford Reach where contaminated groundwater plumes intersect the river and at an upriver control location (Antonio et al. 1993). The 100-N Area, old Hanford Townsite, and the 300 Area had elevated levels of radionuclides. Tritium concentrations were elevated compared to background at all locations. Cobalt-60 and ^{90}Sr were elevated at the 100-N Area, and ^{99}Tc was detected at the old Hanford Townsite. There was some indication of elevated uranium concentrations in milfoil and onions collected at the 300 Area. The concentrations of ^{137}Cs, plutonium, and uranium were slightly higher than background at the 100-N Area, old Hanford

Townsite, and 300 Area; and again, are likely attributable to both fallout and the Hanford Site (Poston 1994).

External Radiation. Shoreline surveys conducted in 1979 indicated that measurable radioactive contamination resulting from past generations was present along the Columbia River shoreline (Sula 1980). In 1994, the DOH conducted a study of the health effects of artificial radioactivity in Columbia River sediment (Wells 1994). This study, which did not address "skyshine" from facilities near the river, shoreline "seeps," or effluent pipes, concluded that the doses resulting from artificial radioactivity in Columbia River sediment were very low, less than 1% of natural background.

Radiological dose rates are measured at selected locations along the Columbia River using thermoluminescent dosimeters (Dirkes and Hanf 1997). Locations are selected based on past aerial and ground radiological surveys that identified areas of elevated exposure rates. As such, average shoreline dose rates in 1996 (89 mrem/yr) were slightly higher than observed background dose rates measured at distant communities (71 mrem/yr). The 1996 average dose rate along the 100-N Area shoreline (129 mrem/yr) was approximately 50% higher than the typical shoreline dose rate (82 mrem/yr). The elevated exposure rate is attributable to skyshine resulting from waste management facilities located near the river at the 100-N Area.

4.5 RISK ASSESSMENT

The Risk Assessment technical element involves (1) developing several location-specific dependency webs according to where and when the antecedent transport modules predict that contamination will or could occur (onsite and down river). This is followed by (2) estimating exposures, risks, and impacts to (a) humans, (b) the environment, (c) specific cultures and quality of life, and (d) selected economies from radioactive and chemical contaminants at those locations. These calculations may be made for current contaminant distributions, as defined by monitoring data and information on historical operations, and for potential future conditions. The objectives are to evaluate the effects of various remediation options and land uses.

The first step in the risk assessment process is to develop several location-specific dependency webs before defining impacts and performing the more quantitative exposure, dose, and risk calculations. A variety of tools are needed to conduct these risk assessments because of the relatively large geographic area influenced by the Hanford Site, the complexity of sources and characteristics of contamination, and the migration of contaminants through a variety of environmental media. These tools address the release of contaminants, geochemistry, and transport through several media (e.g., vadose and saturated zones, river, air, soil), exposures to humans and the ecosystem; human health; ecological, cultural, and economic impacts; and risks from the exposure.

Human health risk assessment involves generally accepted exposure pathways and scenarios originally developed and documented by the EPA. Recently, there has been increased interest (e.g., Columbia River Comprehensive Impact Assessment [CRCIA] and Hanford Remedial Action Environmental Impact Statement [HRA-EIS]) in the assessment of "lifestyle" scenarios

that may involve exposure patterns associated with specific groups, such as Native Americans and others whose lifestyles are closely tied to the Columbia River.

Ecological risk assessment is not as easily outlined as human health risk assessment because of the larger number of potential receptors and pathways, which often result in the need for a very location specific analysis. Of particular interest for assessing ecological risk are locations where sensitive habitat and contaminants coexist, and where the potential uptake of contaminants is most likely. A critical location is one where the entry of contaminants into an exposure pathway and/or the food chain is likely to occur. The pathways or mechanisms by which receptors of interest are potentially exposed to contaminants are characterized as an integral part of a risk assessment. Some of the receptors of interest will be identified through identification of the food webs.

The process of estimating risks to cultures and economies uses the same contaminant location, duration, and concentration information as used by the human and ecological risk estimation process. Several models are being developed to address cultural impacts for tribal cultures and communities. These methods are sufficiently well developed, with published proof-of-principle reports, that they can be used by the Integration Project. It is essential, however, that Tribal Nation technical staff be involved in, or actually perform, the evaluation of risks to tribes, their cultures, their economies, and the determination of potentially disproportionate impacts to tribal communities. A standard economic impact analysis will be appropriate for nontribal economies.

The last step in the risk and impact analyses is to assess cumulative risks and impacts for specific locations and populations. These risks or impacts will be placed into perspective with the other, non-Hanford impacts to the environment.

4.5.1 Current State of Knowledge

Relatively small amounts of radioactive and nonradioactive compounds are released to the atmosphere from Hanford Site sources. These emissions are a potential source of human exposure. Therefore, air samples are collected at locations near potential sources, at the site perimeter, and at offsite locations. A description and results of Hanford Site air monitoring are provided in Dirkes and Hanf (1997).

Transport of airborne emissions is controlled by weather patterns, the source location, and the nature of the emission. Past airborne emissions, which were released from chemical separation processes during the early years of Hanford's defense mission, resulted in offsite exposures. However, airborne emissions from remaining wastes have been shown to have minimal impact when analyzed as a part of the performance assessment for various facilities (Kincaid et al. 1997).

Contaminants from the Hanford Reach human and wildlife receptors through liquid effluents that have been discharged directly to the Columbia River, groundwater seeping into the river, and gaseous effluents released to the atmosphere. Assuming that people are not exposed directly to contaminated groundwater on the Hanford Site and that transport of contaminants through the atmospheric pathway is negligible, the Columbia River is the primary interface between human

receptors and Hanford Site contaminants. Wildlife may also be exposed to surface contaminants on the Hanford Site.

Where possible, impact to receptors is evaluated based on the results of environmental sampling and direct measurements of radiation. However, the concentrations of most radioactive materials released to the environment from the Hanford Site are too small to be measured directly once they are dispersed in the environment, or it is difficult to identify contributions from the Hanford Site in the presence of worldwide fallout and naturally occurring radionuclides. Therefore, environmental pathway modeling is conducted to determine the impact of these releases. Modeling is also used to determine the potential impact of future releases. The dose to the maximally exposed individual in 1997 was 0.0152 mrem/yr (Dirkes and Hanf 1998).

In addition to effects on humans, effects on the ecosystem are also of concern. One example is the potential effect of contaminants on salmon spawning beds located in the Columbia River adjacent to the 100 Areas.

4.6 MONITORING

4.6.1 Scope

The Monitoring technical element includes the spatial and temporal measurement of chemical concentrations and associated transport parameters in the vadose zone, groundwater, and Columbia River. These measurements are evaluated against a baseline or trend to determine if changes have occurred and to judge if and how contaminants move from source terms, through the vadose zone and groundwater, and into the Columbia River system.

The primary goals of the Monitoring technical element are to detect new sources of contamination and track the movement of existing contamination from source term to the Columbia River downstream of the Hanford Site. Contaminant plumes emanating from existing sources must be monitored to provide data for hazards assessment, developing remedial measures, and judging the success of applied remedial actions. The need for monitoring any portion of the transport pathway between a source and the Columbia River begins with a perceived hazard. Depending on results of a risk assessment or a decision to apply remedial measures, the decision to monitor will be made. Not all sites can be characterized at the same time, making it necessary to prioritize the order in which sites are evaluated. In addition to these requirements, some monitoring is required to comply with environmental regulations (i.e., *Resource Conservation and Recovery Act of 1976* [RCRA], CERCLA, or the *Atomic Energy Act of 1954* [AEA]).

The environmental transport pathways that are subject to monitoring are leaching of contaminants through the vadose zone into the groundwater, advective transport of contaminants through the groundwater system to the Columbia River, and the advective transport of contaminants downstream from the Hanford Site in the Columbia River. The contaminants monitored, monitoring locations, and monitoring frequency depend on the proximity of the plume to its source and the transport behavior of the contaminant considered.

Monitoring methods include collecting discrete samples of water and soil, and in situ monitoring using pressure transducers for water level measurements, specific ion probes for water quality data, and moisture-sensing instruments. Geophysical tools lowered into boreholes are used for radiological monitoring. Monitoring locations include vadose zone boreholes (dry wells), groundwater wells, riverbank seepage sites, aquifer sampling tubes near the river shoreline, porewater sampling tubes in the riverbed sediments, riverbed sediment, and the river water column.

A primary task of monitoring is detecting (1) new sources of contamination; (2) changes in the movement of existing contamination; and (3) changes in the characteristics of contamination. An equally important task is supplying data to evaluate the performance of remedial actions. The geographic scope varies, depending on the requirements defined by other technical elements, but may extend from contaminant source areas on the Hanford Site to locations in the Columbia River downstream of the Hanford Site.

4.6.2 Current State of Knowledge

This section documents the current status of environmental monitoring related to the Groundwater/Vadose Zone/Columbia River project. The emphasis is on the monitoring that is performed, not the contamination status of each media type monitored. Refer to the vadose zone, groundwater, and Columbia River technical elements for discussions of the current conditions in each of the media types.

Regulatory Requirements for Environmental Monitoring

Environmental monitoring at the Hanford Site is based on a wide range of legislation, promulgated regulations, and regulatory agreements. This section summarizes the regulatory framework on which the monitoring is based.

The four major legislative drivers for environmental monitoring are the AEA, RCRA, CERCLA, and the *Superfund Amendments and Reauthorization Act of 1986* (SARA). From these major pieces of legislation, federal regulations and Washington State Codes were promulgated and DOE orders were enacted. These overlapping regulations govern all aspects of environmental monitoring, remedial investigations, and remediation. The integration of these activities is summarized in the *Environmental Monitoring Plan United States Department of Energy Richland Operations Office* (DOE 1997e). The monitoring requirements specified focus on groundwater and Columbia River monitoring. No regulations specifically address vadose monitoring except as pertaining to leak detection associated with underground storage tanks. CERCLA and RCRA address vadose zone characterization, but not monitoring.

Vadose zone monitoring is currently being performed in and around tank farms and liquid waste disposal sites. Tank farm monitoring is at the stage where a baseline is being established by performing the first systematic monitoring of all SSTs in which high-level radioactive wastes are stored (DOE 1995a). The baseline is established by applying borehole spectral gamma logging, which will be repeated in subsequent years. This baseline is scheduled for completion in

mid-FY99. Field logging is scheduled for completion in October 1998, with final reports issued in April 1999.

Leak detection monitoring is planned to take place during retrieval activities associated with SSTs. Primary COCs have been identified as the long-lived mobile radionuclides (i.e., ^{99}Tc, ^{79}Se, and uranium isotopes). Potential other analytes include moisture content/change and temperature. Monitoring activities within the tank farm vadose zone will likely be concentrated on tanks that contain drainable liquid components or those that are undergoing retrieval activities. Primary tank monitoring is performed inside the tanks. Leak detection monitoring systems that are ex situ will be designed and implemented on either tank- or tank farm-specific bases. Active monitoring of the TWRS vadose zone will be initiated during investigation of or following designation of a tank as an assumed leaker. Minimal monitoring of SSTs is planned; this monitoring will take place immediately before a tank is retrieved and following completion of retrieval. Leak detection monitoring is envisaged as monitoring moisture content changes in a real-time mode, allowing corrections to be made in a timely fashion. Boreholes will be installed predominantly for vadose zone characterization and, possibly, for leak detection. Pending the successful demonstration of cone penetrometer deployed sensors, these tools may be substituted for selected boreholes. Directional drilling (horizontal to subhorizontal) boreholes are being considered for placing leak detection sensors and for characterization sampling. Boreholes that present direct pathways through the vadose zone to the groundwater will require abandonment.

Other vadose zone monitoring within the Groundwater Program is at an early stage. A draft of the first high-level monitoring plan is currently being prepared, and a few selected sites have been monitored using spectral gamma logging. In the past, wells around many of the tank farms and liquid disposal sites were routinely logged using gross gamma logging techniques (Additon et al. 1978a; 1978b; Fecht et al. 1977).

Current Status of Hanford Groundwater Monitoring

Contaminant monitoring is conducted at those CERCLA OUs with known groundwater contaminants that cannot or will not be remediated, but that require plume monitoring to ensure natural attenuation and for plume tracking purposes. Assessment monitoring at OUs is conducted to ascertain and monitor the effectiveness of groundwater remediation activities (i.e., contaminant plume pump-and-treat projects).

The G*roundwater Remediation Strategy* (DOE-RL 1995c) establishes that the overall goal of groundwater remediation on the Hanford Site is to restore groundwater to its beneficial uses in terms of protecting human health and the environment and its use as a natural resource. In recognition of the Hanford Future Site Uses Working Group (Drummond 1992) and public values, the strategy establishes that the site-wide approach to groundwater cleanup is to remediate the major plumes found in the reactor areas and to contain the spread and reduce the mass of the major plumes found in the 200 Areas.

The extent, frequency, and type of groundwater monitoring are determined using the EPA's DQO process. This process leads to collecting new environmental data that support decisions associated with remediation alternatives. By following the DQO process, new data are obtained in an effective and cost-efficient manner.

Records of Decision (RODs) between regulators and principal responsible parties (e.g., DOE) are published that describe the agreed-upon remediation alternative. Where active groundwater remediation is pursued, a monitoring plan is developed to (1) evaluate the performance of the activities relative to stated objectives, and/or (2) demonstrate that ROD requirements are being met at compliance locations.

Some RODs may stipulate no remediation activities other than natural attenuation. Monitoring will usually be required to demonstrate that groundwater conditions remain as anticipated by the remedial investigation. This monitoring is intended to ensure the public that the contamination problem is not becoming worse with time.

The following provides a brief status of each groundwater OU, with respect to groundwater monitoring:

- **100-BC-5**. No interim action groundwater remediation activities. Operable unit environmental monitoring is conducted under a *Tri-Party Agreement* Change Control Form (M-15-96-07, dated July 31, 1996). There are no RCRA treatment, storage, and/or disposal (TSD) facilities or operating facilities in the OU. Remediation of surface waste sites is under way and includes large-scale excavations.

- **100-KR-4**. An interim action pump-and-treat system is addressing chromium contamination between the 116-K-2 “mile long trench” and the river. Performance environmental monitoring is conducted under DOE-RL 1997d. Additional OU monitoring is conducted under a *Tri-Party Agreement* NPL Agreement/Change Control Form (Control No. 108, dated November 20, 1996). Operational monitoring associated with the 100-K Area Fuel Storage Basins is conducted under Johnson and Chou (1995). There are no RCRA TSD facilities in the OU. Remediation involving large-scale excavations of surface waste sites has not yet started.

- **100-NR-2**. An interim action pump-and-treat system is addressing the movement of ^{90}Sr-contaminated groundwater toward the Columbia River. Extracting groundwater reduces the water table gradient that controls the rate of flow to the river. A minor amount of ^{90}Sr is also removed from the aquifer. Environmental monitoring is conducted as a requirement in an Action Memorandum from Ecology (Butler and Smith 1994, as interpreted in 100 NPL Agreement/Change Control Form, Control No. 113, dated March 25, 1997). Other OU monitoring is conducted under a *Tri-Party Agreement* Change Control Form (M-15-96-08, dated October 9, 1996). The previous monitoring activities are summarized in an update to the remediation system performance monitoring plan (Peterson 1998). RCRA TSD monitoring is also conducted for several TSD facilities and is described in a monitoring plan (Hartman 1993a). Large-scale excavations to remediate surface waste sites have not started.

- **100-HR-3**. An interim action pump-and-treat system addresses chromium contamination in groundwater that discharges to the river in areas of sensitive benthic habitat. Groundwater is extracted from well networks in the 100-D/DR and 100-H Areas, and chromium is removed. Performance monitoring is described in a plan (DOE-RL 1997d). Other OU monitoring is conducted under a *Tri-Party Agreement* NPL Agreement/Change Control Form (Control

No. 107, dated November 20, 1996). RCRA postclosure monitoring for the 183-H TSD facility in the 100-H Area is described in a monitoring plan (Hartman 1997). Large-scale excavations to remediate surface waste sites is in progress at the 100-D/DR Area, but has not yet started in the 100-H Area.

- **100-FR-3**. There are no interim action groundwater remediation activities under way in the 100-F Area. Operable unit monitoring is conducted under a *Tri-Party Agreement* Change Control Form (M-15-96-06, dated July 31, 1996). There are no RCRA TSD facilities or operating facilities in the OU. Remediation of surface waste sites involving large-scale excavations has not begun.

- **200-UP-1**. An interim action pump-and-treat system is operating to remove uranium and technetium from the high-concentration area of the groundwater plume in the 200 West Area. The extracted water is piped to the 200 Areas ETF for treatment, and sent to the State-Approved Land-Disposal Site north of the 200 West Area for disposal. The Interim Remedial Measure (IRM) ROD was issued in February 1997 (Ecology et al. 1997). Performance monitoring is described in DOE-RL 1997a.

- **200-ZP-1**. An interim action pump-and-treat system is operating to remove carbon tetrachloride from the high-concentration area of the groundwater plume in the 200 West Area. Carbon tetrachloride is removed from the extracted water at an onsite treatment facility, and the resulting clean water is reinjected into the aquifer. The IRM ROD was issued in June 1995 (EPA 1995b). Performance monitoring is described in the *200-ZP-1 IRM Phase II and Phase III Remedial Design Report* (DOE-RL 1996b), and in the *200-ZP-1 Groundwater Sampling and Analysis Plan* (BHI 1995b).

- **200-ZP-2**. An interim action soil vapor extraction system is operating to remove carbon tetrachloride from the vadose zone in the 200 West Area to minimize additional contamination of the underlying groundwater. Authorization to conduct the interim action was provided in an Action Memorandum from EPA and Ecology (EPA 1992). Soil vapor monitoring of carbon tetrachloride concentrations throughout the vadose zone is conducted using wells and soil vapor probes. The monitoring plans are modified periodically and approved by EPA and RL at Unit Manager Meetings.

