

**Groundwater/Vadose Zone Integration Project
Inventory Scoping Study for
the System Assessment
Capability**

**Groundwater/Vadose Zone Integration Project
Inventory Scoping Study for the
System Assessment Capability**

October 1999

TABLE OF CONTENTS

1.0	INTRODUCTION	1-1
1.1	PURPOSE	1-2
1.2	APPROACH	1-3
2.0	CURRENT HANFORD CONSTITUENT INVENTORY	2-1
2.1	WIDS DATABASE	2-1
2.2	TWINS2/BEST-BASIS INVENTORY DATABASES.....	2-1
2.2.1	Hanford Site Bounding Inventory Estimates	2-2
2.3	US ECOLOGY LOW-LEVEL WASTE DISPOSAL SITE	2-5
2.4	SAC DATABASE EFFORTS.....	2-5
2.4.1	Waste Site Groupings.....	2-6
2.5	HANFORD FACILITIES	2-10
2.6	INVENTORY WEAKNESSES	2-11
2.6.1	WIDS.....	2-12
2.6.2	Best-Basis Inventory	2-12
2.6.3	100 Area Characterization.....	2-14
2.6.4	ERDF.....	2-14
2.7	HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION RIVER RELEASE INVENTORIES	2-14
2.7.1	Routine Reactor Releases.....	2-15
2.7.2	Fuel Element Failures.....	2-16
2.8	EXISTING GROUNDWATER PLUMES	2-18
2.9	DIFFUSE ATMOSPHERIC SOURCES AND FALLOUT RUN-OFF	2-20
2.10	SUMMARY INVENTORIES.....	2-22
3.0	SCOPING MODEL FOR ENVIRONMENTAL TRANSPORT	3-1
3.1	THEORETICAL DESCRIPTION	3-1
3.2	STELLA APPLICATION.....	3-6
3.3	VALIDATION OF SCOPING MODEL PREDICTIONS.....	3-16
4.0	SCOPING BENCHMARKS	4-1
4.1	NATIVE AMERICAN HUMAN EXPOSURE SCENARIO	4-1
4.2	ECOSYSTEM BENCHMARKS	4-18
4.3	BACKGROUND/DETECTABILITY AS A SURROGATE FOR SOCIO-CULTURAL IMPACTS.....	4-22
5.0	REGULATORY DRIVERS	5-1

Table of Contents

6.0	SCOPING RESULTS	6-1
6.1	HUMAN HEALTH.....	6-2
6.2	ECOSYSTEM IMPACTS.....	6-2
6.3	SOCIO-CULTURAL IMPACTS.....	6-2
6.4	OTHER CONSIDERATIONS.....	6-3
6.4.1	SAC Transport Model Inputs.....	6-3
6.4.2	Validation and Groundwater Transport History Matching.....	6-3
6.4.3	Regulatory Influences.....	6-4
6.4.4	Public Interest.....	6-5
6.5	SUMMARY.....	6-5
7.0	RECOMMENDATIONS	7-1
8.0	REFERENCES	8-1

APPENDICES

A	SCOPING MODEL FOR ENVIRONMENTAL TRANSPORT.....	A-1
B	FUEL FAILURE RELEASES TO THE COLUMBIA RIVER.....	B-1
C	NECESSARY PARAMETERS.....	C-1
D	NATIVE AMERICAN SCENARIO RADIONUCLIDE AND CHEMICAL SPREADSHEETS.....	D-1
E	RADIOLOGICAL AND CHEMICAL PARAMETERS.....	E-1
F	NUMERICAL RESULTS OF SCOPING STUDIES.....	F-1

FIGURES

3-1.	Simple Scoping Contaminant Transport Model.....	3-2
3-2.	STELLA Representation of Contaminant Scoping Transport Model.....	3-6
3-3.	Influence of K_d on Peak Release Concentration for a Unit Inventory of Nondecaying Material in the 200 Areas.....	3-8
3-4.	Influence of K_d on Time to Peak Release for a Nondecaying Material in the 200 Areas.....	3-8