- **200-BP-5**. Groundwater within the 200-BP-5 OU in the 200 East Area contains a $^{90}Sr/^{137}Cs/^{239,240}Pu$ plume and a $^{60}Co/^{99}Tc$/cyanide/nitrate plume. Treatability tests (using pump-and-treat systems) were conducted in FY95. Following these treatability tests, it was determined that no further action at either plume was required. Annual groundwater monitoring for the 200-BP-5 OU is performed.

- **200-PO-1**. The 200-PO-1 OU contains tritium, ^{129}I, and nitrate groundwater plumes, which cover broad areas within and southeast of the 200 East Area. The preferred corrective action proposed in the RCRA permit modification is natural attenuation coupled with groundwater monitoring (DOE-RL 1996a). Groundwater monitoring of the 200-PO-1 OU is currently included in the site-wide groundwater monitoring strategy (DOE-RL 1995c, BHI 1996).

Groundwater monitoring plans for the nine RCRA TSD units within 200-PO-1 also specify monitoring requirements.

- **300-FF-5**. Groundwater within the 300-FF-5 OU contains primarily uranium and two chlorinated hydrocarbon contaminants. The remedial action specified in the ROD is natural attenuation coupled with groundwater monitoring (Ecology et al. 1996b). Groundwater monitoring requirements are specified in the operations and maintenance plan (DOE-RL 1995d).

- **1100-EM-1**. The 1100-EM-1 OU contains the Horn Rapids Landfill. The remedial action specified in the ROD is monitored natural attenuation, with institutional controls on drilling of new water-supply wells (Ecology et al. 1993). The 1100-EM-1 OU was removed from the National Priorities List in September 1996. A compliance network of groundwater wells adjacent to the Horn Rapids Landfill is monitored for volatile organic compounds, chromium, and nitrate (DOE-RL 1995a).

There are 25 RCRA facilities and units (or waste management areas) that require groundwater. Samples were collected from approximately 239 RCRA wells site wide in 1997. Groundwater samples were analyzed for a variety of dangerous waste constituents and site-specific constituents, including selected radionuclides. The constituent lists meet the minimum RCRA regulatory requirements and are integrated with other groundwater project (e.g., environmental surveillance to meet DOE orders, and CERCLA) requirements at the Hanford Site. During FY97, no new RCRA wells were installed, but 11 new wells will be added to the groundwater network during FY98. Of these 11 wells, 8 will be installed to replace RCRA network wells going dry due to declining groundwater conditions in the 200 West Area, one well is for RCRA assessment at the SST waste management area B-BX-BY, and one is to enhance the detection program at SST waste management area U. In addition to these existing network additions, one borehole is being added to characterize and monitor a proposed new RCRA facility, the ILAW Disposal Complex, located in the 200 East Area.

As of June 1998, 16 waste management areas were monitored under detection programs and did not adversely affect groundwater quality. The other nine waste management areas were monitored under assessment or compliance programs to determine the impacts (source, rate, and extent) of contamination detected in groundwater. Highlights of 1997 RCRA monitoring activities are summarized below.

Four of the seven SST waste management areas were monitored under assessment programs in 1997, primarily to determine the source of contamination detected in downgradient and surrounding wells. The groundwater quality assessment results for these waste management areas, T, TX-TY, S-SX, and B-BX-BY, were released in early calendar year 1998 (Hodges 1998; Johnson and Chou 1998; and Narbutovskih 1998). These reports conclude that the tank farms cannot be ruled out as a potential source of groundwater contamination. The report findings require groundwater monitoring at the T, TX-TY, S-SX, and B-BX-BY Tank Farms to continue under a new phase (II) of assessment, which will be planned and initiated in 1998.

The groundwater quality assessment results for the 216-U-12 Crib were reported during 1997 (Williams 1998), and concluded that the crib is the source of nitrate and ^{99}Tc contamination in the groundwater. RCRA regulations require the site to remain in assessment monitoring. The objectives of the assessment program are to (1) determine if the flux of constituents out of the vadose zone into the groundwater is increasing or decreasing; (2) monitor the known contaminants until a near-term interim corrective action is defined; and (3) monitoring under interim status assessment until a final-status monitoring plan is implemented during closure of the facility.

The groundwater quality assessment results for the 216-B-3 Pond were reported during 1997 (Barnett 1998), and concluded that the pond has contributed no definable hazardous waste contamination to groundwater, despite erratic elevated total organic halides. The site reverted to an indicator evaluation program in October 1997.

The 183-H solar evaporator basins were monitored under final-status regulations during 1997. The basins have contaminated the groundwater with ^{99}Tc, uranium, nitrate, and chromium at levels that exceed applicable concentration limits. Corrective action will be addressed under the CERCLA program; an interim remedial action (pump-and-treat system) for chromium began operation in 1997. Groundwater monitoring to meet RCRA requirements will continue during the remediation.

The 316-5 process trenches changed from an interim-status assessment program to a final-status compliance-monitoring program in December 1996. The site was immediately triggered into a corrective action program because the concentration limits for some constituents were exceeded. A RCRA corrective action groundwater monitoring plan was submitted to Ecology, and is expected to be implemented in 1998. Contaminant concentrations at the site will be allowed to attenuate naturally as approved under the CERCLA ROD.

RCRA groundwater monitoring programs for the 216-A-10, 216-A-36B, and 216-A-37-1 Cribs were combined into a single assessment program in 1997. Specific conductance is elevated downgradient of the cribs and has a direct correlation with nitrate and tritium contaminant plumes in the area.

Current Status of Hanford Reach Columbia River Monitoring

The Columbia River near the Hanford Site is primarily monitored according to the Environmental Monitoring Plan (EMP) (DOE-RL 1997b). Additional Columbia River monitoring is to collect riverbank spring water samples and measure external radiation at the 100-N shoreline (Perkins et al. 1997).

The design of the surface water monitoring program is based on the DOE guide for environmental surveillance (DOE 1991). The sampling plan is published annually (Bisping 1997a), and includes the media, locations, sample types, frequency, and analytes. All samples are collected according to documented procedures (PNL-MA-580). Selected duplicate samples are collected with the DOH (Dirkes and Hanf 1997). Sampling locations and analytes are determined using a pathway analysis process.

River Water. Contaminants are known to have entered the Columbia River from operations at the Hanford Site. Consumption of water or biota from the Columbia River or irrigated foodstuffs, and direct exposure from recreational uses can expose the public to these contaminants.

Background samples are collected at the Priest Rapids Dam and Vernita Bridge. Continuous samples are collected at Priest Rapids Dam and the Richland pumphouse to assess any changes in contaminant concentrations entering the river through the Hanford Reach. The Richland pumphouse is the first public water supply downstream of the Hanford Site. River transect samples are collected to determine the cross-river concentrations and to determine localized zones of influence near contaminated groundwater discharges. Cross-river transects are collected periodically from locations at the Vernita Bridge (background), the 100-N Area, the 100-F Area, old Hanford Townsite, the 300 Area, and the Richland pumphouse. Contaminants of concern include gross alpha, gross beta, gamma-emitting radionuclides, ^{3}H, ^{90}Sr, ^{99}Tc, ^{129}I, uranium, plutonium, metals, volatile organic compounds, anions, and water quality parameters. In addition to the SESP monitoring, the U.S. Geological Survey conducts environmental monitoring on the Columbia River in conjunction with the National Stream Quality Accounting Network (NASQAN).

Periodic monitoring of contaminant concentrations in select aquifer tubes is required to monitor the extent of contaminated groundwater plumes, particularly in locations with limited access to riverbank springs, and to monitor the flux of contaminant to the river during high river stage. Aquifer tube sampling is required to monitor the spatial extent of underwater upwelling. This work should include bottom-contacting conductivity and gamma measurement probes to determine the spatial extent of upwelling.

Riverbank Springs. Riverbank springs discharge contaminated groundwater at select locations along the Hanford Reach. Seasonal monitoring of riverbank springs and sediments associated with these springs is required to determine changes in the extent of the contaminated groundwater plumes. In addition, riverbank spring sampling is needed to monitor the effect of river stage on contaminant concentrations. This monitoring also confirms findings of the Groundwater Monitoring Project on the extent of contaminated groundwater plumes. Riverbank springs are sampled at 100-B, 100-K, 100-N, 100-D, 100-H, 100-F, old Hanford Townsite, and the 300 Area. Contaminants of concern include ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, uranium, metals (primarily Cr), volatile organics, and anions.

Columbia River Sediment. Sediments along the Hanford Reach are known to contain elevated concentrations of radionuclides and produce higher than background levels of external radiation. Contaminants in sediments may lead to public exposure through the ingestion of aquatic species, through sediment resuspension into drinking water systems, and as an external radiation source. Sampling of the upper layer of the sediments (i.e., most recent sediment deposits) is conducted annually at Priest Rapids Dam (background), sediment accumulation areas in the Hanford Reach, and at McNary Dam. Sampling is conducted after the spring high-water period to provide consistent measurements and a more easily interpreted information base. Core samples may need to be collected periodically to determine the fate and buildup of sediment material over

time or for any future river activity that may disturb the sediments. Contaminants of concern in sediments include gamma-emitting radionuclides, ^{90}Sr, uranium, plutonium, and metals.

Periodic sediment core sampling may be required in the larger sediment deposits, particularly if sediment resuspension is possible. A bottom-contacting gamma probe should be developed to screen sediment deposition zones for contaminants. A sampling methodology using sediment traps should be developed to monitor the movement of contaminated sediment.

External Radiation. Monitoring of external radiation levels near the Hanford Reach shoreline is conducted on a continuous basis using thermoluminescent dosimeters, and on a periodic basis using survey equipment. The 100-N Area shoreline is an area of special interest because of elevated radiation levels at the shoreline from the waste effluent cribs.

Columbia River Aquatic and Riparian Biota. Monitoring of contaminant concentrations in Hanford Reach biota is conducted on a seasonal basis to verify that ecological exposures and human consumption dose remains low. Contaminants of concern include gamma-emitting radionuclides, ^{90}Sr, uranium, and metals.

Offsite Irrigation Water. Periodic monitoring of irrigation water withdrawn downstream from Hanford facilities is conducted to evaluate this pathway. Contaminants of concern include gross alpha, gross beta, gamma emitters, ^{3}H, ^{90}Sr, and uranium.

Onsite Surface Water. While not accessible to the public, West Lake and the Fast Flux Test Facility process water pond/drainfield are used by wildlife that can move off site. The water bodies are monitored periodically to determine the potential exposure to the public through this pathway. Contaminants of concern include gross alpha, gross beta, gamma-emitting radionuclides, ^{3}H, ^{90}Sr, and ^{99}Tc.

Monitoring Strategy

Decisions regarding application of remedial measures and end states will be based on data collected during a characterization phase. After remedial measures have been applied, future site risks will depend on the end states and resulting transport behavior of remaining contamination. Monitoring of key contaminants or conditions on which their transport behavior is based will be decided at that time. Some sites may have to be monitored before characterization and remedial actions due to priority decisions and budget constraints that result in delays in characterization for years in the future. During this interim, an appropriate monitoring system for each source term must be determined from a holistic consideration of all of the transport pathways associated with the source and a strategy for minimizing environmental degradation. The key is to monitor the constituent producing the risk, if possible; monitor surrogate constituents, if necessary and possible; and/or monitor indicators of changing transport conditions, if warranted. These data would then be evaluated in light of change from an established baseline and predetermined action/notification criteria. The elements of a monitoring project include specific plume data needs such as COCs, surrogate constituents, site properties such as moisture content, monitoring technologies, monitoring location in space and time, and delineation of critical parameter values against which monitoring data are compared.

4.7 REGULATORY PATH

4.7.1 Scope

The scope of the regulatory path forward activity is (1) developing a site-wide approach to vadose zone, groundwater, and Columbia River assessment that is integrated, consistent, and practical, and (2) ensuring that all applicable regulatory requirements and drivers are fully integrated into and across the technical activities associated with the assessment. The scope would include the following elements:

Regulatory Authority. Define the regulatory authority(ies) applicable to the assessment activities. The lead regulatory authority and secondary authorities will define the process and requirements for regulatory compliance.

Land Use. In concert with the stakeholders, clearly establish land use and exposure scenarios for the Hanford Site and the relationship between land use and remediation under RCRA[1], CERCLA, the *Model Toxics Control Act* (MTCA), and the AEA. The exposure scenarios will be a key element in performing the impact assessment and will be used to define end states for environmental media. Land-use decisions must be in place for the Hanford Site to move forward on a unified and cost-effective assessment.

Constituents of Concern. Identify the full range of RCRA hazardous constituents and CERCLA hazardous substances and ensure that they are considered in planning data collection and impact assessment activities.

Specific Requirements. Identify the specific regulatory requirements applicable to individual activities, and ensure consistency of application across projects. Regulatory requirements and constraints should be considered early in planning specific projects and with an attention equal to that given to the technical requirements and constraints.

4.7.2 Current State of Knowledge

Regulatory Authority. Both CERCLA and RCRA authorities apply at the Hanford Site. Assessment and management of releases to the vadose zone, the underlying groundwater, the Columbia River, and the accessible environment are the focal points of these regulatory programs and complementary regulatory programs implemented by DOE under authority of the AEA.

Two key documents govern implementation of CERCLA and RCRA at the Hanford Site and the response to releases. The *Tri-Party Agreement* (Ecology et al. 1996a) provides a regulatory framework and schedule for evaluating and remediating releases to the environment. The *Tri-Party Agreement* divides all source sites into one of three categories: CERCLA past-practice,

[1] Although the term "RCRA" is used throughout this technical element, it is implicit that many elements of the federal RCRA program have been delegated to the State of Washington and are implemented via the state Dangerous Waste Program.

RCRA past-practice, and dangerous waste management units. Although the *Tri-Party Agreement* encourages integration of RCRA and CERCLA, it does not detail the integration process, and actual integration has been slow. The current emphasis is focusing on the similarities in the programs (e.g., MTCA standards are used to establish cleanup levels under both programs) rather than differences in terminology. Ideally, one regulatory authority would be identified as the lead for purposes of terminology, but the process would incorporate requirements of both authorities. The draft *200 Area Implementation Plan* is a good example (DOE-RL 1998a). The *Tri-Party Agreement* also establishes a series of milestones that determine the sequence of remediation activities that are to occur. The Hanford Facility RCRA Permit also governs response actions for dangerous waste management units and RCRA past-practice units (Ecology 1994).

To date, there have been several waste site evaluations leading to CERCLA RODs that require specific remedial action (see Remediation technical element). The exposure scenarios forming the basis for cleanup levels in these RODs have included rural-residential (100 Areas) and industrial (300 Areas) (EPA 1995a, 1996). Some of these CERCLA RODs have also addressed remediation at RCRA past-practice units (EPA 1997). There have been no RCRA past-practice units added to the RCRA Permit, in part because the process for governing RCRA past-practice units is still under development by Ecology.

Of the many dangerous waste management units at the Hanford Site, only a fraction has been placed in the RCRA Permit. The closure plans to date for these units have typically been based on clean closure (unrestricted future use), although the Permit allows for modified and landfill closure under specific conditions. Due to the age and constructions of many of Hanford's other units (e.g., single-shell and double-shell tanks), the units are not fully compliant with all applicable RCRA regulations, and instead have RCRA "interim status" to operate until they can be brought into compliance or safely closed.

Land Use. Land use was the subject of a stakeholder working group in 1992 (Drummond 1992), and future land use at the Hanford Site is the subject of the draft *Hanford Remedial Action EIS and Comprehensive Land Use Plan*, soon to be released for public review (DOE 1996a). The EIS evaluates impacts of land-use alternatives for the various areas at the Hanford Site. The EIS does not evaluate impacts associated with remediation; rather, it states that land-use decisions made via the EIS can provide a basis to DOE and the regulatory agencies for making remediation decisions.

Constituents of Concern. Data collection and evaluation activities at the Hanford Site currently are conducted under multiple programs (e.g., RCRA, CERCLA, and DOE orders). There have been efforts to coordinate these activities to address the regulatory requirements of the multiple programs, but further effort is needed. In particular, whether it is to close a RCRA site or remove a CERCLA site from the National Priorities List, there must have been comprehensive consideration of RCRA hazardous constituents and CERCLA hazardous substances. This consideration can be through detailed process knowledge or actual data. There are currently gaps in that analysis for many waste sites.

4.8 REMEDIATION OPTIONS

4.8.1 Scope

The ultimate goal of Hanford Site mitigation and remediation is to (1) prevent further degradation and (2) reduce the impact of existing contamination on human health and the environment. Various options currently are being implemented or considered to attain this goal. Objectives that guide selection of remedial actions include the following:

- Reduce or prevent contamination of the Columbia River.
- Remediate areas of soil contamination consistent with land-use goals.
- Control and/or stabilize sources of contamination.
- Contain and/or remove solid waste stored in landfills.
- Remediate and/or contain groundwater contamination.

Interim actions. Interim remediation is undertaken to mitigate a contamination problem before sufficient information is obtained to make a final closure or remediation decision. These actions include expedited response actions (ERAs) and IRMs. The activities are intended to accelerate cleanup to control further spread of contamination at inactive facilities. Surveillance and monitoring activities at inactive facilities and waste sites are used to verify that an acceptable condition exists until full-scale remedial actions are initiated.

Remediation alternatives. Selecting an alternative for near-term remediation involves evaluating the available options in light of site conditions and types of contamination. Remediation alternatives that have been successfully implemented on the Hanford Site, or that are considered to have potential application, include the following: no action, institutional controls, engineered surface barriers, removal and disposal, and pump and treat.

No action is required to be evaluated as a baseline for comparison with other remedial alternatives. For the no-action alternative to be selected, a site (in its current condition) must pose no unacceptable threat to human health and the environment.

Institutional controls involve the use of physical barriers (fences) and deed restrictions on access to reduce or eliminate exposure to contamination. Institutional controls are often coupled with groundwater, vadose, surface soil, biotic and/or air monitoring to ensure that exposures are limited by the imposed controls. Many access and land-use restrictions are currently in place at the Hanford Site, and will remain in place during remedial work.

Engineered surface barriers (i.e., caps) function as hydraulic barriers to control the amount of water infiltrating into contaminated media, thus, reducing potential leaching of contamination to groundwater. In addition to their hydraulic performance, barriers also function as a physical limit to direct human and biotic interaction with contamination. Barriers are engineered to limit wind and water erosion and, if needed, can control the release of accumulated gases or attenuate radiation.

Removal and disposal involves the excavation of contaminated material and ultimate disposal in a landfill or other environmentally safe configuration. Depending on the nature (e.g., radioactivity levels, hazardous waste classification) of the waste removed, ex situ treatment may be performed before disposal.

Removal and disposal are effective because contaminated materials are physically removed, there are no long-term requirements for monitoring and maintenance of the site, and there is greater flexibility in future land use. These methods are easily implemented at sites with shallow contamination. Requirements for safety, monitoring, and sampling are generally well understood. Radioactive waste require special handling protocols, and may require remotely controlled equipment if radiation levels are high to preclude the use of standard construction equipment.

Groundwater pump and treat involves the extraction and ex situ treatment of contaminated groundwater, and can be effective for a variety of contaminants. This alternative can also be used to hydraulically control the movement of contaminants in groundwater, to remove contaminant mass, and/or reduce contaminant concentrations. A variety of ex situ treatment processes, such as ion exchange, carbon absorption, and air stripping, are available to address a wide range of contaminants. Pump and treat is a well-developed, commonly used technology that can be easily implemented. Pump-and-treat systems have been applied at the Hanford Site to remove contaminant mass and/or control contaminant plume movement. The effectiveness of a pump-and-treat system to remove contaminants diminishes as contaminant levels decrease and, depending on cleanup goals, a shift to an alternative remediation technology (such as in situ treatment) may be needed.

Other Technologies. In situ treatment technologies include a broad range of processes in which waste, contaminated soil, or groundwater is treated or immobilized in place or removed by transport through permeable reactive bermes. This feature is advantageous when exposure or worker safety concerns are significant, such as during excavation or where deep vadose zone contamination exists and excavation or placement of surface barriers is impractical or ineffective. Examples of in situ treatments include in situ vitrification, in situ stabilization, soil vapor extraction, in situ redox manipulation, and in situ biotreatment. In situ vapor extraction currently is being used to remediate carbon tetrachloride-contaminated soil at the 200-ZP-2 OU. Examples of in situ groundwater treatments include air sparging and reactive walls.

Monitored Natural Attenuation. Natural attenuation is a passive rather than active treatment. It encompasses natural processes to reduce contaminant toxicity, mobility, or volume. Natural attenuation processes include radioactive decay, biodegradation, biological stabilization, volatilization, dispersion, dilution, chemical or biological stabilization, transformation or destruction, adsorption and desorption, and mineral precipitation.

4.9 SYSTEM ASSESSMENT

The system assessment technical element quantifies the environmental consequences of past, present, and future Hanford Site activities on the vadose zone, groundwater, and the Columbia

River. Assessment capabilities evaluate the effects of residual contamination from past activities, as well as potential future contamination. The scope of the system assessment technical element includes designing, developing, and applying assessment methods that meet the objectives of the Integration Project. This technical element also provides a vehicle to integrate activities and information generated by the other technical elements, so that coherent and consistent information is available for making major cleanup decisions. The iterative aspect of (1) defining requirements and objectives; (2) obtaining required information and data; (3) interpreting and using the new information; and (4) evaluating the new information in terms of the original requirements is part of this technical element.

The scope and results of assessments made for specific projects, which may be at physical and temporal scales that are more highly resolved than those for an overall system assessment, are coordinated within the system assessment technical element. This integration ensures that the system analysis is reasonably complete and adequate, and that it is internally consistent.

The system assessment scope is oriented toward site-wide and broader scales that consider the significant components of the natural system and waste management issues when evaluating environmental and human health consequences. As a result, system assessments tend to be directed at the longer term consequences of contaminants in the environment. However, because of the need to evaluate mitigation and remediation alternatives, and impacts from past discharges to the environment, system assessment capabilities must also include near-term durations. To ensure the coordination and overall consistency of analyses contributing to the system assessment, the system assessment technical element establishes common requirements for shared databases and consensus interpretations of the environmental setting. This technical element is responsible for data-sharing structures. The data-sharing structure recognizes the multiple temporal and spatial scales of observations and required assessments, and ensures that consistent methods are employed for scales ranging from an individual pore or mineral-grain surface to the regional aquifer and the Columbia River.

Once system requirements and standards are agreed upon, they are imposed for all technical elements and scales of analysis. This process ensures completeness and consistency of analyses conducted for other technical elements (e.g., the vadose zone and the groundwater technical elements). In turn, this ensures the applicability of results at a system-assessment scale.

The system assessment technical element is responsible for reconciling technical differences at interfaces between technical elements. For example, the vadose zone technical element provides estimates of past and future releases of contaminants from the vadose zone to the uppermost aquifer. Similarly, the groundwater technical element provides estimates of current and future contaminants within the uppermost aquifer. If the estimate of past releases of vadose zone contaminants to the aquifer fails to agree with the estimate of contaminants in the aquifer, the system assessment technical element, which uses results of both the vadose zone technical element and the groundwater technical element, must satisfactorily resolve the difference.

4.9.1 Current State of Knowledge

Many project-specific analyses have been made for single contaminated sites or singular aspects of waste migration at the Hanford Site. However, no system-wide assessments of the overall radiological and chemical effects of waste storage and disposal on water resources have been completed. The environmental impact statements issued in 1975 (ERDA 1975) and 1987 (DOE 1987) compiled the data available at those times. The ERDA EIS contains a wealth of information on past Hanford Site operations, but little information on assessed impacts. DOE (1987) contains data and analyses, but it reported only on the alternatives for final disposition of high-level and TRU wastes, and omitted low-level and hazardous chemical wastes.

In the late 1980s, the DOE reached agreement with regulatory agencies on the applicability of RCRA to active facilities and CERCLA to retired facilities, and issued guidance on disposal of radioactive waste (DOE Order 5820.2a). Since then, numerous analyses have supported remediation decisions and continued disposal of low-level radioactive waste. Among the most prominent are the performance assessments for solid waste burial grounds in the 200 West Area (Wood et al. 1995) and 200 East Area (Wood et al. 1996), for the ILAW from the high-level underground waste tanks (Mann et al. 1998), and the TWRS Retrieval Performance Evaluation of the AX Tank Farm for waste retrieval and closure (Jacobs 1998). Another prominent study is the RI/FS for the ERDF (DOE-RL 1994b). Each study examined the environmental impact a single waste form (e.g., solid low-level radioactive waste) or facility (e.g., the ERDF trench), and forecast contaminant release and subsequent migration through the vadose zone and uppermost aquifer to the Columbia River.

During the late 1980s and early 1990s, estimates were made of the radiation that individuals may have received from radionuclide emissions at the Hanford Site since 1944. A major objective of the study was to estimate doses from exposure to airborne releases of ^{131}I. That regional-scale study was conducted by the Center for Disease Control under the guidance of an independent technical steering panel. Exposure pathways of most interest in this study were the atmosphere (Farris et al. 1994) and the Columbia River (Walters et al. 1994).

In response to Defense Nuclear Facility Safety Board (DNFSB) Recommendation 94-2, DOE-Headquarters issued guidance to the DOE complex to prepare Composite Analyses to supplement existing analyses of specific waste types or waste disposal sites. This supplemental analysis was to assess the potential for multiple waste forms and contaminated sites to release contamination in ways that superimpose contaminants in time and space, thus potentially exceeding regulatory standards. The first iteration of this Composite Analysis of a post-closure Hanford site (Kincaid et al. 1998) was restricted to planned radioactive waste disposal in the 200 Area Central Plateau. This analysis was further restricted to consider only the most mobile radionuclides with long half-lives, (i.e., ^{14}C, ^{36}Cl, ^{79}Se ^{99}Tc, ^{129}I, and uranium isotopes and their daughter products). Its scope was limited to developing inventory information; simulating contaminant movement in vadose zone, groundwater, and atmospheric pathways; and simulating doses arising from exposure scenarios defined by the *Hanford Site Risk Assessment Methodology* (DOE-RL 1995b).

The CRCIA (Pacific Northwest National Laboratory and CRCIA Management Team Representatives 1998) provided two products. Part 1 of that report is a screening assessment evaluating the potential impact to the Columbia River from current levels of Hanford-derived contaminants. Part 2 of the report provides a suite of guiding principles for an acceptably comprehensive river impact assessment.

The Retrieval Performance Evaluation (Jacobs 1998), scheduled for public release in October 1998, includes a system assessment of the AX Tank Farm. The analysis addressed source term, vadose zone, and groundwater transport, and human health risks; it provides a deterministic calculation for a variety of strategies (Figure 4-62) and an uncertainty and sensitivity analysis of the baseline retrieval and closure strategy. The analysis concludes that there are substantial uncertainties associated with long-term risk calculations (4 to 7 orders of magnitude as shown in Figure 4-63), and the parameters that dominate uncertainty are associated with the receptor and source terms followed by contaminant transport properties (Tables 4-5 and 4-6).

Each of these modeling activities as well as other efforts at the Hanford Site have generated a suite of models (codes and data) that can be used to support the system assessment, if they are appropriate. To evaluate the appropriateness of existing models and establish the need for model development, a team of project scientists, regulators, and stakeholders is evaluating the requirements established for CRCIA. From this activity, requirements will be set to guide development of the system assessment capability.

Figure 4-62. Uncertainty Analysis Results for Total Human Health Risk for the AX Tank Farm.

Figure 4-63. Long-Term Risk Variations Between Exposure Scenarios, Composite Source Term Nominal Retrieval Losses (1a) AX Tank Farm.

Table 4-5. AX Tank Farm Sensitivity Analysis Results with Fixed Exposure Parameters.

Constituent	Variable	Partial
Tc-99	Milk consumption	0.1553
	Retrieval leak volume	0.0901
	Exposure duration	0.0486
	Retrieval leak concentration	0.0274
	Darcy velocity in the groundwater	0.0281
	Past leak concentration	0.0260
	Groundwater thickness	0.0122
	Concentration of Tc-99 in residual waste	0.0112
	Model R^2	0.3988
I-129	Milk consumption	0.2169
	Past leak volume	0.1195
	Exposure duration	0.1352
	Retrieval leak volume	0.0446
	Retrieval leak concentration	0.0323
	Retrieval leak liquid flux (volume/area)	0.0159
	Leafy vegetable consumption	0.0158
	Hydraulic conductivity in vadose zone layer #6	0.0101
	Model R^2	0.5902
U-238	Retrieval leak water volume	0.2300
	Retrieval leak concentration	0.0682
	Exposure duration	0.0658
	Leafy vegetable consumption	0.0201
	Retrieval leak liquid flux (volume/area)	0.0164
	Meat consumption	0.0152
	Past leak volume	0.0141
	Infiltration rate following surface barrier degradation (>500 years)	0.0131
	Total porosity in vadose zone Layer #5	0.0103
	Hydraulic conductivity in vadose zone Layer #5	0.0110
	Field capacity in vadose zone Layer #5 (see Note 2)	0.0099
	Field capacity in vadose zone Layer #8 (see Note 2)	0.0085
	Model R^2	0.4825

Jacobs 1998

Table 4-6. AX Tank Farm Sensitivity Analysis Results.

Constituent	Variable	Partial
Tc-99	Retrieval leak volume	0.2228
	Darcy velocity in groundwater	0.0823
	Past leak concentration	0.0733
	Retrieval leak concentration	0.0762
	Groundwater thickness	0.0338
	Past leak infiltration rate (volume/area)	0.0213
	Total porosity in saturated zone	0.0082
	Past leak volume	0.0085
	Model R^2	0.5263
I-129	Past leak concentration	0.6088
	Retrieval leak volume	0.1139
	Retrieval leak concentration	0.0204
	Darcy velocity in groundwater	0.0223
	Groundwater thickness	0.0094
	Past leak volume	0.0074
	K_d in layer 3	0.0050
	K_d in layer 7	0.0036
	Model R^2	0.7908
U-238	Retrieval leak volume	0.3799
	Retrieval leak concentration	0.0654
	Past leak concentration	0.0244
	Total porosity in saturated zone	0.0188
	Groundwater thickness	0.0152
	K_d in layer 3	0.0141
	Residual waste solubility	0.0098
	Model R^2	0.5276

Jacobs 1998

5.0 COMPOSITE ANALYSIS INVENTORY SUMMARY

A small group of mobile radionuclides and chemicals are known to be of primary interest relative to long-term groundwater contamination because they have already contaminated the unconfined aquifer and are known to be chemically mobile. Radionuclides include ^{99}Tc, ^{129}I, uranium, and tritium. Chemicals include carbon tetrachloride, trichloroethylene, nitrite, nitrate, cyanide, and chromium. Other radionuclides that are likely to be less mobile but present in groundwater due to direct injection are ^{139}Cs, ^{90}Sr, and plutonium.

5.1 ACTIVE OR PLANNED DISPOSAL FACILITIES

The four active or planned LLW disposal facilities at the Hanford Site are as follows:

- Post-1988 solid waste burial ground in the 200 West Area
- Post-1988 solid waste burial ground in the 200 East Area
- Environmental Restoration Disposal Facility
- Disposal facility for ILAW.

Each of these disposal sites is located on the central or 200 Area Plateau of the Hanford Site. Figures 1-5 and 1-6 show the position of these LLW disposal sites on the 200 Area Plateau.

In accordance with DOE Order 5820.2A (DOE 1988b), performance assessments have been completed for the solid waste burial grounds located in the 200 West and 200 East Areas. These burial grounds have received solid waste since DOE Order 5820.2A went into effect (September 26, 1988). Burial grounds in the 200 West and 200 East Areas were treated separately in performance assessments by Wood et al. (1995) and Wood et al. (1996). Under the CERCLA program, an RI/FS was completed for the ERDF (DOE-RL 1994b). RL submitted a performance assessment (Mann et al. 1998) for the ILAW from Hanford Site tanks to DOE-Headquarters. Pending review and approval by DOE-Headquarters, the ILAW will be disposed of in a combination of four existing vaults and new facilities that are now in the conceptual design stage.

5.2 OTHER SOURCES OF RADIOACTIVE CONTAMINATION

As is apparent from the description of Hanford Site operations, other radioactive sources are present or will be placed on the 200 Area Plateau of the Hanford Site. These sources may create contaminant plumes in the unconfined aquifer at the same time and in the immediate vicinity of plumes generated by the four LLW disposal facility sources described above.

These sources are the responsibility of the DOE and include the following list:

- 149 SSTs arrayed in 12 tank farms (i.e., T, TX, TY, U, S, SX, B, BX, BY, C, A, and AX).
- 28 double-shell tanks arrayed in six tank farms (i.e., SY, AP, AN, AZ, AY, and AW).
- Past-practice (pre-1988) solid waste burial grounds.
- Past-practice (pre-1988) liquid discharges to cribs, ditches, french drains, trenches, and ponds.
- Graphite cores from nine surplus production reactors.
- Canyon buildings and related structures (e.g., B Plant, PUREX, T Plant, U Plant, REDOX, Z Plant [PFP], and the PUREX tunnels).

In addition, a commercial low-level radioactive waste disposal facility operated by Ecology is located immediately southwest of the 200 East Area, and was included in this analysis because of its proximity to DOE operations on the plateau. The treatment of each of these facilities was addressed in the analysis.

5.3 SOLID WASTE BURIAL GROUNDS

Low-level waste has been disposed in the 200 West and 200 East Area solid waste burial grounds since nuclear materials production and processing began at the Hanford Site. The initial generators of the majority of disposed waste were the chemical separations plants in each area: T Plant, U Plant, REDOX, and PFP, and tank farm operations in the 200 West Area; and PUREX, B Plant, and tank farm operations in 200 East Area. Disposals to the 200 West Area LLW facility support both onsite and offsite generators. The U.S. Navy is the only offsite generator contributing to waste disposal in the 200 East Area.

Solid waste disposals have occurred for several decades, and as one burial ground filled up, another burial ground was opened. The current method of disposal for LLW is to place waste in an unlined trench about 6 to 7 m deep and of variable length up to about 500 m. Slopes of trenches are angled at about 45 degrees. Waste packages are stacked to within about 2.5 m of the surface, and soil is placed over the packages to grade. Some surfaces have been vegetated with grasses to stabilize the cover. In the future, efforts may be made to stabilize the waste in situ to prevent subsidence and to reduce recharge through the waste deposit.

Active burial grounds are defined as those that have received waste since September 26, 1988. Active disposal trenches are found in burial grounds 218-W-3A, 218-W-3AE, 218-W-4C, and 218-W-5 in the 200 West Area; and in burial grounds 218-E-10 and 218-E-12B in the 200 East Area. Since September 26, 1988, when DOE Order 5820.2A went into effect, 23 trenches have been open and receiving waste in the 200 West Area burial grounds, and 6 trenches have been

open and receiving waste in the 200 East Area burial grounds. One additional trench in 218-E-12B, Trench 94, is dedicated to the disposal of defueled ship reactor compartments generated by the U.S. Navy. The performance assessments for the active 200 West and active 200 East solid waste burial grounds stipulate an expected 30 years of operation from the September 1988 start date.

In the past, wastes from the chemical separations plants were a function of plant operation. Today the wastes disposed in solid waste burial grounds at the Hanford Site are from facility deactivation projects. Whatever the source, those wastes containing sufficient inventories of waste that could migrate through the environment and result in potential radiation dose (e.g., ^{99}Tc and uranium) are stabilized in various grout formulations or disposed in high-integrity containers, or both.