Table of Contents

TABLES

2-1.	Radionuclide Quantities Included in the Tank Global Inventory	2-3
2-2.	Chemical Components Included in the Tank Global Inventory.....	2-4
2-3.	SAC Inventory Waste Categories	2-8
2-4.	Examples of Major Facilities at Hanford.	2-10
2-5.	Inventories in the 200 Area Processing Facilities	2-11
2-6.	Cumulative Radionuclide Release to the Columbia River from Hanford Once-Through-Cooled Plutonium Production Reactors.	2-15
2-7.	Radionuclides Released to the Columbia River From Fuel Failures	2-16
2-8.	Peak Concentrations in Groundwater Plumes on the Hanford Site	2-18
2-9.	Comparison of Bomb-Testing Fallout and Hanford Releases of Selected Radionuclides.	2-22
2-10.	Site Inventories Available in the SAC Database by Waste Site Grouping Type.....	2-23
2-11.	100 Area Radionuclide Inventory Summary by SAC Waste Type Grouping.	2-26
2-12.	200 Area Radionuclide Inventory Summary by SAC Waste Type Grouping	2-27
2-13.	100 Area Chemical Inventory Summary.....	2-29
2-14.	200 Area Chemical Inventory Summary.....	2-30
2-15.	All Other Area Chemical Inventory Summary.	2-32
3-1.	Common Parameters use in Transport Modeling.....	3-7
3-2.	Peak Groundwater and Surface Water Concentrations for Unit Releases in the 100 and 200 Areas (Radionuclides)	3-9
3-3.	Peak Groundwater and Surface Water Concentrations for Unit Releases in the 100 and 200 Areas (Chemicals)	3-12
4-1.	Exposure Factors for the Native American Subsistence Resident Scenario	4-3
4-2.	Surface Water Concentration Values and References Used as Benchmarks for the Scoping Analysis, $\mu\text{g/L}$	4-19
4-3.	Background Levels of Radionuclides in Hanford Site Groundwater, fCi/L	4-23
4-4.	Background Concentrations of Chemicals in Hanford Site Groundwater.	4-24
5-1.	Pertinent Federal Laws, Regulations, and DOE Orders.....	5-3
5-2.	Pertinent State of Washington Laws and Regulations	5-14
6-1.	Radionuclides and Chemicals Identified by the Various Scoping Criteria.....	6-1

ACRONYMS

ARAR	applicable or relevant and appropriate requirements
ASCII	American Standard Code for Information Interchange
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CFR	<i>Code of Federal Regulations</i>
CRCIA	<i>Columbia River Comprehensive Impact Assessment</i>
DOE	U.S. Department of Energy
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FFTF	Fast Flux Test Facility
FY	fiscal year
GW/VZ	Groundwater/Vadose Zone
HDW	Hanford Defined Wastes
HEAST	Health Effects Assessment Summary Tables
HEDR	Hanford Environmental Dose Reconstruction
HEIS	Hanford Environmental Information System
HLW	high-level waste
HRA-EIS	Hanford Remedial Action Environmental Impact Statement
HSRAM	<i>Hanford Site Risk Assessment Methodology</i>
HTCE	Historical Tank Contents Estimate
IAEA	International Atomic Energy Agency
IRIS	Integrated Risk Information System
LLW	low-level waste
MCL	maximum contaminant levels
MTCA	<i>Model Toxics Control Act</i>
MUST	miscellaneous underground storage tank
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission
PCB	polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest National Laboratory
PUREX	Plutonium Uranium Extraction (Facility)
RCRA	<i>Resource Conservation and Recovery Act</i>
REDOX	Reduction Oxidation (Plant)
RPP	River Protection Program
RTECS	<i>Registry of Toxic Effects of Chemical Substances</i>
SAC	System Assessment Capability
SWITS	Solid Waste Inventory Tracking System
TCD	Tank Characterization Database
TCR	Tank Characterization Report
TLV	threshold limit value
TRAC	Track RadioActive Components
TRU	transuranic

Acronyms

TSCA	<i>Toxic Substances Control Act of 1976</i>
TVD	Tank Vapor Database
TWINS	Tank Waste Information Network System
TWRS	Tank Waste Remediation System
WAC	<i>Washington Administrative Code</i>
WESF	Waste Encapsulization and Storage Facility
WIDS	Waste Inventory Data System

1.0 INTRODUCTION

The Groundwater/Vadose Zone (GW/VZ) Integration Project has undertaken an effort to perform an assessment of future Hanford Site impacts on water resources including the Columbia River, living systems, cultures and regional socioeconomics. The capability to perform this assessment is called the System Assessment Capability (SAC).

During operations, Hanford derived radionuclides and hazardous chemicals were discharged directly to the Columbia River via reactor cooling water discharge. During these operations, monitoring programs were able to trace radionuclides of Hanford origin to the mouth of the Columbia River and along the Pacific coast as far north as the Straits of Juan de Fuca and as far south as southern Oregon. Wastes were also discharged to ground near the Columbia River shoreline resulting in rapid movement of contaminants to the river and downstream. Wastes were also placed in trenches and underground tanks for storage and were discharged to the soil at sites farther from the river. Some of the material stored in these facilities has leaked, and in other cases was directly discharged, and has contaminated the soil column and groundwater beneath the site.

The planned SAC assessment is being designed to focus on the movement of wastes remaining in Hanford facilities, in soils surrounding those facilities and in the groundwater. The assessment will represent how these wastes will move and determine what their impact will be on human health, ecological health, cultures and the economy of the region. Addressing this question will require the determination of the location and mass of wastes remaining at Hanford and identifying how those wastes will release into the environment. In most cases the initial release will be to the vadose zone. How wastes move through the vadose zone and groundwater must be understood so that the location and concentration of these materials in the future can be predicted. Of particular interest are if, where, and when the contaminants will discharge to the Columbia River and what their fate will be in the river. This includes understanding the role of biotic transport. Finally, how the contaminants will effect living systems and the cultural and socioeconomic impacts of their presence must be assessed. To support the SAC assessment, conceptual models for the waste inventory and its release, vadose zone, groundwater, Columbia River, and risk and impact technical elements are being developed.

The requirements of the *Columbia River Comprehensive Impact Assessment (CRCIA)*, Part II (DOE-RL 1998) define a Candidate Contaminants Set that includes all known radionuclides and potentially harmful chemicals on the Hanford Site. A Candidate Inventories Set is required that defines the amounts and locations of the contaminants. These candidate sets are to be evaluated through a series of iterative screenings, resulting in a Contaminants and Inventories Study Set. The inventories set needs to contain information about the physical and chemical forms of the waste and its containers to allow assessment of the contaminant release rates into the vadose zone and/or groundwater.

This report describes a screening process implemented to reduce the Candidate Contaminants Set to the initial Study Set. This screening process systematically identifies the key contaminants.

Introduction

At this time, it has not been determined whether the initial SAC efforts will address only a proposed future “cleaned-up” Hanford Site, a baseline condition similar to today’s conditions, or some combination. Therefore, this report mainly discusses wastes currently at the site in their current conditions. This should serve the needs of the initial Study Set determination.

This introduction describes the purpose of the current screening analysis and its general approach. Section 2.0 provides a summary discussion of available information about the Hanford Site and its inventories of radionuclides and chemicals. The simple screening model developed to estimate upper bounds of future environmental concentrations of these contaminants is described in Section 3.0. The screening benchmarks used in the analysis are defined and explained in Section 4.0. A brief discussion of regulatory issues is presented in Section 5.0. The numerical results of the scoping analysis are presented in Section 6.0, with results and recommendations summarized in Section 7.0. Section 8.0 supplies references. Supporting information on the SAC initial inventory database, the scoping models, necessary parameters, and numerical screening results is presented in appendices.

1.1 PURPOSE

CRCIA Part II defines the Candidate Set of possible contaminants to be considered in site-wide analyses as the set of all identifiable masses of materials and contaminants that could cause harmful effects to humans, ecosystems, or cultures. Criteria were developed to define this Candidate Set for radionuclides and chemicals at the Hanford Site. These criteria are:

- **For radionuclides**, any Hanford produced or imported radionuclide in excess of 1 curie (when generated or imported) and with a half life greater than 5 years will be considered.
- **For chemicals**, anything imported, manufactured, or produced (*note: produced is meant to represent secondary products or waste*) at Hanford for use in operations or disposal, as well as any additional contaminant identified in the monitoring and characterization programs will be considered. (*Note -this criterion captures the principles of chemicals purchased and brought onto the site and changes in chemicals brought on by chemical and biological activity*).

This report describes a screening process implemented to reduce the Candidate Contaminants Set to the initial Study Set. This screening process systematically identifies the key contaminants.

In order to support the screening, a substantial amount of information about the Hanford Site, its operations and history, and current and projected status is needed. A secondary object of this report is to provide an initial structure and contents for a SAC source term database.

In the process of compiling the initial inventory database, a large amount of currently-available information was organized. A final objective of this report is to provide the SAC information about the following:

- What is known
- What is present

Introduction

- What is missing
- What must be planned for future work.

1.2 APPROACH

A set of criteria was developed by the SAC team regarding the collection of contaminant-related information into “inventories” - those locations on the Hanford Site that now or in the future will actually contain the contaminants. These criteria are:

- Any locations or facilities of known past or proposed future radionuclide or chemical processing, storage, disposal, or accidental release will be considered. Locations with unique materials will be given particular attention.
- The locations must contain quantities of the contaminants identified in the Candidate Contaminants Set.
- A physical description of each location must be provided.

These two sets of criteria (i.e., for defining radionuclides and chemicals of interest, and establishing inventories) are used to define a Study Set. CRCIA Part II defines a Study Set to be a subset of the corresponding candidate set that is to be used for the assessment analysis. Elements of the study set are to be represented explicitly in the assessment analysis. It is uniquely defined for one or more iterations of the assessment analysis.

Study sets are defined for use in the problem at hand. The overall purpose of current SAC efforts is to perform a cumulative assessment of Hanford impacts. The purpose of the Study Sets is to allow development of the SAC and support a “Rev. 0” demonstration (proof-of-principle) assessment by the end of fiscal year 2000 (FY00). The Study Sets must include those sites containing radionuclides and chemicals that are important to human and ecological health, socioeconomic and cultural impacts, and system modeling and validation. Importance is defined later in this report in terms of each of these attributes.

The approach involves a screening assessment that:

1. Identifies a performance indicator (like risk)
2. Conducts a screening analysis
3. Selects those contaminants that exceed the indicator (in accordance with the concept of dominance), over some accepted threshold value.

The locations of processing or waste handling are incorporated into the screens.