Radionuclides remaining after the screening process for the 200 East Area burial grounds were long-lived and mobile (Wood et al. 1996). A list of all radionuclides considered in the dose analysis for the 200 East Area burial grounds appears in Wood et al. (1996). The screening process eliminated all moderately to strongly sorbed radionuclides because they were predicted to have no significant ability to contaminate groundwater in the next 1,000 years. Radionuclides passing the screen were tritium, ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, 187^{Re}, and the uranium isotopes. Because of their unique inventory and waste form degradation characteristics, the U.S. Navy ship reactor compartments were treated as a special case. In this special case, the list of radionuclides potentially able to contaminate groundwater is a subset of the above list: ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, and ^{129}I.

One isotope, ^{187}Re, that passed the screen was eliminated from further consideration. The screen criteria included potential mobility and decay half-life; however, ^{187}Re is not present at the Hanford Site in sufficient quantity to present a health threat. Rhenium-187 is an activation product of tungsten, and its existence in significant quantities in the DOE radioactive waste would indicate that a significant quantity of tungsten had been employed in the fuel or its cladding. This was not the case. Schmittroth et al. (1995) estimated the total production of ^{187}Re at 8.6 x 10^{-6} Ci using the Oak Ridge Isotope Generation and Depletion (ORIGEN2) code (Croff 1980). Based on its potential contribution to drinking water dose, this quantity will not significantly contribute to dose.

Shallow land burial of solid waste has occurred at the Hanford Site since the mid-1940s. Burial grounds closed prior to September 26, 1988, are considered among the other sources of radioactive contamination. Prior to 1970, no distinction was made between TRU waste and LLW. In 1970, the Atomic Energy Commission required that TRU waste be retrievably stored. In the early 1980s, low-level liquid organic waste was segregated from LLW and placed in retrievable storage underground. Low-level waste was further categorized in 1987 when mixed waste (i.e., waste containing both radioactive and hazardous chemicals) disposal in unlined trenches was discontinued. Contact-handled mixed waste is currently stored in aboveground buildings in the Central Waste Complex. Post-1988 LLW in burial grounds exhibits much lower inventories compared to the inventories of pre-1988 burial grounds. The pre-1988 solid waste burial grounds are designated past-practice units, and their remediation, final closure, and end state will be negotiated through the CERCLA process.

The SWITS database (Clark 1995) accounts for all waste disposed in the LLBGs and is kept current as waste is disposed. Inventories for both inactive and active burial grounds are recorded. Both radionuclides and hazardous chemicals are tracked in SWITS. The completeness of the records decreases for earlier disposed wastes. Radionuclide estimates are provided for all disposed waste, but chemical inventories are generally unavailable for waste disposed prior to 1980 and marginally available between 1980 and 1987.

Inventories of key mobile radionuclides disposed in each of the 200 East and 200 West Area solid waste burial grounds were estimated for pre-September 1988 and post-September 1988 amounts using an aged-fuel-ratio methodology and the record of cesium, uranium, or plutonium disposal. These inventories of the key mobile radionuclides were estimated using radionuclide inventory information from the SWITS database (Clark 1995). In addition, the ORIGEN2 code (Croff 1980) was used to estimate the abundance of key mobile radionuclides potentially present but not reported in the SWITS database.

Activities of ^{137}Cs and masses of uranium and plutonium disposed were obtained directly from the SWITS database. Two types of SWITS database reports were generated for two periods. The types of reports summarized unsegregated waste and post-1970 non-TRU segregated wastes. These reports were generated for startup through September 1988 and startup through December 1996. The inventories of uranium, plutonium, and ^{137}Cs disposed were totaled between the unsegregated disposal inventory and the segregated non-TRU inventory. This excluded the TRU waste, which was not expected to remain onsite. By subtracting the September 1988 inventory from the December 1996 inventory, an estimate of the post-September 1988 inventory disposed was obtained.

5.3.1 Suspect Transuranic Waste and Pre-1988 Inventory

Before 1970, TRU waste at the Hanford Site was not segregated prior to disposal (Wood et al. 1995). After 1970, TRU waste, defined as >10 nCi/g, was segregated prior to disposal so that it could be retrieved and eventually be disposed offsite. In 1984, the definition of TRU waste was changed from >10 nCi/g to >100 nCi/g. Therefore, a portion of segregated TRU waste disposed between 1970 and 1984 may be reclassified as LLW and be disposed on the Hanford Site. The plans for dealing with this type of waste are being developed. The estimated inventory of pre-September 1988 waste was incremented by the estimated suspect TRU waste inventory that will be reclassified as LLW.

5.3.2 Future Disposal Inventories

Future disposal inventories are uncertain. In past analyses the inventory disposed between September 1988 and December 1996 was extrapolated for the planned 30 years of disposal assuming a constant rate of disposal. The inventory values were compared to projections made in the performance assessments for the 200 East and 200 West Area solid waste burial grounds (Wood et al. 1995; 1996). Table 5-1 includes the future inventory of key radionuclides for the post-1988 period of disposal in the solid waste burial grounds. Although key radionuclides in Table 5-1 are listed in association with disposal areas, future waste disposal may not occur in the same locations.

Table 5-1. Inventory of Key Radionuclides for the Solid Waste Burial Grounds.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
218-EC-9(a)[c]	2.29E-03	1.51E-04	1.23E-05	1.84E-04	6.22E-03	0.00E+00
218-EC-9(b)[d]	2.79E-05	1.83E-06	1.49E-07	2.24E-06	7.57E-05	0.00E+00
218-E-1(b)	1.39E-04	9.15E-06	7.45E-07	1.12E-05	3.77E-04	1.35E-01
218-E-10(b)	7.73E+01	5.08E+00	4.14E-01	6.19E+00	2.10E+02	2.69E-01
218-E-10(a)	1.15E-01	7.58E-03	6.17E-04	9.23E-03	3.13E-01	0.00E+00
218-E-12A(b)	1.24E-03	8.14E-05	6.63E-06	9.92E-05	3.36E-03	3.33E-01
218-E-12B(b)	2.03E+00	1.34E-01	1.09E-02	1.63E-01	5.51E+00	6.57E-02
218-E-12B(a)	1.73E-02	1.14E-03	4.14E-02	1.38E-03	4.69E-02	6.68E-02
218-E-2(b)	3.48E-02	2.29E-03	1.86E-04	2.79E-03	9.44E-02	1.01E-01
218-E-4(b)	1.39E-05	9.15E-07	7.45E-08	1.12E-06	3.77E-05	3.36E-04
218-E-5(b)	1.04E-02	6.86E-04	5.59E-05	8.36E-04	2.83E-02	4.04E-02
218-E-5A(b)	2.30E-02	1.51E-03	1.23E-04	1.84E-03	6.23E-02	4.04E-02
218-E-8(b)	1.39E-05	9.15E-07	7.45E-08	1.12E-06	3.77E-05	6.73E-04
218-W-1(b)	2.78E-04	1.83E-05	1.49E-06	2.23E-05	7.55E-04	2.35E-01
218-W-11(b)	1.39E-07	9.15E-09	7.45E-10	1.12E-08	3.77E-07	0.00E+00
218-W-1A(b)	6.68E-02	4.40E-03	3.58E-04	5.36E-03	1.81E-01	3.03E-01
218-W-2(b)	6.96E-04	4.58E-05	3.72E-06	5.58E-05	1.89E-03	4.71E-01
218-W-2A(b)	3.63E-01	2.39E-02	1.94E-03	2.91E-02	9.84E-01	9.05E-01
218-W-3(b)	1.25E-03	8.24E-05	6.70E-06	1.00E-04	3.40E-03	2.35E+01
218-W-3A(b)	1.99E+01	1.31E+00	1.06E-01	1.59E+00	5.39E+01	1.99E+01
218-W-3A(a)	6.62E-01	4.36E-02	3.68E-03	5.31E-02	2.89E+00	4.23E-01
218-W-3AE(b)	8.15E-01	5.36E-02	4.36E-03	6.53E-02	2.21E+00	8.93E+00
218-W-3AE(a)	1.10E+01	7.25E-01	5.47E-02	8.83E-01	3.58E+01	1.87E+02
218-W-4A(b)	4.61E-03	3.03E-04	2.47E-05	3.70E-04	1.25E-02	1.33E+02
218-W-4B-c(b)	2.35E-01	1.55E-02	1.26E-03	1.88E-02	6.37E-01	1.00E-01
218-W-4B-n(b)	5.13E-01	3.37E-02	5.00E-01	4.11E-02	1.39E+00	0.00E+00
218-W-4B-c(a)	5.68E-02	3.74E-03	3.04E-04	4.55E-03	1.54E-01	0.00E+00
218-W-4C(a)	4.10E+00	9.42E-03	1.13E-02	6.24E-02	9.88E+00	1.39E+02
218-W-4C(b)	2.90E+00	1.25E-02	1.02E-03	1.61E-02	6.07E-01	7.90E-01
218-W-5(b)	4.09E+00	2.73E-03	3.00E-03	3.33E-03	1.13E-01	3.99E+00
218-W-5(a)	1.51E+00	5.09E-02	1.40E-01	6.20E-02	2.77E+00	1.98E+01
218-W-7(b)	5.61E-03	3.69E-04	3.00E-05	4.49E-04	1.52E-02	2.35E-04
218-W-8(b)	1.07E-03	7.05E-05	5.73E-06	8.58E-05	2.91E-03	1.01E-04
218-W-9(b)	1.39E-07	9.15E-09	7.45E-10	1.12E-08	3.77E-07	0.00E+00

a See Appendix A for greater detail in the development of solid waste burial ground inventories.
b Inventories are decayed to a common date of 2050.
c (a) refers to waste disposed after September 30, 1988.
d (b) refers to waste disposed before September 30, 1988.

5.3.3 Estimation of Nonreported Radionuclides

While uranium, plutonium, and ^{137}Cs are relatively well reported within the SWITS database (Clark 1995), a number of radionuclides may also be present but are not consistently reported. Some of these radionuclides are potentially important to performance assessment calculations, (e.g., ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, and ^{129}I). In an effort to estimate inventories of these radionuclides, Version 2.1 of the ORIGEN2 code was used to estimate the relative abundance of other radionuclides that are important but not consistently reported, compared to the major radionuclides that were reported. This method was applied to develop inventory for solid waste burial grounds (see Table 5-1) and those liquid discharge sites that did not receive tank waste (see Section 3.4.5 on CERCLA Sources).

ORIGEN2 calculations were made for single-pass reactor and N Reactor irradiation to determine radionuclide concentrations in spent fuel and cladding. Impurities in the fuel and cladding were included in the model. The quantities are based on Bergsman (1993). A weighted average between the single-pass and N Reactor nuclide concentrations was used to estimate the overall average nuclide composition. About 90% of the fuels processed at the Hanford Site were irradiated in the single-pass reactors.

Inventories of omitted fission products in solid waste were estimated by multiplying the undecayed ^{137}Cs inventory from SWITS by the ratio of the Ci/kg concentration of the radionuclide of interest to that of ^{137}Cs from the ORIGEN2 calculation. The ratios were developed for a fuel age of 10 years after discharge from the reactor. Estimates based on fuel decayed for 1 year are more conservative for radionuclides with decay half-lives less than that of ^{137}Cs (~30 years). The key radionuclides have longer decay half-lives. Estimates based on 10 years of decay prior to disposal were more conservative for radionuclides with longer half-lives. Where the activity of a fission product increased over time beyond 1 year, the maximum activity between 1 and 3,000 years was used to calculate the ratio to ^{137}Cs at 10 years.

The SWITS database reports provide both a mass of uranium disposed, which is not identified by isotope, and quantities of uranium isotopes that are specifically identified. The ORIGEN2 results were used to divide the uranium that was not identified by isotope among the uranium isotopes, and to estimate the quantity of other actinides (except plutonium) that may be present. This was accomplished by multiplying the uranium mass reported in SWITS by the ratio of activity of actinide (or daughter) to uranium mass in discharged fuel. Similar to the fission product case, estimates were provided for fuel with 10 years of decay. As in the case of fission products, the maximum activity between 1 and 3,000 years in the ORIGEN2 calculation was used to calculate the ratio to uranium mass. Plutonium reported without isotopic distribution was divided into isotopes based on the relative abundance indicated in the ORIGEN2 results. Quantities of plutonium reported in SWITS as specific isotopes were then added to arrive at total plutonium isotopic values.

5.4 ENVIRONMENTAL RESTORATION DISPOSAL FACILITY

In the summer of 1996, disposal of wastes generated during excavation and remediation of CERCLA past-practice sites at the Hanford Site began. These wastes are disposed in the ERDF trench. Inventory estimates for CERCLA sites have been developed from process knowledge and sampling and analyses of site materials. CERCLA sites include cribs, ponds, and ditches in the 100, 200, and 300 Areas; decommissioned buildings (reactors, processing plants, auxiliary structures); and inactive solid waste burial grounds. Minimal radionuclide and chemical inventory data exist for many sites, and the process of collecting more detailed inventory information at specific sites is dependent on the remediation schedule.

This trench is a belowgrade excavation that is lined to collect leachate. The excavated material is mounded abovegrade to create a trench of greater disposal volume or capacity. When filled with remediation waste, the trench will be closed with a protective surface barrier. Only remediation wastes originating at Hanford will be disposed in the ERDF. The waste is expected to consist of dangerous and hazardous waste, polychlorinated biphenyl (PCB) and asbestos waste, low-level radioactive waste, and low-level mixed waste containing both dangerous and radioactive waste. The ERDF trench is being developed in stages. Currently it consists of two disposal cells, and approval is now being sought for additional cells. Based on need, it is anticipated the ERDF will be expanded to receive all remediation wastes from Hanford's CERCLA past-practice sites.

At present, the remediation efforts for CERCLA sites are focused on those nearest the Columbia River, i.e., those in the 300 Area and 100 Areas (Hartman and Dresel 1997). In the 300 Area, the effort is focused on past-practice solid waste disposal sites and liquid discharge sites associated with research conducted in the facilities and fuel fabrication efforts. In the 100 Areas, the effort is focused on similar burial ground and liquid discharge sites associated with reactor operation and with the demolition of structures other than of the reactor buildings themselves.

Remediation plans for 200 Area past-practice sites are being developed. These plans require the joint agreement of the DOE, Ecology, and EPA. Facility decommissioning wastes will be disposed in the ERDF trench and not the solid waste burial grounds. The final dispositions of past-practice burial grounds, liquid discharge sites, and canyon facilities are unknown.

In the review of the inventory for the ERDF trench, ^{40}K was identified as a potential isotope of concern; however, it was also identified as a radionuclide considered to be derived completely from natural background. Wood et al. (1995) noted that an average background value of ~15 pCi/g supports this hypothesis. Wood et al. (1995) also noted that ^{40}K is not a known fission product, and consequently, its activity was not considered when calculating the potential dose from DOE wastes such as those in the ERDF. Accordingly, for the purposes of the Composite Analysis, ^{40}K was omitted from the calculation of composite dose from either DOE sites or the commercial LLW disposal facility.

A variety of burial grounds and liquid discharge sites in the 300 Area and 100 Areas are undergoing cleanup efforts. The goals are to excavate contaminated soils and clean sites up so that they may support unlimited or unrestricted industrial (300 Area) and residential (100 Areas)

use, to control sources of groundwater contamination to protect the Columbia River, and to control future groundwater cleanup costs (DOE-RL 1996c). Wastes from these sites are being disposed in the ERDF trench. The objectives and methods of remediation for 200 Area sites have not yet been negotiated between DOE, Ecology, and the EPA. However, only wastes from CERCLA cleanup activities will be disposed in the ERDF trench.

Two documents describe the environmental consequences of the ERDF disposal facility: the RI/FS report (DOE-RL 1994b) and a performance assessment (Wood et al. 1995). As a result of decisions made by DOE regarding the applicability of DOE Order 5820.2a (DOE 1988b) to the disposal of cleanup wastes from CERCLA sites, the final performance assessment (Wood et al. 1995) was not peer reviewed but was published as a record of work completed and analyses conducted. Based on the RI/FS (DOE-RL 1994b), a record of decision (ROD 1995) was issued January 1995 that authorized the construction and operation of two disposal cells with an expected capacity of 920,000 m^3 (1,200,000 yd^3).

The RI/FS lists the maximum detected concentrations of radionuclides for soils in the waste sites of the 100, 200 and 300 Areas. Overall maximum contaminant concentrations (pCi/g) for soils in all three areas are listed in the RI/FS (DOE-RL 1994b, Table 3.8). Based on the RI/FS, these concentrations of radionuclides were assumed to be disposed in the ERDF. Consequently, these maximum concentrations were assumed to exist in all wastes disposed at the ERDF.

While the ROD describes the initial construction and operation of two cells, planning is currently underway for the disposal of 3.59×10^6 m^3 (4.7×10^6 yd^3) in up to six cells. If approved, extending the disposal pit excavation to the east will create the additional four cells. The volume for a six-cell facility is the current projected waste volume for the cleanup and removal of wastes from all 100 and 300 Area CERCLA sites. The density of these wastes upon delivery to the ERDF is an assumed loose density of 1.66×10^6 g/m^3 (1.4 $tons/yd^3$). The in-place density compacted to 90% is 2.02×10^6 g/m^3 (1.7 $tons/yd^3$). Therefore, the in-place compacted volume of the disposal will be 2.96×10^6 m^3 (3.87×10^6 yd^3). Location details (e.g., Washington State Plane coordinates for the disposal cell corners, bottom elevation of the disposal) for the ERDF were taken from the subgrade survey control drawing,[(*)] and the eastward projection of the construction was based on personal communications with contractor staff.

The maximum contaminant concentrations from the RI/FS (DOE-RL 1994b, Table 3.8) were applied to the estimated 3.59×10^6 m^3 (4.7×10^6 yd^3) of loose waste to be delivered to the ERDF to produce the total curies of each radionuclide disposed. This assumption is conservative and likely results in an overestimate of the inventory. The key radionuclide inventory of the ERDF is shown in Table 5-2.

[(*)]U.S. Department of Energy, Drawing No. 0600X-DD-C0033, Rev. 1. Date: 11/18/96. Record number H-6-14624 SHT 1.

Table 5-2. Inventory of Key Radionuclides for ERDF.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
ERDF	3.80E+03				6.57E+00	5.43E+04

a Total inventory was calculated using waste volumes for a full six-cell ERDF trench and maximum concentrations reported in the ERDF RI/FS (DOE-RL 1994b). Chlorine, iodine, and selenium values were not reported.
b Inventories are decayed to a common date of 2050.

5.5 CERCLA SOURCES

The CERCLA source term includes past-practice waste sites that are being addressed under the CERCLA process and inactive sites that are being addressed under RCRA. The Environmental Restoration Contractor (ERC) is responsible for evaluation and remediation of these sites. For administrative purposes, the waste sites have been grouped into operable units (OUs), and are designated as either CERCLA past-practice units or RCRA past-practice units. The CERCLA source term does not include past-practice waste sites that are under the jurisdiction of tank farm operations or decontamination and decommissioning.

5.5.1 Description of CERCLA Sources

A total of 190 separate CERCLA waste sites have some level of inventory developed for them. The CERCLA source term includes liquid discharge sites such as cribs, trenches, and ponds. It also includes a few solid waste sites (landfills) and storage tanks.

In addition to the 190 CERCLA sites, 151 waste sites and more than 200 “unplanned releases” in the 200 Area Plateau that do not have any documented inventory estimates were identified. These were classified as CERCLA sites. Most of these waste sites and unplanned releases have very low radionuclide inventories, have already been remediated, or have been included in another source inventory.

5.5.2 CERCLA Radionuclide Inventories

There are two primary sources of inventory information for CERCLA site radionuclides, *Waste Site Groupings for 200 Areas Soils Investigations* (DOE-RL 1997e, Table A.1), and *Tank Wastes Discharged Directly to the Soil at the Hanford Site* (Waite 1991).

In DOE-RL (1997e, Table A.1), there are 23 waste categories based on the type and concentration of both radioactive and chemical contaminants that are likely to be present in the waste. The report lists 662 waste sites located in central plateau area that are under the jurisdiction of the ERC. Of these, 36 are nonradioactive waste burial grounds, 55 are septic tanks or drain fields that are not suspected of having received any radioactive contaminants, and 30 are burial grounds that are already covered under the LLBG source term. Of the remaining 541 potential sources, partial inventory information was listed for 184 sites. However, radionuclides reported were limited to ^{137}Cs, ^{90}Sr, total uranium, total plutonium, and ^{241}Am. A secondary data source was a spreadsheet provided by the ERC. This spreadsheet contained

inventories for additional radionuclides at many of the 184 sites, and at 6 additional sites, which brought the total number of sites with inventory information to 190.

The radionuclides most significantly affecting the analyses results are mobile in the subsurface and have relatively long half-lives. Inventory data for most of these radionuclides are not available for most of the waste sites because they were not commonly measured in waste streams. A strategy based on the use of radionuclide ratios in aged fuel is used to estimate the absent inventories of key mobile nuclides. Thus, the estimated inventories of fission products and actinides are based on inventories of ^{137}Cs, total uranium, and total plutonium, which are usually reported. Some sites were missing the inventory of ^{137}Cs, total uranium, and total plutonium. To calculate the mobile radionuclide inventory, the missing ^{137}Cs, total uranium, and total plutonium inventories were first estimated. This estimate was based on the average ratios of total uranium to ^{137}Cs, total plutonium to ^{137}Cs, or total plutonium to total uranium for other waste sites in the same waste site group defined in DOE-RL (1997e). The average ratios of these species for each waste site group are listed in Table 5-3. The spreadsheet provided by the ERC contained reported inventory data for some specific radionuclides in addition to ^{137}Cs, total uranium, and total plutonium for some of the waste sites.

Waite (1991) reported the type, quantity, and characteristics of wastes associated with the single-shell storage tanks and discharged intentionally to the subsurface at the Hanford Site. Wodrich (1991) also described these wastes and their inventories in a presentation, including those wastes discharged from the SSTs directly to ground through cascade overflow and by pumping wastes to cribs or specific retention trenches. Being limited to facilities that received different forms of tank waste, these estimates of liquid waste volumes and inventories were generated for relatively few of the CERCLA liquid discharge sites. However, these discharges contain potentially significant radionuclide inventories, e.g., 930 Ci of ^{99}Tc and 1.8 Ci of ^{129}I. Based on the Track Radioactive Components (TRAC) model (Jungfleisch 1980, 1983), inventories were assigned to individual cribs and specific retention trenches (see Table 5-4).(*) For those sites that received tank waste discharges, the inventories estimated by Coony(**) are applied because they are higher than inventories reported in the Waste Site Groupings report published by the Environmental Restoration program. Inventories of key nuclides for the CERCLA sites are listed in Table 5-5.

5.6 TANK WASTE REMEDIATION SYSTEM WASTE

Since 1944, high-level wastes from the chemical separation plants have been stored in and transferred between large single-shell and double-shell tanks. They include waste streams from the dissolution of cladding materials and irradiated fuel slugs, the original bismuth-phosphate precipitation process, the solvent extraction processes used to recover plutonium and uranium, and the evaporators used to concentrate the waste in the tank farms.

(*) Inventories were developed by F. M. Coony of Waste Management Federal Services of Hanford. Information was received in two electronic mail messages with attached files sent by Coony to C. T. Kincaid: 1) Subject, "Questions on Crib Releases in the 200 Areas," dated November 5, 1997; 2) Subject, "Tc-99 (and I-129)," dated October 29, 1997.

(**) F. M. Coony is the individual responsible for the SWITS database and Hanford input to the complex-wide integrated database.

Table 5-3. Ratios of Cesium-137, Uranium (Total), and Plutonium (Total) for Waste Site Groups.

Waste Site Groups[a]	U/Pu	U/Cs-137 (g/Ci)	Pu/Cs-137 (g/Ci)	Notes
Group 2	4604	2773		
Groups 3 & 4	5.18		7.19	
Group 5				U, Pu, and Cs-137 reported for all sites
Group 6			0.371	
Group 7		348	9.89	
Group 8		970	31.8	
Group 9	400	101		
Group 10			4.07	
Group 11				U, Pu, and Cs-137 reported for all sites
Groups 12-16		46,200	54.7	
Group 17		66,300		
Group 18			138	
Group 19	1,000			Assumed
Groups 21 and 23		21,000	6.08	

a Groups 2 through 23 refer to waste site groups defined in DOE (1997b).

Table 5-4. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-A-1	5.12E-02		
216-A-10	8.09E-02		
216-A-18	4.69E-01		
216-A-19	1.30E+01		
216-A-2	2.60E-02		
216-A-20	1.35E-01		
216-A-21	6.49E-02		
216-A-24	1.66E-02		
216-A-25	4.24E+00		
216-A-27	2.26E-02		
216-A-28	2.11E-01		
216-A-3	5.59E-01		
216-A-30	9.98E-02		
216-A-31	6.99E-03		
216-A-36A	4.83E-02		
216-A-36B	3.99E-02		
216-A-37	1.10E-02		
216-A-37-2	1.73E-02		
216-A-39	0.00E+00		
216-A-4	1.33E-01		
216-A-40	0.00E+00		
216-A-45	2.33E-03		
216-A-5	8.75E-02		
216-A-6	5.49E-02		
216-A-7	2.33E-03		
216-A-8	1.23E-01		
216-A-9	0.00E+00		
216-B-10	3.00E-03		
216-B-10B	0.00E+00		
216-B-11	4.66E-03		
216-B-12	6.96E+00		
216-B-14	7.25E-02	6.44E+00	2.24E-02
216-B-15	3.49E-02	5.20E+00	1.81E-02
216-B-16	1.07E-01	1.67E+01	5.83E-02
216-B-17	1.18E-01	5.65E+00	1.97E-02
216-B-18	7.85E-02	6.44E+00	2.24E-02
216-B-22	1.39E-01	1.19E+00	1.88E-03
216-B-23	5.19E-02	2.88E+00	4.56E-03
216-B-24	8.19E-02	3.33E+00	5.28E-03
216-B-25	5.09E-02	1.47E+00	2.33E-03

Table 5-4. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-B-26	1.96E-01	2.48E+01	3.92E-02
216-B-27	1.14E-01	9.04E-01	1.43E-03
216-B-28	9.98E-02	6.22E-01	9.84E-04
216-B-29	1.15E-01	1.53E+00	2.42E-03
216-B-3	2.10E+00		
216-B-30	2.93E-02	8.87E+01	1.40E-01
216-B-31	4.06E-02	7.35E-01	1.16E-03
216-B-32	3.66E-03	3.33E+00	5.28E-03
216-B-33	6.66E-03	7.18E+00	1.14E-02
216-B-34	2.83E-02	4.52E-01	7.16E-04
216-B-35	5.66E-03	1.05E+01	1.66E-02
216-B-36	5.32E-03	1.90E+01	3.01E-02
216-B-37	1.33E-03	7.63E+01	1.21E-01
216-B-38	1.40E-02	1.25E+01	1.98E-02
216-B-39	2.00E-03	1.09E+01	1.72E-02
216-B-40	1.16E-02	8.65E+00	1.37E-02
216-B-41	2.66E-03	2.18E+01	3.45E-02
216-B-42	2.27E-01	2.43E+00	3.85E-03
216-B-43	4.66E-03	7.35E+00	2.56E-02
216-B-44	6.66E-04	1.75E+01	6.08E-02
216-B-45	2.33E-03	3.76E+01	1.31E-01
216-B-46	6.36E-02	5.03E+00	1.75E-02
216-B-47	2.33E-03	3.79E+00	1.32E-02
216-B-48	6.66E-04	1.13E+01	3.94E-02
216-B-49	1.06E-01	1.03E+01	3.58E-02
216-B-5	0.00E+00		
216-B-50	0.00E+00		
216-B-52	9.98E-03	9.04E+00	1.43E-02
216-B-55	2.66E-02		
216-B-57	3.33E-04		
216-B-58	3.00E-03		
216-B-59	0.00E+00		
216-B-60	2.39E-01		
216-B-62	9.98E-03		
216-B-63	1.50E-01		
216-B-7	6.06E-02	2.43E+00	8.47E-03
216-B-8	1.50E-02	1.13E+00	3.94E-03
216-B-9	1.50E-02		
216-C-1	9.82E-02		
216-C-10	0.00E+00		
216-C-3	1.50E-02		

Table 5-4. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-C-4	9.98E-04		
216-C-5	1.80E-02		
216-C-6	0.00E+00		
216-C-7	0.00E+00		
216-C-9	3.33E-04		
216-N-2	0.00E+00		
216-N-3	0.00E+00		
216-N-4	1.66E-03		
216-N-5	0.00E+00		
216-N-6	1.66E-03		
216-N-7	0.00E+00		
216-S-1&2	7.55E-01		
216-S-10	6.72E-02		
216-S-11	6.99E-03		
216-S-12	1.66E-03		
216-S-13	3.03E-02		
216-S-16	1.05E+00		
216-S-17	4.53E-02		
216-S-19	5.19E-02		
216-S-20	1.26E-02		
216-S-21	1.33E-03		
216-S-3	0.00E+00		
216-S-5	9.05E-02		
216-S-6	9.05E-02		
216-S-7	8.62E-01		
216-S-8	6.49E-02		
216-S-9	1.13E-02		
216-T-1	1.66E-03		
216-T-12	1.50E-02		
216-T-14	9.98E-03	1.15E+01	1.83E-02
216-T-15	8.99E-03	2.54E+01	4.03E-02
216-T-16	7.32E-03	1.28E+01	2.03E-02
216-T-17	6.66E-03	9.15E+00	1.45E-02
216-T-18	8.99E-03	1.36E+00	4.73E-03
216-T-19	3.33E-03	9.89E+00	3.45E-02
216-T-20	1.66E-03		
216-T-21	3.33E-04	9.83E+00	1.56E-02
216-T-22	6.66E-04	4.54E+01	7.19E-02
216-T-23	3.33E-04	3.26E+01	5.16E-02
216-T-24	2.66E-03	3.49E+01	5.52E-02

Table 5-4. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-T-25	3.33E-04	2.18E+02	3.45E-01
216-T-26	4.99E-02	4.29E+00	1.50E-02
216-T-27	2.33E-03		
216-T-28	1.30E-01	1.09E+01	3.80E-02
216-T-3	0.00E+00		
216-T-30	1.66E-03		
216-T-32	7.56E-01	5.65E-01	1.97E-03
216-T-33	1.66E-03		
216-T-34	1.33E-03		
216-T-35	1.63E-02		
216-T-36	3.33E-04		
216-T-4	2.32E-01		
216-T-5	1.66E-03	1.75E+00	2.77E-03
216-T-6	7.65E-03		
216-U-10	1.88E+00		
216-U-12	6.77E-01		
216-U-13	0.00E+00		
216-U-15	6.66E-04		
216-U-16	5.99E-03		
216-U-17	3.33E-04		
216-U-3	5.99E-03		
216-U-4A	3.00E-03		
216-U-4B	0.00E+00		
216-U-5	1.21E-01		
216-U-6	1.21E-01		
216-U-8	8.00E+00		
216-W-LWC	6.66E-04		
216-Z-1&2	2.70E-02		
216-Z-10	0.00E+00		
216-Z-12	0.00E+00		
216-Z-16	0.00E+00		
216-Z-17	0.00E+00		
216-Z-18	0.00E+00		
216-Z-1A	0.00E+00		
216-Z-1A A	0.00E+00		
216-Z-1A B	0.00E+00		
216-Z-1A C	0.00E+00		
216-Z-20	0.00E+00		
216-Z-3	0.00E+00		
216-Z-4	0.00E+00		
216-Z-5	0.00E+00		

Table 5-4. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-Z-6	0.00E+00		
216-Z-7	1.66E-03		
216-Z-8	0.00E+00		
216-Z-9	0.00E+00		

a Inventories decayed to a common date of 2050.
b Inventory was developed by F. M. Coony. From an electronic mail message with attached files regarding "Questions on Crib Releases in the 200 Areas." Sent by F. M. Coony of Waste Management Federal Services of Hanford to C. T. Kincaid on November 5, 1997.
c Inventories were developed by F. M. Coony. From an electronic mail message with attached files regarding Tc-99 (and I-129). Sent by F. M. Coony of Waste Management Federal Services of Hanford to C. T. Kincaid on October 29, 1997.

Table 5-5. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
207-U	6.38E-05	4.2E-06	3.42E-07	5.11E-06	1.73E-04	1.51E-02
216-A-1	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	5.12E-02
216-A-10	5.27E-03	3.47E-04	1.07E-01	4.23E-04	1.43E-02	8.09E-02
216-A-18	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	4.69E-01
216-A-19	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.30E+01
216-A-2	9.5E-05	6.25E-06	5.08E-07	7.61E-06	2.58E-04	2.60E-02
216-A-20	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.35E-01
216-A-21	5.14E-03	3.38E-04	2.75E-05	4.12E-04	1.40E-02	6.49E-02
216-A-24	1.76E-02	1.15E-03	9.4E-05	1.41E-03	4.76E-02	1.66E-02
216-A-25	1.34E-02	8.79E-04	7.15E-05	1.07E-03	3.63E-02	4.24E+00
216-A-27	2.12E-03	1.40E-04	1.14E-05	1.70E-04	5.76E-03	2.26E-02
216-A-28	1.48E-02	9.75E-04	7.93E-05	1.19E-03	4.02E-02	2.11E-01
216-A-3	2.98E-06	1.96E-07	1.6E-08	2.39E-07	8.09E-06	5.59E-01
216-A-30	7.66E-03	5.04E-04	4.1E-05	6.14E-04	2.08E-02	9.98E-02
216-A-31	5.37E-03	3.53E-04	2.88E-05	4.31E-04	1.46E-02	6.99E-03
216-A-36A/B	7.84E-02	5.16E-03	4.20E-04	6.28E-03	2.13E-01	8.82E-02
216-A-37-1	6.2E-06	4.08E-07	4.26E-03	4.97E-07	1.68E-05	1.10E-02
216-A-37-2	1.34E-05	8.79E-07	7.15E-08	1.07E-06	3.63E-05	1.73E-02
216-A-4	4.54E-04	2.99E-05	2.43E-06	3.64E-05	1.23E-03	1.33E-01
216-A-45	6.35E-07	4.18E-08	1.10E-02	5.09E-08	1.72E-06	2.33E-03
216-A-5	7.93E-04	5.21E-05	4.24E-06	6.35E-05	2.15E-03	8.75E-02
216-A-6	6.88E-03	4.52E-04	3.68E-05	5.51E-04	1.87E-02	5.49E-02
216-A-7	1.51E-04	9.95E-06	8.1E-07	1.21E-05	4.11E-04	2.33E-03
216-A-8	3.42E-02	2.25E-03	1.83E-04	2.74E-03	9.28E-02	1.23E-01
216-A-9	3.05E-04	2E-05	1.63E-06	2.44E-05	8.26E-04	8E-05
216-B-10A	2.63E-05	1.73E-06	1.41E-07	2.11E-06	7.13E-05	3.00E-03
216-B-10B	6.55E-09	4.31E-10	3.51E-11	5.25E-10	1.78E-08	2.23E-06
216-B-11A&B	1.40E-03	9.18E-05	7.47E-06	1.12E-04	3.79E-03	4.66E-03
216-B-12	4.69E-02	3.09E-03	2.51E-04	3.76E-03	1.27E-01	6.96E+00
216-B-14	7.47E-03	4.91E-04	2.24E-02	5.99E-04	6.44E+00	7.25E-02
216-B-15	6.05E-03	3.98E-04	1.81E-02	4.85E-04	5.20E+00	3.49E-02
216-B-16	1.94E-02	1.28E-03	5.83E-02	1.55E-03	1.67E+01	1.07E-01
216-B-17	6.55E-03	4.31E-04	1.97E-02	5.25E-04	5.65E+00	1.18E-01
216-B-18	7.47E-03	4.91E-04	2.24E-02	5.99E-04	6.44E+00	7.85E-02
216-B-19	8.25E-03	5.43E-04	2.48E-02	6.62E-04	7.12E+00	6.06E-02
216-B-20	4.48E-02	2.95E-03	6.12E-02	3.59E-03	3.86E+01	1.17E-01
216-B-21	1.11E-02	7.28E-04	1.51E-02	8.87E-04	9.55E+00	2.25E-01
216-B-2-1	6.13E-03	4.03E-04	3.28E-05	4.91E-04	1.66E-02	1.45E+00
216-B-2-2	2.06E-05	1.35E-06	1.1E-07	1.65E-06	5.58E-05	4.88E-03
216-B-23	3.33E-03	2.19E-04	4.56E-03	2.67E-04	2.881494	5.19E-02
216-B-2-3	2.06E-05	1.35E-06	1.1E-07	1.65E-06	5.58E-05	4.88E-03
216-B-24	3.84E-03	2.53E-04	5.28E-03	3.08E-04	3.33E+00	8.19E-02
216-B-25	1.67E-03	1.10E-04	2.33E-03	1.34E-04	1.47E+00	5.09E-02