Introduction

The performance indicators fall into the categories of human health, ecological health, socioeconomic and cultural impact, modeling requirements and validation, regulatory drivers, and public interest. Because there are a large number of source locations and all source locations may not be equally important with respect to system impact, a process for focussing efforts on key sites has been developed. A simplified screening model has been developed to predict potential maximal concentrations in these media from their current locations. Quantities of potential contaminants of concern from the Candidate Set are estimated for aggregate waste site groupings based on geographic location. Criteria for determining the contents of the Study Set were developed:

- **For human health**, individual risk of cancer, evaluated using a consistent exposure scenario for all media that includes exposures at various ages to several common exposure pathways, will be estimated with Cancer Potency Factors from the Health Effects Assessment Summary Tables (HEAST) (or an appropriate substitution made) for chemicals and from Federal Guidance Reports for radionuclides. Individual noncancer effects, evaluated using a consistent exposure scenario for all media that includes exposures at various ages to several common exposure pathways, will be estimated with Reference Doses from the HEAST (or an appropriate substitution made) for chemicals. For both cancer and noncancer effects, the impact to an individual will be considered at the highest projected concentration/impact times. The contaminants which together provide impacts over a reference value will be considered to have passed the screen and be included in the Study Set.
- **For ecosystem health**, ecosystem toxicity and sub-lethal effects will be considered via comparison of estimated concentrations to available standards and effects levels (see Section 4.2). The total impact to the environment will be considered at the highest concentration/impact times. The contaminants which exceed the standards will be considered to have passed the screen and be included in the Study Set.
- **For socio-cultural impact**, the concepts of loss-of-use, loss of religious or spiritual value, and intangible mental stress are all related to the possible contamination of environmental materials. Detection limits will be considered as the benchmark; predicted environmental contaminant concentrations in groundwater, as prepared for the human health and ecological health calculations, will be compared to background values. Those materials for which predicted Hanford-related incremental concentrations exceed the background will be included in the Study Set.
- **For modeling requirements and validation**, materials present in waste streams that affect the transport or mobility of other contaminants will be included as contaminants to support the modeling efforts. Materials with documented impacts will be included. This will include materials that make up the bulk of contaminant mass – low-level trace materials will not be included. Examples include sodium, aluminum, and organic carbon. Contaminants that have available historical measurements in sufficient quantity to provide a basis for comparisons of predicted versus modeled environmental concentrations will be included, even if they do not pass the previous screens.

Introduction

- **For regulatory drivers**, pertinent regulations and Treaties with Tribal Nations will be reviewed and required contaminants will be included.
- **For Site Grouping**, waste disposal sites may be considered collectively based on the process streams that have been discharged to them, physical proximity, and hydrogeological setting. For example, wastewater disposal cribs at the Plutonium Uranium Extraction (PUREX) Facility might be grouped, but separately from wastewater disposal cribs at the Reduction Oxidation (REDOX) Plant.
- **For physical state**, a description of the contaminated area/volume, including approximate dimensions, physical form of material when released/emplaced (liquid, solid, powder, etc.), temperature, or other important characteristics will be provided.
- **For public interest**, potential Hanford contaminants will be evaluated using the prior screens, and through an agreed upon screening process, candidate contaminants will be narrowed down to a study set. However, some contaminants eliminated through this process may still be of significant tribal, stakeholder, and/or public interest or concern. If these concerns are not adequately addressed by existing project rationale, then additional scoping studies or criteria may be necessary to justify including the contaminant in the assessment. The scoping studies will be designed, reviewed, and conducted consistent with established GW/VZ Integration Project protocols, including appropriate technical reviews and tribal, stakeholder, and public involvement.

A simple, robust method for projecting concentrations of contaminants in groundwater, river water, and biota concentrations based on inventory estimates has been prepared. (This model is described fully in Section 3.0.) This model is for screening purposes only; it is not designed to be of sufficient predictive power for other uses. This model requires a minimal amount of site description and other input information. The basic processes are simulated in a way intended to be moderately realistic, but intentionally conservative. Environmental concentrations predicted with this model are not expected to be exceeded in actuality. Thus, any contaminant that does not exceed a benchmark can safely be considered to have been screened out from further analyses.

This report documents the Study Set recommended by the authors for SAC, Rev. 0. The results of this scoping study are intended to apply to SAC, Rev. 0 only, and they will need to be revisited as needed for future SAC iterations.

2.0 CURRENT HANFORD CONSTITUENT INVENTORY

A number of waste tracking systems have historically been developed and used at Hanford for a variety of purposes. These include the Waste Inventory Data System (WIDS), the Solid Waste Inventory Tracking System (SWITS), and the Track RadioActive Components (TRAC) computerized databases, and the Hanford Environmental Information System (HEIS) database for environmental sample tracking. The recently developed Hanford Defined Wastes (HDW) model is similar to the TRAC system in intent and design for the tank wastes. The Tank Waste Information Network System 2 (TWINS2) has evolved from the HDW model. Summaries of releases to the air and ground are compiled annually (e.g., Diediker 1999). The draft *Hanford Remedial Action Environmental Impact Statement* (HRA-EIS), the Composite Analysis, and the Hanford Solid Waste EIS (underdevelopment) have all assembled inventory information. In addition, older site documents, such as the Surplus Production Reactor Decommissioning EIS, the Hanford Defense Waste EIS, and other analyses, also have sources of inventory information.