Table 5-5. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-B-26	2.87E-02	1.89E-03	3.92E-02	2.30E-03	2.47E+01	1.96E-01
216-B-27	1.04E-03	6.81E-05	1.43E-03	8.3E-05	9.04E-01	1.14E-01
216-B-28	7.01E-04	4.61E-05	9.84E-04	5.62E-05	6.21E-01	9.98E-02
216-B-29	1.80E-03	1.18E-04	2.42E-03	1.44E-04	1.53E+00	1.15E-01
216-B-3	6.13E-03	4.03E-04	3.28E-05	4.91E-04	1.66E-02	2.10E+00
216-B-30	1.03E-01	6.77E-03	1.40E-01	8.24E-03	8.87E+01	2.93E-02
216-B-31	7.80E-02	5.13E-03	1.16E-03	6.25E-03	7.34E-01	4.06E-02
216-B-32	3.84E-03	2.53E-04	5.28E-03	3.08E-04	3.33E+00	3.66E-03
216-B-33	8.32E-03	5.47E-04	1.14E-02	6.67E-04	7.18E+00	6.66E-03
216-B-34	5.18E-04	3.41E-05	7.16E-04	4.15E-05	4.52E-01	2.83E-02
216-B-35	1.21E-02	7.97E-04	1.66E-02	9.71E-04	1.05E+01	5.66E-03
216-B-36	2.20E-02	1.45E-03	3.01E-02	1.76E-03	1.90E+01	5.32E-03
216-B-37	8.84E-02	5.82E-03	1.21E-01	7.09E-03	7.63E+01	1.33E-03
216-B-38	1.45E-02	9.52E-04	1.98E-02	1.16E-03	1.25E+01	1.40E-02
216-B-39	1.26E-02	8.27E-04	1.72E-02	1.01E-03	1.08E+01	2.00E-03
216-B-40	1.00E-02	6.59E-04	1.37E-02	8.03E-04	8.64E+00	1.16E-02
216-B-41	2.53E-02	1.66E-03	3.45E-02	2.03E-03	2.18E+01	2.66E-03
216-B-42	2.80E-03	1.84E-04	3.85E-03	2.24E-04	2.43E+00	2.27E-01
216-B-43	8.52E-03	5.60E-04	2.56E-02	6.83E-04	7.34E+00	4.66E-03
216-B-44	2.02E-02	1.33E-03	6.08E-02	1.62E-03	1.75E+01	6.66E-04
216-B-45	4.36E-02	2.87E-03	1.31E-01	3.50E-03	3.76E+01	2.33E-03
216-B-46	5.82E-03	3.83E-04	1.75E-02	4.67E-04	5.03E+00	6.36E-02
216-B-47	4.36E-03	2.87E-04	1.32E-02	3.50E-04	3.79E+00	2.33E-03
216-B-48	1.31E-02	8.62E-04	3.94E-02	1.05E-03	1.13E+01	6.66E-04
216-B-49	1.19E-02	7.84E-04	3.58E-02	9.56E-04	1.03E+01	1.06E-01
216-B-5	1.91E-03	1.26E-04	1.02E-05	1.53E-04	5.19E-03	9.52E-03
216-B-50	3.35E-03	2.21E-04	1.8E-05	2.69E-04	9.10E-03	1E-04
216-B-52	1.05E-02	6.89E-04	1.43E-02	8.40E-04	9.04E+00	9.98E-03
216-B-53A	3.66E-06	2.41E-07	1.96E-08	2.94E-07	9.93E-06	7.65E-03
216-B-53B	2.42E-04	1.59E-05	1.3E-06	1.94E-05	6.58E-04	3.00E-03
216-B-54	3.58E-06	2.36E-07	1.92E-08	2.87E-07	9.72E-06	3.00E-03
216-B-55	8.98E-04	5.9E-05	4.8E-06	7.19E-05	2.43E-03	2.66E-02
216-B-57	1.48E-02	9.74E-04	7.92E-05	1.19E-03	4.02E-02	3.33E-04
216-B-58	2.88E-04	1.9E-05	1.54E-06	2.31E-05	7.82E-04	3.00E-03
216-B-59	7.86E-07	5.17E-08	4.21E-09	6.3E-08	2.13E-06	1.86E-04
216-B-60	1.70E-02	1.12E-03	9.1E-05	1.36E-03	4.61E-02	2.39E-01
216-B-62	8.84E-03	5.82E-04	4.73E-05	7.09E-04	2.40E-02	9.98E-03
216-B-63	4.09E-05	2.69E-06	2.19E-07	3.28E-06	1.11E-04	1.50E-01
216-B-7A&B	2.83E-03	1.86E-04	8.47E-03	2.27E-04	2.43E+00	6.06E-02
216-B-8	1.30E-03	8.53E-05	3.94E-03	1.04E-04	1.13E+00	1.50E-02
216-B-9	2.57E-04	1.69E-05	1.37E-06	2.06E-05	6.97E-04	1.50E-02
216-C-1	2.98E-06	1.96E-07	1.6E-08	2.39E-07	8.09E-06	9.82E-02
216-C-10	5.6E-06	3.68E-07	3E-08	4.49E-07	1.52E-05	1.68E-05

Table 5-5. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-C-3	2.78E-06	1.83E-07	1.49E-08	2.23E-07	7.53E-06	1.50E-02
216-C-4	2.84E-06	1.87E-07	1.52E-08	2.27E-07	7.69E-06	9.98E-04
216-C-5	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.80E-02
216-C-6	3.05E-06	2E-07	1.63E-08	2.44E-07	8.26E-06	1E-04
216-C-7	3.5E-06	2.3E-07	1.87E-08	2.8E-07	9.49E-06	3.36E-06
216-C-9	4.61E-05	3.03E-06	2.46E-07	3.69E-06	1.25E-04	3.33E-04
216-N-2	5.14E-06	3.38E-07	2.75E-08	4.12E-07	1.4E-05	1.22E-03
216-N-3	5.77E-06	3.8E-07	3.09E-08	4.63E-07	1.57E-05	1.37E-03
216-N-4	5.33E-06	3.5E-07	2.85E-08	4.27E-07	1.44E-05	1.66E-03
216-N-5	5.77E-06	3.8E-07	3.09E-08	4.63E-07	1.57E-05	1.37E-03
216-N-6	5.33E-06	3.5E-07	2.85E-08	4.27E-07	1.44E-05	1.66E-03
216-N-7	5.77E-06	3.8E-07	3.09E-08	4.63E-07	1.57E-05	1.37E-03
216-S-1&2	7.21E-02	4.74E-03	3.86E-04	5.78E-03	1.95E-01	7.55E-01
216-S-10D	8.12E-05	5.34E-06	4.35E-07	6.51E-06	2.20E-04	6.72E-02
216-S-11	5.37E-05	3.53E-06	2.88E-07	4.31E-06	1.46E-04	6.99E-03
216-S-12	2.84E-05	1.87E-06	1.52E-07	2.28E-06	7.71E-05	1.66E-03
216-S-13	1.81E-04	1.19E-05	9.71E-07	1.45E-05	4.92E-04	3.03E-02
216-S-16P	1.97E-03	1.29E-04	1.05E-05	1.58E-04	5.33E-03	1.05E+00
216-S-17	8.32E-04	5.47E-05	4.45E-06	6.67E-05	2.26E-03	4.53E-02
216-S-19	8.45E-05	5.56E-06	4.52E-07	6.77E-06	2.29E-04	5.19E-02
216-S-20	3.70E-03	2.43E-04	1.98E-05	2.97E-04	1.00E-02	1.26E-02
216-S-21	5.77E-03	3.79E-04	3.09E-05	4.62E-04	1.56E-02	1.33E-03
216-S-22	3.13E-05	2.06E-06	1.68E-07	2.51E-06	8.49E-05	1.68E-05
216-S-23	2.27E-04	1.5E-05	1.22E-06	1.82E-05	6.17E-04	9.75E-05
216-S-25	4.24E-06	2.79E-07	2.27E-08	3.4E-07	1.15E-05	5.56E-02
216-S-26	2.02E-07	1.33E-08	1.08E-09	1.62E-08	5.49E-07	6.89E-05
216-S-3	1.43E-03	9.44E-05	7.68E-06	1.15E-04	3.89E-03	9.75E-05
216-S-5	1.73E-03	1.14E-04	9.26E-06	1.39E-04	4.69E-03	9.05E-02
216-S-6	7.53E-03	4.96E-04	4.03E-05	6.04E-04	2.04E-02	9.05E-02
216-S-7	4.61E-02	3.03E-03	2.46E-04	3.69E-03	1.25E-01	8.62E-01
216-S-8	3.22E-04	2.12E-05	1.73E-06	2.58E-05	8.74E-04	6.49E-02
216-S-9	1.90E-02	1.25E-03	1.02E-04	1.52E-03	5.15E-02	1.13E-02
216-T-1	2.54E-06	1.67E-07	1.36E-08	2.03E-07	6.88E-06	1.66E-03
216-T-12	2.84E-04	1.87E-05	1.52E-06	2.28E-05	7.71E-04	1.50E-02
216-T-14	1.34E-02	8.79E-04	1.83E-02	1.07E-03	1.15E+01	9.98E-03
216-T-15	2.95E-02	1.94E-03	4.03E-02	2.36E-03	2.54E+01	8.99E-03
216-T-16	1.49E-02	9.78E-04	2.03E-02	1.19E-03	1.28E+01	7.32E-03
216-T-17	1.06E-02	6.98E-04	1.45E-02	8.51E-04	9.15E+00	6.66E-03
216-T-18	1.59E-03	1.04E-04	4.73E-03	1.27E-04	1.36E+00	8.99E-03
216-T-19	1.15E-03	7.54E-05	3.45E-02	9.19E-05	9.89E+00	3.33E-03
216-T-20	2.88E-05	1.9E-06	1.54E-07	2.31E-06	7.82E-05	1.66E-03
216-T-21	1.14E-02	7.50E-04	0.01557	9.14E-04	9.83E+00	3.33E-04
216-T-22	5.26E-02	3.46E-03	7.19E-02	4.22E-03	4.54E+01	6.66E-04

Table 5-5. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-T-23	3.78E-02	2.49E-03	5.16E-02	3.03E-03	3.26E+01	3.33E-04
216-T-24	4.04E-02	2.66E-03	5.52E-02	3.24E-03	3.49E+01	2.66E-03
216-T-25	2.53E-01	1.66E-02	3.45E-01	2.03E-02	2.18E+02	3.33E-04
216-T-26	4.95E-03	3.26E-04	1.50E-02	3.97E-04	4.29E+00	4.99E-02
216-T-27	3.66E-03	2.41E-04	1.96E-05	2.94E-04	9.93E-03	2.33E-03
216-T-28	1.26E-02	8.32E-04	3.80E-02	1.01E-03	1.09E+01	1.30E-01
216-T-3	1.40E-03	9.18E-05	7.47E-06	1.12E-04	3.79E-03	6.95E-03
216-T-32	6.36E-04	4.18E-05	1.97E-03	5.1E-05	5.65E-01	7.56E-01
216-T-33	1.75E-05	1.15E-06	9.36E-08	1.4E-06	4.74E-05	1.66E-03
216-T-34	1.03E-02	6.77E-04	5.5E-05	8.24E-04	2.79E-02	1.33E-03
216-T-35	7.66E-04	5.04E-05	4.1E-06	6.14E-05	2.08E-03	1.63E-02
216-T-36	2.48E-04	1.63E-05	1.33E-06	1.99E-05	6.74E-04	3.33E-04
216-T-4B	4.08E-04	2.68E-05	2.18E-06	3.27E-05	1.11E-03	2.32E-01
216-T-5	2.04E-03	1.34E-04	2.77E-03	1.63E-04	1.75E+00	1.66E-03
216-T-6	7.21E-03	4.74E-04	3.86E-05	5.78E-04	1.95E-02	7.65E-03
216-T-7	1.39E-03	9.14E-05	4.14E-03	1.11E-04	1.19E+00	3.00E-03
216-T-8	2.63E-06	1.73E-07	1.41E-08	2.11E-07	7.13E-06	1.66E-03
216-U-1&2	2.86E-04	1.88E-05	1.53E-06	2.29E-05	7.75E-04	7.02E-01
216-U-10	7.21E-04	4.74E-05	3.86E-06	5.78E-05	1.95E-03	1.88E+00
216-U-12	3.71E-06	2.44E-07	1.98E-08	2.97E-07	1.01E-05	6.77E-01
216-U-13	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.20E-04
216-U-15	3.05E-06	2E-07	1.63E-08	2.44E-07	8.26E-06	6.66E-04
216-U-16	1.08E-06	7.11E-08	5.79E-09	8.66E-08	2.93E-06	5.99E-03
216-U-17	2.67E-04	1.76E-05	1.43E-06	2.14E-05	7.24E-04	3.33E-04
216-U-3	2.84E-05	1.87E-06	1.52E-07	2.28E-06	7.71E-05	5.99E-03
216-U-4A	1.21E-05	7.97E-07	6.49E-08	9.71E-07	3.29E-05	3.00E-03
216-U-4B	1.29E-05	8.49E-07	6.91E-08	1.03E-06	3.5E-05	4.39E-03
216-U-5	8.57E-03	5.64E-04	4.59E-05	6.87E-04	2.32E-02	1.21E-01
216-U-6	8.57E-03	5.64E-04	4.59E-05	6.87E-04	2.32E-02	1.21E-01
216-U-7	4.37E-04	2.87E-05	2.34E-06	3.5E-05	1.18E-03	4.71E-02
216-U-8	2.98E-06	1.96E-07	1.6E-08	2.39E-07	8.09E-06	8.00E+00
216-Z-1&2	2.62E-06	1.72E-07	1.4E-08	2.1E-07	7.11E-06	2.70E-02
216-Z-10	4.55E-04	2.99E-05	2.44E-06	3.65E-05	1.24E-03	8.71E-05
216-Z-12	3.47E-06	2.28E-07	1.86E-08	2.78E-07	9.42E-06	1.7E-05
216-Z-16	3.42E-05	2.25E-06	1.83E-07	2.74E-06	9.27E-05	1.16E-02
216-Z-17	2.37E-05	1.56E-06	1.27E-07	1.9E-06	6.44E-05	5E-05
216-Z-18	2.09E-01	1.38E-02	1.12E-03	1.68E-02	5.68E-01	4.01E-02
216-Z-1A	1.05E-05	6.89E-07	5.61E-08	8.4E-07	2.84E-05	0.00E+00
216-Z-20	5.66E-06	3.72E-07	3.03E-08	4.54E-07	1.54E-05	1.34E-03
216-Z-3	3.14E-06	2.07E-07	1.68E-08	2.52E-07	8.53E-06	1.7E-05
216-Z-4	2.29E-06	1.51E-07	1.23E-08	1.84E-07	6.22E-06	1.7E-05
216-Z-5	2.36E-04	1.55E-05	1.26E-06	1.89E-05	6.40E-04	1.7E-05
216-Z-6	2.29E-06	1.51E-07	1.23E-08	1.84E-07	6.22E-06	1.7E-05

Table 5-5. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-Z-7	1.31E-02	8.62E-04	7.01E-05	1.05E-03	3.55E-02	1.66E-03
216-Z-8	1.82E-05	1.2E-06	9.75E-08	1.46E-06	4.94E-05	3.48E-06
216-Z-9	3.41E-06	2.24E-07	1.82E-08	2.73E-07	9.24E-06	1.7E-05

a Refer to Sections 3.4.5 for a detailed discussion of the development of CERCLA radionuclide inventories.
b Inventories decayed to a common date of 2050.

As processes used to capture plutonium and uranium from solutions changed, the characteristics of wastes changed. These tank wastes are characterized as concentrated complexed waste, dilute complexed waste, double-shell slurry and double-shell slurry feed, aging waste, and noncomplexed waste (Hanlon 1997). Because carbon steel tanks were used at the Hanford Site, wastes stored in the tanks were neutralized and often have pH values between 12 and 14. Wastes containing complexants were segregated from those that do not.