2.1 WIDS DATABASE

WIDS contains the official summary of the history and status of Hanford waste sites. WIDS provides access to information concerning each of more than 2,500 potential waste sites at Hanford.¹ WIDS supplies a description of the site, location, operational process conducted at the site, start and end dates for waste disposal, contaminants (decayed to a standard date), cleanup activities, and includes comments as well as hazards, dimensions, references, and regulatory information.

Waste site contaminant inventories for this document for both radionuclides and chemicals site were taken from an older version of WIDS, because inventory information is not yet included in the revised (Microsoft Access) version of the database.

2.2 TWINS2/BEST-BASIS INVENTORY DATABASES

TWINS2 is an Internet data access interface and architecture, which provides access to several relational databases containing Hanford Site waste tank characterization data. The following databases are used:

- **Tank Characterization Database (TCD)** is a comprehensive relational database of solid and liquid phase Tank Waste Remediation System (TWRS) characterization data. Within TCD, estimates of tank inventory are based on the following:

¹ Potential sites include those classified “accepted” (solid waste management unit), “rejected” (not a waste management unit) or “discovery” (not enough information) sites. After remediation or subsequent investigation, a site may be reclassified (“Closed Out,” “Deleted from NPL,” “No Action,” or “Rejected”).

Current Hanford Constituent Inventory

- Historical Tank Contents Estimate (HTCE)
- Tank Characterization Report (TCR)
- Best Basis Inventory: basis is indicated as one of the following:

S – Sample concentration from the tank of interest

M – HDW model concentration data

C – Calculated from other analyte data (e.g., 90Y from 90Sr, 137mBa from 137Cs, U isotopes from UTOTAL, OH from charge balance, alpha isotopes from total alpha, etc.)

E – Derived from engineering assessment or process knowledge including application of sample data from other tanks of interest.

- **Tank Vapor Database (TVD)** contains tank headspace characterization data obtained after 1992.

The TWINS2 interface allows the user to extract data from databases and return data to the user's web browser, in American Standard Code for Information Interchange (ASCII) format, to be loaded into a spreadsheet program for viewing and analysis.

2.2.1 Hanford Site Bounding Inventory Estimates

The TWRS program (now the River Protection Program [RPP]) has developed a global inventory of tank wastes based on process history (Kupfer et al. 1999). This independent estimate is derived primarily from a review of essential material procurement records, from various chemical flowsheets used in reprocessing of Hanford Site reactor fuels, and from calculations of radionuclide generation and decay. The global inventory complements and supplements the Best-Basis Inventory described above by providing an alternative basis for comparison. The global inventory estimate involved a thorough review of all pertinent sources to identify errors, biases, inconsistencies, and missing information. The data sources include sample analyses, process flowsheets, waste transaction records, reactor fuel data, and essential material records. Kupfer et al. (1999) provides a global inventory for 25 nonradioactive components that comprise over 99 percent of the total tank waste mass, estimates for four other minor chemical components, and global estimates for 46 radionuclides. To ensure that inventory values resulting from the evaluations are technically defensible and reproducible, the originating sources of assumptions, data, and background information are thoroughly documented.

The global inventory of radionuclides presented by Kupfer et al. is listed in Table 2-1 (decayed through 1/1/1994). The global inventory of chemicals is in Table 2-2. These inventories compare well to those of the total SAC database (see Section 2.10).

Current Hanford Constituent Inventory

Table 2-1. Radionuclide Quantities Included in the Tank Global Inventory (Kupfer et al. 1999). (2 Pages)

Radionuclides	Curies
Hydrogen 3 (tritium)	3.40E+04
Carbon 14	4.81E+03
Nickel 59	9.34E+02
Cobalt 60	1.23E+04
Nickel 63	9.20E+04
Selenium 79	7.73E+02
Strontium 90	7.16E+07
Yttrium 90	7.16E+07
Zirconium 93	3.63E+03
Niobium 93m	2.69E+03
Technetium 99	3.26E+04
Ruthenium 106	1.04E+05
Cadmium 113m	1.69E+04
Antimony 125	2.08E+05
Tin 126	1.19E+03
Iodine 129	6.30E+01
Cesium 134	8.89E+04
Cesium 137	4.64E+07
Barium 137m	4.39E+07
Samarium 151	2.75E+06
Europium 152	1.48E+03
Europium 154	1.47E+05
Europium 155	1.36E+05
Radium 226	6.31E-2
Actinium 227	8.76E+01
Radium 228	7.71E+01
Thorium 229	1.81e+00
Protactinium 231	1.56E+02
Thorium 232	2.11E+01
Uranium 232	1.23E+02
Uranium 233	4.76E+02
Uranium 234	3.46E+02
Uranium 235	1.45E+01
Uranium 236	9.57E+00
Neptunium 237	1.41E+02
Plutonium 238	2.7E+03

Current Hanford Constituent Inventory

Table 2-1. Radionuclide Quantities Included in the Tank Global Inventory (Kupfer et al. 1999). (2 Pages)

Radionuclides	Curies
Uranium 238	3.22E+02
Plutonium 238	2.77E+03
Plutonium 239	3.91E+04
Plutonium 240	8.93E+03
Americium 241	6.99E+04
Plutonium 241	2.29E+05
Curium 242	7.70E+01
Plutonium 242	1.16E+00
Americium 243	9.34E+00
Curium 243	1.00E+01
Curium 244	2.42E+02

Table 2-2. Chemical Components Included in the Tank Global Inventory (Kupfer et al. 1999). (2 Pages)

Chemicals	Kilograms
Aluminum	7845000
Bismuth	580000
Cadmium	8200
Calcium	214000
Carbonate	4830000
Cerium	8800
Chloride	500000
Chromium	785000
Fluoride	1360000
Hydroxide	23000000
Iron	1230000
Lanthanum	51000
Lead	279000
Manganese	105000
Mercury	2100
Nickel	111000
Nitrate and nitrite	85700000
Phosphate	6000000
Potassium	481000
Silicon	570000

Current Hanford Constituent Inventory

**Table 2-2. Chemical Components Included in the Tank Global Inventory (Kupfer et al. 1999).
(2 Pages)**

Chemicals	Kilograms
Silver	8930
Sodium	54200000
Sulfate (as SO ₄)	5000000
Strontium	31300
Thorium	25600
Tungsten	15900
Total Organic Carbon	4000000
Uranium	965000
Zirconium	440000

2.3 US ECOLOGY LOW-LEVEL WASTE DISPOSAL SITE

The US Ecology Company operates one of the few operating commercial low-level waste (LLW) disposal sites in the United States on land leased from the State of Washington directly across from the 200 East Area. Information about the projected future inventories of materials in this site were obtained from the Washington State Department of Health staff currently preparing an environmental analysis of the site for licensing reasons. The inventories are generally smaller than those from Hanford operations, but record keeping and projects there have the same limitations as the U.S. Department of Energy (DOE) Hanford sites. In particular, the estimated inventory of uranium in the US Ecology site is questionable – it comes to thousands of tons of uranium, which in all likelihood is not really present. This portion of the inventory estimate is so uncertain that it was not provided by the State staff and is not included in the initial inventory estimates. For this scoping study, the US Ecology inventory was combined with Hanford 200 Areas inventories.

2.4 SAC DATABASE EFFORTS

In order to provide the SAC with a preliminary estimate of the various inventories of radionuclides and chemicals present at Hanford, the WIDS and TWINS databases were queried, and the results verified and combined with information from other reports and sources to prepare an initial inventory database. This database includes all of the contaminants in the source databases, the waste site locations, descriptors, operating histories, and a SAC-defined site categorization. The current accumulation of inventory information provides a summary of where these wastes are today, or at the time the record was last updated. It is *not* a forecast of post-closure location in all cases.

Current Hanford Constituent Inventory

2.4.1 Waste Site Groupings

In general, the WIDS database identifies all Hanford waste sites and facilities. To better manage the 2592 sites in WIDS as of May 1999, each site was categorized under one of the 45 types listed below. This grouping was developed for this effort. Although each WIDS site was given one of these types, not all sites fit neatly into any one category. Best judgement of the authors was used in those instances to categorize all WIDS waste sites.

Physical Plant

- 1A** Miscellaneous contaminated structure
- 1B** Tunnels
- 1C** Fuel storage basins
- 1D** Reactor cooling water storage basin
- 1E** Reactor structures with cores
- 1F** BiPO₄ process
- 1G** Uranium extraction process
- 1H** REDOX process
- 1I** PUREX process
- 1J** Cesium/strontium recovery process
- 1K** Thoria (PUREX) process
- 1L** Plutonium Finishing Plant (PFP) process
- 1M** Waste throughput structures and associated structures
- 1P** Evaporation and waste condensate processes

High-Level Waste (HLW) Tanks

- 2A** Leaking single-shell tanks
- 2B** Nonleaking single-shell tanks
- 2C** Double-shell tanks

Liquid Ground Disposal – high volumes of liquid

- 3A** Evaporator and tank condensates
- 3B** Plant steam condensate
- 3C** Plant cooling water crib
- 3D** Reactor cooling water crib
- 3E** Miscellaneous high-volume cribs/french drains
- 3F** BiPO₄ process waste crib/french drain
- 3G** Uranium extraction process waste crib/french drain
- 3H** REDOX process waste crib/french drain
- 3J** PUREX process waste crib/french drain
- 3K** Cesium/strontium recovery waste crib/french drain
- 3L** Thoria (PUREX) waste crib/french drain
- 3M** PFP waste crib/french drain

Current Hanford Constituent Inventory

Solid Waste Landfill

- 4A Radioactive pre-Sep1988 (Land Disposal Requirements imposed)
- 4B Radioactive post-Sep1988
- 4C Mixed post-Sep1988
- 4D Hazardous
- 4E Inert
- 4F Low volume/incidental (rad and/or haz)

Miscellaneous and Low Volume

- 5A Laboratory
- 5B Decontamination liquid effluent to ground
- 5C Miscellaneous underground storage tank (MUST)
- 5D Miscellaneous crib, french drain or other liquid ground disposal (low volume)
- 5E Soil residuals (residuals from removal of tank, support blg, piping, etc)
- 5F Sanitary sewer

Atmospheric

- 6A Airborne release (non-UPR)

Unplanned Releases

- 7U Any unplanned release (non-single-shell tank leak)

Rejected

- RR No further analyses.