Sixty-seven of 149 SSTs have leaked or are suspected to have leaked a portion of their inventory into the environment (Hanlon 1997). If sluicing is the method adopted for removal of tank wastes, it is anticipated that some of the SSTs will lose more liquid tank waste to the vadose zone. The TWRS program is evaluating retrieval technologies using low volumes of liquids, which would result in much lower levels of retrieval loss than possible using sluicing. The TWRS program and private contractors will recover the tank waste, separate it into high-level and LLW fractions, and immobilize each. The TWRS program has begun the process to have the LLW fraction that will be disposed onsite declared incident waste, i.e., not high-level waste[(*)]. The U.S. Nuclear Regulatory Commission (NRC) has confirmed that based on current information, the ILAW can be disposed of as incidental waste. This low-activity waste fraction from the tanks will become ILAW and will be disposed of at the Hanford Site. Over 200,000 m^3 of ILAW LLW will be disposed. The high-level waste will be stored until it can be transferred to a national high-level waste repository. The formal process to declare past tank leaks, future losses, and tank waste residuals incident waste has not begun; however, the TWRS program has conducted evaluations to consider the issues regarding resolution prior to approval by the NRC.

The activation products, actinides, and fission products generated in the reactors at the Hanford Site are anticipated components of the low-activity radioactive stream coming from Hanford single- and double-shell tanks. The complete list of these isotopes can be found in Schmittroth et al. (1995) and Watrous and Wooten (1997).

The screen applied by Schmittroth et al. (1995) to identify those radionuclides that could be potentially significant contributors to dose in groundwater pathway scenarios yielded 12 potentially important isotopes. In order of their contribution to drinking water dose, a major component to all-pathways dose, the 12 isotopes were ^{99}Tc, ^{79}Se, ^{233}U, ^{234}U, ^{238}U, ^{228}Ra, ^{93m}Nb, ^{129}I, ^{226}Ra, ^{236}U, ^{245}Cm, and ^{235}U. To arrive at this list, Schmittroth et al. (1995) used a simple retardation model, and where K_d data were absent, made the conservative assumption of no sorption. After reviewing the Kds, the following values were assigned to several of the elements (Kaplan and Serne 1995; Kaplan et al. 1996): technetium and selenium, 0 mL/g; uranium, 0.6 mL/g; radium, 15 mL/g; niobium, 40 mL/g; iodine, 3 mL/g; and curium, 100 mL/g. The radionuclides that were assigned nonzero K_d values in the study by Schmittroth et al. (1995) failed the screen as significant contributors to dose via the groundwater pathway. Consequently, those elements (i.e., radium, niobium, and curium) assigned the higher values after the initial screen were also eliminated. Accordingly, only the top eight isotopes contributing to drinking

(*) From a letter, dated June 1997, sent by C. J. Papiello, Director of the Office of Nuclear Material Safety and Safeguards, of the U.S. Nuclear Regulatory Commission, to J. Kinzer, Assistant Manager, Office of Tank Waste Remediation System, DOE, "Classification of Hanford Low-Activity Waste Fraction." This letter may be found in Mann et al. (1997).

water dose were identified as potential key radionuclides for the Composite Analysis: ^{99}Tc; ^{79}Se; ^{129}I; and $^{233, -234, -235, -236, -238}$U, and their daughters.

The recovery of wastes from both single- and double-shell tanks will not be perfect. The interim retrieval goal in Milestone M-45 of the *Tri-Party Agreement* (Ecology et al. 1989a) is to leave no more than 10 m^3 (360 ft^3) of waste in each 100-series SST, and no more than 0.8 m^3 (30 ft^3) of waste in each 200-series SST. This corresponds to 1% of the current SST waste inventory of 36 million gallons, allocated equally to each of the 149 SSTs in proportion to the cross-sectional area of the tanks. Thus, an estimated 1% of the waste volume will remain in each tank following completion of recovery operations. For SSTs, the waste source types include leaks, losses during recovery operations, and a residual in the tanks after recovery. In addition to tank waste source types listed above, the TWRS program, specifically the privatization contractors, will produce secondary waste streams during their separations and immobilization steps. These wastes will be returned to DOE for final disposal.

In addition to the disposal of ILAW, releases to the environment originating from the SSTs must also be considered. Sixty-seven SSTs are known or assumed to have leaked. The *Tri-Party Agreement* (Ecology et al. 1989b) calls for approximately 99% of the waste volume in each of the 149 tanks to be removed. At present, sluicing is the method of choice for the removal of these wastes. It is believed that some contaminated liquid could be lost from each SST during recovery operations. Finally, each of the single- and double-shell tanks will contain some residual after wastes are recovered, separated, and solidified. These residuals will also release radioactive contamination to the surrounding environment in the future.

Some waste currently stored in tanks at the Hanford Site will remain at Hanford after closure in one of four forms (DOE and Ecology 1996). The majority will be an ILAW created from the incidental waste fraction recovered from tanks. Some will be in the form of a residual left in the tanks after waste recovery operations. These source inventories, ILAW from tanks, leaks and slurry losses from SSTs, residuals in SSTs, and residuals in double-shell tanks, are described in the following four sections.

The TWRS program has established standard inventories for chemicals and radionuclides in the tank wastes (Kupfer et al. 1997). The Kupfer et al. (1997) inventory is a best-basis global inventory. A best basis tank-by-tank estimate was also produced.(*) The fourth revision of the HDW model (Agnew et al. 1997) was also issued. Agnew et al. (1997) is a supporting document to the more recently published best-basis or standard inventory (Kupfer et al. 1997).

(*) From letter FDH-9757750 dated August 29, 1997 from D. J. Washenfelder (Fluor Daniel Hanford) to J. K. McClusky (DOE), "Contract Number DE-AC06-96RL 13200; Completion of Milestone T24-97-158, Contractor Letter to Department of Energy, Richland Operations Office, Reporting Completion of Standard Inventory Estimates for All Tanks."

5.7 IMMOBILIZED LOW-ACTIVITY WASTE FROM TANKS

The source inventory for the incident waste fraction of waste currently stored in single- and double-shell tanks is reported in the interim performance assessment for low-level tank waste (Mann et al. 1997, Table 3.1). Following recovery from the tanks, waste will be separated into high-level waste and incident waste fractions. The incident waste fraction will be immobilized and returned to the DOE for disposal as ILAW. The high-level fraction is to be returned to DOE for storage until it also is immobilized. After immobilization, it will be stored until the national high-level waste repository is opened, and then it will be shipped to the repository and disposed.

The inventory that appears in the interim performance assessment is fully documented (Schmittroth et al. 1995) as one among many data packages (Mann 1995) developed in support of the interim performance assessment. Plans call for these wastes to be disposed in two locations in four existing vaults and several new disposal vaults. The inventory of ILAW to be disposed in existing facilities is based on the fraction of the waste volume they can contain, and the total inventory reported by Mann et al. (1997). Table 5-6 shows the key radionuclide inventory assumed for each disposal location.

Table 5-6. Inventory of Key Radionuclides for TWRS Low-Activity Waste.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
TWRS glass grout vault	4.54E-01		3.91E-01	6.07E+01	1.32E+03	1.05E+00
TWRS glass new site	7.24E+00		6.23E+00	9.69E+02	2.10E+04	1.67E+01

a The waste inventory in each site is based on the fraction of waste volume in each site and the total inventory.
b Inventories are decayed to a common date of 2050.

5.8 SINGLE-SHELL TANK FARMS – TANK LEAKS AND SLURRY LOSSES

There are 12 SST farms containing 149 tanks on the 200 Area Plateau. Six tank farms (S, SX, T, TX, TY, and U) containing 83 tanks are located in the 200 West Area. Six tank farms (A, AX, B, BX, BY, and C) containing 66 tanks are located in the 200 East Area.

The TWRS program has published the initial retrieval sequence and blending strategy (Penwell et al. 1996). The retrieval operation is projected to occur over a 15-year period beginning in 2004 and ending in 2019. Penwell et al. (1996) provided detail on the retrieval sequence of each tank and each tank farm. The TWRS program is committed to revise annually the SST retrieval sequence, (Kirkbride et al. 1997). Using currently available leak detection and mitigation technologies, a tank leak could not be detected before 4,000 gal (15 m^3) has been released, and not stopped for most tanks before approximately 8,000 gal (30 m^3) had been released (WHC 1996). Consequently, the TWRS program assumed an average release volume per SST of 8,000 gal (30 m^3). This is a more current estimate than the 4,000 gal (15 m^3) per tank value assumed in the TWRS EIS (DOE and Ecology 1996). Conservative assumptions to establish an

upper bound on the amount of leakage from SST 241-C-106, and its potential impact resulted in a calculated leak volume of 40,000 gal (150 m^3) because of hydraulic sluicing of that tank (Lowe 1993). While an average loss volume of 8,000 gal (30 m^3) has been assumed, there are reasons to expect a lower average. For example, some tanks will have better leak detection and mitigation capabilities than others, and tanks that are confirmed leakers (~50 SSTs) are candidates for alternate cleanout technologies that use robotic arms or low-volume liquid methodologies or both being considered under the Hanford Tanks Initiative (HTI) project. Additionally, some of the tanks are known to have leaked from headers and not along the base of the tank. These tanks may be able to be sluiced with low risk for leakage to soils.

The mobile contaminate inventories for the SST farms are shown in Table 5-7.

Table 5-7. Inventory of Key Radionuclides for TWRS Single-Shell Tanks. (2 Pages)

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
TK-A-S[b]	9.43E-02	0.00E+00	2.81E-02	1.68E-02	3.31E+01	7.36E-04
TK-A-L[c]	1.10E+00	0.00E+00	1.83E-01	1.96E-01	1.25E+02	8.57E-03
TK-A-R[d]	2.11E+00		1.71E-03	8.33E-02	1.15E+00	1.52E-01
TK-AX-S-1[e]	8.00E-02	0.00E+00	0.00E+00	0.00E+00	1.68E+00	0.00E+00
TK-AX-S-2	3.14E-02	0.00E+00	9.38E-03	5.60E-03	1.10E+01	2.45E-04
TK-AX-L-1	1.50E-02	0.00E+00	0.00E+00	0.00E+00	0.3156146	0.00E+00
TK-AX-L-2	3.14E-02	0.00E+00	5.14E-03	5.60E-03	3.43E+00	2.45E-04
TK-AX-R-1	2.75E-02		3.90E-05	1.95E-03	2.68E-02	2.13E-03
TK-AX-R-2	1.37E-01		1.95E-04	9.74E-03	1.34E-01	1.07E-02
TK-B-S	5.03E-01	0.00E+00	8.23E-02	8.96E-02	5.48E+01	3.92E-03
TK-B-L	2.12E-01	0.00E+00	3.46E-02	3.77E-02	2.31E+01	1.65E-03
TK-B-R	4.98E+00		2.02E-02	1.01E+00	1.39E+01	3.41E-01
TK-BX-S	3.77E-01	0.00E+00	6.17E-02	6.72E-02	4.11E+01	2.94E-03
TK-BX-L	3.79E-01	0.00E+00	6.20E-02	6.75E-02	4.13E+01	2.96E-03
TK-BX-R	9.18E+00		4.78E-02	2.39E+00	3.28E+01	4.87E-01
TK-BY-S	3.77E-01	0.00E+00	6.17E-02	6.72E-02	4.11E+01	2.94E-03
TK-BY-L	1.61E-01	0.00E+00	2.64E-02	2.88E-02	1.76E+01	1.26E-03
TK-BY-R	2.18E+00		1.76E-02	8.83E-01	1.22E+01	7.93E-01
TK-C-S-1	5.80E-02	0.00E+00	2.16E-03	5.60E-03	3.27E+00	2.35E-04
TK-C-S-2	3.46E-01	0.00E+00	5.66E-02	6.16E-02	3.77E+01	2.70E-03
TK-C-L-1	1.50E-03	0.00E+00	1.80E-04	4.67E-04	2.02E-01	1.96E-05
TK-C-L-2	1.07E-01	0.00E+00	1.75E-02	1.91E-02	1.17E+01	8.35E-04
TK-C-R-1	9.49E-01		3.53E-03	1.68E-01	2.32E+00	3.05E-01
TK-C-R-2	8.79E-01		3.27E-03	1.55E-01	2.15E+00	2.83E-01
TK-S-S	3.14E-01	0.00E+00	5.99E-02	5.60E-02	4.95E+01	2.45E-03
TK-S-L	9.43E-02	0.00E+00	1.54E-02	1.68E-02	1.03E+01	7.36E-04
TK-S-R	3.82E+00		2.38E-02	1.19E+00	1.65E+01	1.82E-01
TK-SX-S-1	5.99E-03	0.00E+00	7.21E-04	1.87E-03	8.08E-01	7.84E-05
TK-SX-S-2	3.46E-01	0.00E+00	6.93E-02	6.16E-02	6.05E+01	2.70E-03
TK-SX-L-2	6.30E-01	0.00E+00	1.06E-01	1.12E-01	7.45E+01	4.92E-03

Table 5-7. Inventory of Key Radionuclides for TWRS Single-Shell Tanks. (2 Pages)

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
TK-SX-R-1	1.94E-01		2.17E-03	1.09E-01	1.50E+00	1.69E-02
TK-SX-R-2	1.68E+00		1.88E-02	9.50E-01	1.30E+01	1.47E-01
TK-T-S	5.03E-01	0.00E+00	8.23E-02	8.96E-02	5.48E+01	3.92E-03
TK-T-L	5.28E-01	0.00E+00	8.65E-02	9.41E-02	5.76E+01	4.12E-03
TK-T-R	1.50E-01		5.09E-04	2.57E-02	3.51E-01	8.05E-02
TK-TX-S	1.89E-01	0.00E+00	3.09E-02	3.36E-02	2.06E+01	1.47E-03
TK-TX-L	2.30E-01	0.00E+00	3.76E-02	4.09E-02	2.51E+01	1.79E-03
TK-TX-R	2.91E+00		1.35E-02	6.76E-01	9.34E+00	1.56E+00
TK-TY-R	4.81E-01		5.34E-03	2.68E-01	3.68E+00	7.78E-02
TK-U-S	4.40E-01	0.00E+00	8.05E-02	7.84E-02	6.32E+01	3.43E-03
TK-U-L	3.99E-01	0.00E+00	6.53E-02	7.11E-02	4.35E+01	3.11E-03
TK-U-R	1.35E-01		1.32E-03	6.52E-02	9.08E-01	3.10E-01

a Inventories are decayed to a common date of 2050.
b "S" refers to sluicing losses during recovery of tank wastes. The inventory is based on an 8,000-gallon-per-tank loss and radionuclide concentrations developed from tank characterization reports.
c "L" refers to past tank leaks as identified in Hanlon (1997). The inventories are based on leak volumes from Hanlon and radionuclide concentrations developed from tank characterization reports.
d "R" refers to residual wastes remaining in tank after tank waste recovery. Inventories are based on 1% of tank farm inventory reported in the TWRS EIS (DOE and Ecology 1996).
e "1" and "2" refer to complexed and non-complexed waste, respectively.

5.9 SINGLE-SHELL TANK FARM RESIDUALS

Source inventories for the tank wastes were recently compiled and published in the TWRS EIS (DOE and Ecology 1996). The inventory for the no-action alternative of the TWRS EIS (DOE and Ecology 1996, Figure 2.2.2 in Appendix F) was an estimate of the contents of the tanks. Regarding the residuals remaining after the tank wastes are recovered, the TWRS EIS (DOE and Ecology 1996) states:

> "The amount and type of waste that would remain in the tanks after retrieval is uncertain. The Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) (Ecology et al. 1994) set a goal of no more than 1 percent residuals and the ex situ alternatives have been developed to attempt to achieve that goal. However, achieving this level of tank waste retrieval may require extraordinary efforts and cost and it may not be practical to achieve 99 percent retrieval. Conversely, the contaminants that are not recovered are likely to be those that are insoluble in water since substantial quantities of water would be used in an attempt to dissolve or suspend the waste in water during retrieval. Since neither of these issues can be resolved, a conservative assumption was made to bound the impacts of the residual waste. For purposes of this analysis it was assumed that 99 percent recovery would be achieved but that the residual would contain 1 percent of all the contaminants including the water soluble contaminants."

As in the TWRS EIS, the Composite Analysis estimate of residual was assumed to be 1% of the original inventory. One percent of each radionuclide was assumed to remain in the tank farms following completion of waste recovery (Table 5-7). In general, radionuclides with long decay half-lives and potentially significant geochemical mobility have been shown to contribute significantly to long-term dose. The 1% residual is believed to overestimate the inventories of these radionuclides (i.e., ^{14}C, ^{79}Se, and ^{99}Tc) that remain in the tanks following Hanford Site closure.

In the release model for tank residuals, leachate concentrations from residual tank wastes were defined as a function of nitrate dissolution (i.e., a maximum nitrate concentration of 360 g/L is maintained) with congruent release of all radionuclides. Thus, the nitrate inventory, water infiltration rate, and solubility of nitrate define the time required for nitrate to be leached from residual wastes. All radionuclides were assumed to linearly release over the same time.

5.10 DOUBLE-SHELL TANK FARM RESIDUALS

There are six double-shell tank farms in the 200 Areas at the Hanford Site. The SY Tank Farm contains three tanks and is located in the 200 West Area. The AN, AP, AW, AY, and AZ Tank Farms contain 25 tanks and are all located on the eastern side of the 200 East Area. The source inventories for the double-shell tank wastes were also recently compiled and published in the TWRS EIS (DOE and Ecology 1996). As for the SSTs, the inventory for the no-action alternative (DOE and Ecology 1995, Table F.2.2.2 in Appendix F) was an estimate of double-shell tank contents and is the basis for estimating residuals to be left in these tanks. As in the case of the SSTs, a 1% residual is assumed in the double-shell tanks upon completion of waste recovery operations. Therefore, the only assumed release from double-shell tanks is the leaching of a 1% residual. The TWRS EIS inventory spreadsheet (DOE and Ecology 1996) contained the necessary tank farm data for ^{14}C and ^{99}Tc, and 1% of the no-action alternative inventory is employed in this release (Table 5-8). Chlorine-36, ^{79}Se, and ^{238}U inventories were not included for double-shell tanks in the TWRS EIS. As in the case of the SSTs, the 1% residual is believed to overestimate the inventories of mobile and long-lived radionuclides in the tanks after completion of waste recovery. As in the case of SST residuals, nitrate dissolution and congruent release of radionuclides was assumed to occur after the high-integrity structure and remediation delay release for 500 years.

5.11 LIQUID DISPOSAL

Since initial processing of irradiated fuels began in 1944, liquid wastes containing radionuclides have been discharged to the subsurface. These large liquid discharges have resulted in water table rises of approximately 24.4 m (80 ft) in the 200 West Area and approximately 9.1 m (30 ft) around the ponds near the 200 East Area (Law et al. 1996). In the past decade this practice has nearly ended; liquid waste discharges continue at only a few sites (e.g., the 200 Area Treated Effluent Disposal Facility [TEDF], the State-Approved Land Disposal Site [SALDS], and the 400 Area discharge ponds). This reduction in liquid disposal will result in the Hanford Site groundwater levels eventually reaching pre-Hanford levels. This will have a significant effect on the routing and movement of contaminants in the aquifer, especially at locations on the Hanford

Table 5-8. Inventory of Key Radionuclides for TWRS Double-Shell Tanks.

Site Name	Radionuclide Inventory[a] in Curies[b]					
	C-14	Cl-36	I-129[c]	Se-79	Tc-99	U-238
TK-AN-R-1[d, e]	8.28E+00				5.56E+01	
TK-AN-R-2	1.14E+01				7.64E+01	
TK-AP-R-1	1.00E-03				2.63E-01	
TK-AP-R-2	2.80E-02				7.35E+00	
TK-AW-R	2.31E-02				8.38E+00	
TK-AY-R-1	3.57E-04				2.77E+00	
TK-AY-R-2	3.29E-04				2.55E+00	
TK-AZ-R	3.48E+00				2.10E+01	
TK-SY-R-1	6.03E-03				2.75E+01	
TK-SY-R-2	1.98E-03				9.05E+00	

a Chlorine-36, selenium-79, and uranium-238 were not reported in the TWRS EIS (DOE and Ecology 1996).
b Inventories decayed to a common date of 2050.
c Iodine-129 is reported in the TWRS EIS, but on a tank-farm-group basis, instead of a tank-farm basis. Therefore iodine-129, which has a total inventory of 22.3 Ci (DOE and Ecology 1996) all in double-shell tanks, is not reported here.
d "R" refers to residual wastes remaining in the tank after the tank waste recovery. Inventories are based on 1% of the tank farm inventory reported in the TWRS EIS (DOE and Ecology 1996).
e "1" and "2" refer to complexed and noncomplexed waste, respectively.

Site where the permeability of the Hanford formation currently dominates the total transmissivity of the system. Past discharges occurred to subsurface facilities including cribs, trenches, french drains, and reverse wells. Large volumes of cooling water and steam condensate generated by chemical separations facilities and evaporators were discharged to surface ponds and ditches. Some of the more significant liquid discharges to the subsurface were the intentional discharge of approximately 120 million gallons (4.5×10^8 L) of tank waste in various forms, e.g., first-cycle supernatant, second-cycle supernatant, and scavenged uranium recovery wastes. These sites are designated past-practice units and their remediation, final closure, and end states will be addressed through the CERCLA process.

5.12 REACTOR CORES

Nine graphite core production reactors were operated at the Hanford Site between 1944 and 1987. Based on the EIS for the eight surplus reactors (DOE 1989), a ROD was issued to follow a safe storage period with one-piece removal of the reactors to the plateau (ROD 1993). Safe storage at their current location along the Columbia River in the 100 Areas would occur for less than 75 years. Then, each reactor block would be transported intact on a tractor-transporter, from its present location to a 200 West Area burial ground for disposal. Since the EIS and ROD were issued, the B Reactor has been declared a national historic monument. Accordingly, it is possible it will be left at its current location along the Columbia River. This reduces the number

of reactors affected by the ROD to seven. The N Reactor was not included in the surplus reactor EIS, and it is probable that it will be removed to the 200 West Area burial ground. Thus, eight reactors are assumed disposed on the 200 Area Plateau in this analysis.

Alternatives for decommissioning the Hanford production reactors were evaluated in a draft EIS (DOE 1989), and its final supplement (DOE 1992). The ROD (1993) states the preferred alternative is for the surplus production reactors to be disposed in the 200 West Area. The EIS evaluated eight of the nine production reactors, omitting the N Reactor because it was not shut down when the study was done. The B Reactor was included in the EIS; however, since then, the B Reactor has been declared a national historic monument and may be preserved for future public display at its present location (ROD 1993). Thus, the EIS contains information on seven reactors, C, D, DR, F, H, KE, and KW, that will be moved to the plateau when the ROD is implemented.

The source inventories for the seven production reactors were derived from Appendix A of the surplus production reactor EIS (DOE 1989, 1992). Twenty radionuclides were included, including tritium, ^{14}C, ^{36}Cl, ^{99}Tc, and ^{238}U. Mobile and long-lived radionuclides of interest in other DOE wastes that were not represented in the graphite cores include ^{79}Se and ^{129}I. The ERC provided an inventory for the graphite core of the N Reactor.(*) The N Reactor core was assumed to be disposed concurrently with the other seven reactor cores in the 200 West Area. Inventories for each of the reactors are shown in Table 5-9.

Table 5-9. Inventory of Key Radionuclides for the Decommissioned Reactor Cores.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129[c]	Se-79[c]	Tc-99	U-238
C Reactor	4.47E+03	1.20E+01			2.00E-03	4.00E-03
D Reactor	4.27E+03	3.40E+01			2.00E-03	0.00E+00
DR Reactor	3.18E+03	2.60E+01			2.00E-03	0.00E+00
F Reactor	3.68E+03	3.30E+01			2.00E-03	0.00E+00
H Reactor	3.48E+03	1.70E+01			2.00E-03	0.00E+00
KE Reactor	6.95E+03	5.40E+01			3.30E-02	0.00E+00
KW Reactor	6.66E+03	5.20E+01			3.30E-02	0.00E+00
N Reactor	9.49E+03	7.50E+01			3.30E-02	0.00E+00

a Inventories were from Appendix A of the draft EIS *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington* (DOE 1989) for all reactors except N Reactor. The N Reactor inventory was provided by V. G. Edens (from Interoffice Memorandum #042809; Subject, "105N and 107N Hazardous Assessment [Inventories]"; sent by R. S. Day to V. G. Edens of Hanford Environmental Restoration contractor; February 11, 1997).

b Inventories were decayed to a common date of 2050.

c Neither iodine-129 nor selenium-79 were reported in the inventories for the decommissioned reactor cores.

(*) The N Reactor inventory was provided by V. G. Edens (from Interoffice Memorandum #042809; Subject, "105 N and 107 N Hazardous Assessment [Inventories]"; sent by R. S. Day to V. G. Edens of Hanford Environmental Restoration Contractor; February 11, 1997).

Chemical Separation Canyons or Process Facilities

Facilities in which the chemical separations were conducted are long, monolithic, concrete structures. These are known as the canyon buildings, and are identified as the 221-B or B Plant, 221-T or T Plant, and other facilities. There are also related nearby structures used in additional process steps (e.g., the 224-B and 224-T Buildings) and storage facilities (e.g., the two subsurface tunnels at PUREX). Two canyon buildings are in the 200 East Area: B Plant and PUREX. Four canyon buildings are in the 200 West Area: T Plant, U Plant, REDOX, and Z Plant (PFP). In general, these structures contain inventories of mixed fission products and mixed activation products; however, they are in fixed or immobile settings inside metal vessels and piping and contained inside monolithic concrete cells. The end state of these structures and associated facilities is being defined through negotiations with regulators; however, the current baseline assumes canyon facilities will be demolished to the cover block grade with the remaining structure covered with a surface barrier.

In the case of each canyon building, the major radionuclide sources and waste within the retired plant will be removed, reduced, or stabilized. Radiological contamination within the facility will be removed or fixed in place. The canyon buildings are massive concrete structures, and concrete is an excellent waste form for sorbed radionuclides. Whatever structure is left in place will be stabilized (i.e., filled with soil, gravel, or concrete) and all services (such as water) will be disconnected. Retired filters will be isolated and stabilized to ensure a safe condition. It is likely that these areas and especially any remaining structure will be covered with a protective barrier to further isolate contamination from intrusion and recharge. Final disposals will be dry with minimal driving force to mobilize and transport radionuclides from facilities.

The PUREX storage tunnels (#1 and #2) branch off from the PUREX railroad tunnel and extend southward from the east end of the PUREX plant. The tunnels are used for storage of mixed waste (e.g., spent equipment and tank cars) from the PUREX Plant and from other onsite sources. The radiological contamination in the tunnels consists primarily of uranium, TRUs, and/or mixed fission products. Currently, each storage tunnel is isolated from the railroad tunnel by a water-filled shielding door. Tunnel #1 is constructed of creosote-treated timber covered by roofing material and 2.4 m of earthen fill. Tunnel #2 is constructed of steel and reinforced concrete covered with 2.4 m of earthen fill.

5.13 COMMERCIAL LLW DISPOSAL FACILITY

The commercial LLW disposal facility opened in 1965 on 100 acres located southwest of the 200 East Area. The LLW that is packaged and shipped for disposal at the facility comes from medical practices, scientific research, industrial processes, and nuclear power plants. Prior to 1993, LLW came from throughout the United States to this site; but today LLW comes only from Washington, Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Wyoming, Colorado, Nevada, and New Mexico. Naturally occurring radioactive materials can still come from all 50 states. The US Ecology Site is regulated by the DOH and Ecology, and is expected to close by 2063.

The closure plan for the commercial LLW site operated by US Ecology on the Hanford Site (Grant Environmental, Chase Environmental Group, and US Ecology 1996) presents a total inventory to date and a projection for disposal at the site until its closure in 2063. The inventory was screened according to two criteria, total activity greater than 1 Ci and decay half-life in excess of 100 years. Of the radionuclides identified for further analysis, several have K_ds at or only slightly greater than zero, including ^{14}C, ^{36}Cl, ^{129}I, ^{40}K, ^{99}Tc, and ^{238}U. While all the other radionuclides were identified in prior analyses, ^{40}K was identified as a contaminant of potential concern.

The inventory for the commercial LLW disposal site operated by US Ecology was derived from the recently completed site stabilization and closure plan. The inventory is reported by Grant Environmental, Chase Environmental Group, and US Ecology (1996, in Volume II, Attachment 3 of Attachment D, subsection "Source Term" in section "Pathways Analysis Report"). A detailed accounting of inventory is presented in the same document (page 3.6, Table 3.1, and page 3.12, Table 3.7). The key radionuclides inventory of the commercial disposal site includes inventories for ^{14}C, ^{36}Cl, ^{99}Tc, ^{129}I, and uranium (see Table 5-10). Of the more mobile radionuclides thought to be of concern in DOE wastes at Hanford, ^{79}Se was the only one for which no data were available in the detailed inventory.

Table 5-10. Inventory of Key Radionuclides for US Ecology.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79[c]	Tc-99	U-238
US Ecology current	3.66E+03	3.44E+01	5.63E+00		6.17E+01	1.08E+04
US Ecology future	1.91E+02	6.00E-02	1.40E-01		3.91E+00	1.21E+02

a Total inventories were taken from the *Site Stabilization and Closure Plan for Low-Level Radioactive Waste Management Facility, US Ecology, Inc., Richland, Washington* (Grant Environmental, Chase Environmental Group, and US Ecology 1996).

b Inventories decayed to a common date of 2050.

c The absence of selenium-79 from the commercial LLW disposal is a result of commercial waste not having a significant source of this radionuclide.

After receiving the site stabilization and closure plan for the commercial LLW disposal site, the DOH decided to complete a *State Environmental Policy Act* (SEPA) EIS for the site. The DOH has developed its own inventory for the commercial disposal site(*). Minor differences exist between the DOH and Grant Environmental, Chase Environmental Group, and US Ecology (1996) inventories. One similarity is that ^{79}Se is also absent from the DOH inventory. Its absence from the commercial inventory is because it is an inconsequential nuclide in the waste streams accepted at the commercial disposal facility. Where there is a large discrepancy for a key mobile radionuclide (e.g., ^{36}Cl), the inventory from the stabilization and closure plan is conservative. However, in one instance the DOH inventory is larger. For ^{14}C, which is slightly sorbed, it shows an inventory of 4,909 Ci, whereas the stabilization and closure plan inventory

(*) From two electronic mail messages; Subject, "Comments for Composite Analysis": 1) from A. H. Thatcher (DOH, Olympia, Washington) to R. D. Hildebrand (DOE-RL), dated February 2, 1998; 2) from M. Dunkelman (DOH, Olympia, Washington) to R. D. Hildebrand (DOE-RL), dated January 28, 1998.

shows 3,850 Ci. Although assigning a higher initial inventory, the DOH assumed 55% of the ^{14}C was biodegradable and that the entire inventory was released through the gas phase to the atmosphere.

5.14 RADIONUCLIDES INCLUDED IN THE GROUNDWATER PATHWAY

Groundwater plumes of tritium, ^{90}Sr, ^{99}Tc, and ^{129}I exist in the unconfined aquifer at the Hanford Site. Curie or gram content in groundwater has been estimated in the *Hanford Sitewide Groundwater Remediation Strategy* (DOE-RL 1995c) (Table 5-11).

Radionuclides included in the groundwater pathway analysis for future sources are ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, and $^{233, -234, -235, -236, -238}U$ and their daughters. This list is the result of merging the two lists from the ILAW from tanks and the solid waste burial grounds. In addition, the RI/FS for the ERDF and other environmental impact statements (DOE 1989, 1992 and 1996a; DOE-RL 1994b; DOE and Ecology 1996) were reviewed, and no other radionuclides were identified as potentially significant contributors to groundwater pathway dose.

Because of its mobility and its disposal to cribs in relatively large volumes of liquid waste, tritium is assumed to be in the aquifer and not significantly retained in the vadose zone. Strontium is highly sorbed in the aquifer and does not pose a threat outside the buffer zone when the source is inside the exclusive waste management area and buffer zone. Strontium-90 will be shown to contribute to dose, but only in the immediate vicinity of these releases.

Table 5-11. Contaminant Plume Dimensions and Volumes.

Project	Target Contaminants	Quantity				Extent of Contamination		
		In Pore Fluid		On Aquifer Solids		Area		Pore Fluid Volume
		(Ci)	(g)	(Ci)	(g)	(m^2)	(mi^2)	(L)
200 West Area								
200-UP-1[a]	Uranium	N/A	1.4E+5	N/A	2.5E+11	5.7E+5	2.2E-1	5.7E+8
	Technetium-99	1.5	9.7E+1	0	0	4.4E+5	1.7E-1	4.2E+8
200-ZP-1[a]	Carbon tetrachloride	N/A	5.3E+6	N/A	-[d]	1.0E+7	3.9	1.1E+10
	Chloroform	N/A	4.3E+4	N/A	-[d]	2.0E+6	7.7E-1	2.0E+9
	Trichloroethylene	N/A	9.7E+3	N/A	-[d]	8.3E+5	3.2E-1	8.3E+8
200 East Area								
B-5Reverse Well[a]	Plutonium-239	1.0E-1	1.6	2.4E+2	4.3E+3	3.1E+2	1.2E-4	7.8E+5
	Cesium-137	8.1E-4	9.3E-6	2.4E-1	9.3E-6	3.1E+2	1.2E-4	7.8E+5
	Strontium-90	4.1E-2	2.9E-4	6.2	4.4E-2	6.6E+4	2.5E-2	1.7E+8
	Technetium-99	18.0	1.0E+3	0	0	2.7E+6	1.0	6.7E+9
	Cobalt-60	3.7E-2	3.3E-5	0	0	9.3E+4	3.6E-2	2.3E+8
Reactor Areas								
100-K Area[b]	Chromium	N/A	2.5E+5	N/A	0	1.3E+6	5.0E-1	1.7E+9
	Strontium-90	2.1E-2	1.5E-4	3.2	2.3E-2	4.0E+5	1.5E-1	5.1E+8
100-D Area[b]	Chromium	N/A	5.9E+5	N/A	0	2.6E+6	1.0	2.9E+9
	Strontium-90	6.6E-4	4.7E-6	9.9E-2	7.0E-4	1.8E+4	6.9E-3	2.2E+7
100-H Area[b]	Chromium	N/A	2.5E+5	N/A	0	2.1E+6	8.1E-1	2.6E+9
	Strontium-90	6.6E-4	4.7E-6	9.9E-2	7.0E-4	1.8E+4	6.9E-3	2.2E+7
100-F Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	7.5E-3	5.3E-5	1.1	7.9E-3	7.5E+4	2.9E-2	9.4E+7
100-N Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	8.8E-2	7.4E-3	1.3E+1	1.1E+0	8.2E+5	3.1E-1	6.5E+8
100-B/C Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	2.6E-2	1.9E-4	3.9E+0	2.8E-2	7.6E+5	2.9E-1	9.5E+8
Sitewide								
Sitewide[c]	Tritium	2.5E+4	1.8E+1	0	0	1.9E+8	7.3E+1	5.3E+11
	Iodine-129	1.2E+0	8.4E+3	0	0	7.5E+7	2.9E+1	3.7E+11
	Nitrate	N/A	4.1E+10	N/A	0	5.5E+7	2.1E+1	1.6E+11
Other Areas								
1100	Trichloroethylene	N/A	41.4 E+3	N/A	-[d]	4.8 E+5	2.0 E-1	1.2 E+9
300[b]	Uranium (DOE-RL 1995c)	.04	6.1E+4	0.47	6.7E+5	5.6E+5	2.2E-1	0.8E+9

a Assumes that plumes have an average thickness of 10 m (32 ft).
b Assumes that plumes have an average thickness of 5 m (16 ft).
c Assumes plume thickness as described in Section 4.2.2.
d No estimates available.

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