The Physical Plant types (1A-1P) are typically facilities used for an indicated process or function. The 1A (miscellaneous contaminated structures) and 1M (waste throughput structures) are similar in that they handled large volumes of radioactive or hazardous materials. The 1A types in the 100 Areas are typically above-ground tanks and outfall structures and in the 200 Areas are buildings and 90-day hazardous waste storage pads. The 1M types in the 100 Areas are primarily the underground pipes and pumping stations transporting cooling water to and from the reactor. The 1M types in the 200 Areas are typically diversion boxes and valve pits.

Solid waste disposal sites are described as 4A-4F types according to the waste that was disposed. The numerous open burn pits were automatically assigned a 4F type if hazardous chemicals are known or suspected to have been burned at the site. The type 4A may be further subdivided as including pre-1970 LLW, pre-1970 transuranic (TRU) waste, post-1970 LLW, and post-1970 TRU. TRU wastes were first segregated from other solid wastes beginning in 1970.

Current Hanford Constituent Inventory

Liquid ground disposal sites are given a 3A-3M type; or a 5A, 5B, 5D, or 5F type. These liquid release categories do not apply to unplanned releases or single-shell tank leaks. The 3A-3M types are the higher-volume disposals, which are broken out by process or as a miscellaneous stream. The 5A, 5B, and 5F types are specific types of liquid that are typically of lower volumes than the 3A-3M types. Type 5D is a miscellaneous category for lower volume liquid effluents. The category for “crib/French drain” also includes other structures such as specific retention trenches and reverse wells.

The remaining types include the atmospheric releases, unplanned releases and rejected types. The atmospheric release sites were assigned to facility stacks. Any valid site recognized by WIDS that had a WIDS site type of “unplanned release” was given a 7U type. Further evaluation of these sites might reassign the type as a solid waste landfill type (4A-4F) or a miscellaneous low volume liquid type (5D). However, in the interest of time, these sites were assigned the 7U type by default.

The rejected type (RR) contains sites which are not of interest in the development of a site-wide inventory of radioactive or hazardous chemicals. Sites were identified in WIDS and classified within the waste types. Once data were entered into WIDS, a site may have been reclassified based on one or more criteria (e.g., on the basis of known site characteristics) there is 1) a lack of hazardous chemicals, or 2) a lack of radionuclide inventory, or 3) knowledge that it is a duplicate site. Designation by WIDS that a site is rejected and is of no interest is accepted by the SAC staff for the purposes of this scoping study. Table 2-3 identifies the distribution of waste site categories among key areas on the Hanford Site.

Table 2-3. SAC Inventory Waste Categories. (2 Pages)

Type	100 Areas	200 Areas	All Other Areas
Physical Plant			
1A Miscellaneous contaminated structure	66	42 c	45 r,c
1B Tunnels	4 r,c	2 c	
1C Fuel storage basins	4 r,c		1 c
1D Reactor cooling water storage basin	8 c		
1E Reactor structures with cores	9 r,c		1 r
1F BiPO4 process		3 r,c	
1G U extraction process		6 r,c	
1H REDOX process		14 r,c	
1I PUREX process		13 r,c	
1J Cs/Sr recovery process		18 r,c	
1K Thoria (PUREX) process			
1L PFP process		9	
1M Waste throughput structures	36	127 c	12 r,c
1P Evaporation and waste condensate processes		15 r,c	

Current Hanford Constituent Inventory

Table 2-3. SAC Inventory Waste Categories. (2 Pages)

Type	100 Areas	200 Areas	All Other Areas
HLW Tanks			
2A Leaking SST leaks		67	
2B Nonleaking SST leaks		82	
2C Double-shell Tanks		28	
High Volume Liquid Disposal			
3A Evaporator and tank condensates		20	
3B Plant steam condensate	1 r,c	2	
3C Plant cooling water crib		12	
3D Reactor cooling water crib	30		1 c
3E Misc high volume cribs/french drains	14 c	26	19
3F BiPO4 process waste crib/french drain		38	
3G U extraction process waste crib/french drain		40	
3H REDOX process waste crib/french drain		18	
3J PUREX process waste crib/french drain		30	
3K Cs/Sr recovery waste crib/french drain		6	
3L Thoria (PUREX) waste crib/french drain			
3M PFP waste crib/french drain		14	
Solid Waste Disposal			
4A Radioactive pre-Sep1988	64 c	30 c	21 c
4B Radioactive post-Sep1988			
4C Mixed post-Sep1988		1 r, c	1 r,c
4D Hazardous	13 r*, c	8 r*,c	31 r*,c
4E Inert	4 *	4 *	3 *
4F Low volume/incidental (rad and/or haz)	23 c	12 r,c	38 r,c
Misc. And Low Volume Liquids			
5A Laboratory	6 c	18	7 r
5B Decontamination liquid effluent to ground	11	14	
5C Misc. underground storage tank	13 r,c	15 r,c	10 r,c
5D Misc. liquid ground disposal (low volume)	46	56	12 r,c
5E Soil residuals	20	7 r,c	15 r,c
5F Sanitary sewer	52 *	56 *	26 *
6A Airborne release (non-UPR)	1 r,c	6 r,c	
7U Unplanned release (non-single-shell tank leak)	77 *	286 *	81 *
RR No further analyses	81 *	79 *	463 *

r = radionuclide inventory available for some or all sites

c = hazardous chemical inventory available for some or all sites

* = inventory data not expected to be available (inert, rejected, or unplanned release sites).

Current Hanford Constituent Inventory

2.5 HANFORD FACILITIES

A variety of facilities containing hazardous and radioactive materials exist at the Hanford Site. These facilities range from 90-day waste storage buildings to the large canyon facilities in the 200 Areas (see Table 2-4). The WIDS database maintains information on inactive facilities, and only a few key active facilities. The inventories of these facilities are being characterized to prepare for final disposition decisions.

Table 2-4. Examples of Major Facilities at Hanford.

Generic Facility	Descriptions
Reactors	Inactive reactors in the 100 Areas and the 400 Area FFTF.
200 Area processing buildings	Canyon buildings and other major facilities used to process spent fuel, to purify plutonium, and to process HLW to a more easily managed form.
200 Area support buildings	Filter buildings and laboratories to support processing operations and <90-day storage buildings.
Tunnels and caves	The 100 and 200 Areas contain enclosed structures used for storage of bulky and/or highly radioactively contaminated materials.
Lined basins	The 100 and 200 Areas contain cement-lined basins for storing spent fuel or cooling water.
300 Area laboratory buildings	The 300 Areas contain numerous laboratories used to support research for processing, use, and impacts of the radioactive materials created on the Hanford site.

The reactors are currently undergoing decommissioning. The C Reactor will be the first production reactor in the DOE complex to be placed in safe storage in a facility shielding the reactor's core from the environment for up to 75 years, or until final disposition. Similar closure activities are planned for the other reactors. Final decisions on the operation or closure of the Fast Flux Test Facility (FFTF) are expected this year. Activation products and lead, cadmium, polychlorinated biphenyls (PCBs), and asbestos are the primary contaminants of the older reactors. The radionuclide inventories are available for all reactors except FFTF. The known inventories were based on core samples of from D Reactor which were extrapolated to the other reactors based on their comparative size and operation levels (Miller and Steffes 1986), or prepared for the Composite Analysis (Kincaid et al. 1998). For this scoping study, the reactor inventories are assumed to reside in the 100 Areas.

The 200 Area processing facilities are contaminated with materials specific to their chemical processing activities. The contamination in the structures can be generalized as shown in Table 2-5. Detailed quantitative information on the hazardous and radioactive materials in the buildings is lacking in the inventory database. The Waste Encapsulization and Storage Facility (WESF) currently holds several thousand stainless steel capsules of separated cesium and strontium. For this scoping study, these have been included in the 200 Areas inventory.

Current Hanford Constituent Inventory

Table 2-5. Inventories in the 200 Area Processing Facilities.^a

Facility	Pu Load	Other Issues
B Plant	Minimal	Cs-137 and Sr-90
T Plant	24 kg	Significant
U Plant	Trace	10,015 Ci beta/gamma
REDOX	24 kg	9000 Ci beta/gamma
PUREX	9-15 kg	Minimal

^a Taken from J. Goodenough and R. Henckel presentation. "Hanford's Canyon Disposition Initiative." Bechtel Hanford Inc., www.bhi-erc.com/canyon/slides.pdf

Decommissioning of support buildings are being completed. The sites are typically decontaminated then removed or destroyed and buried in situ. As decommissioning activities progress, the support building inventories will change.

Tunnels exist in the 100 and 200 Areas. The 100 Area caves are located in 100-C, 100-H, 100-KE, and 100-KW Areas and were used to hold retired rods and other reactor equipment. Currently, the 100-KE tunnel is empty. The inventories of the other 100 Area tunnels are unknown. The 200 East Area contains two tunnels at the PUREX Facility. The equipment contained in the tunnels is known, but the exact contents of the equipment in these facilities is unknown. For example, a potentially significant unknown is the iodine-129 activity inside the silver reactors located in a PUREX tunnel.

Basins were constructed to hold process, cooling water, and spent fuel pools. The open basin inventories appear to be well characterized. A number of basins were buried in situ, with or without disposal of additional waste from other sites. Process and cooling water basins were typically used to hold water to determine if radioactive concentrations were above or below the then-current open release thresholds. Chemical contamination information for the basins, expected to be minor, is not known. An exception is the 100-K Area basins, both of which currently contain about 2,100 tons of spent N Reactor fuel. This inventory has been included in the 100 Area source term for this scoping study. In addition, the sludge contained in the 100-KE Basin has also been included.

The 300 Area facilities were used for research and development activities and nuclear fuel fabrication. The inventory database lacks much information for the 300 Area facilities.

2.6 INVENTORY WEAKNESSES

A number of weaknesses or omissions were noted during the consolidation of the SAC initial inventory database.

Current Hanford Constituent Inventory

2.6.1 WIDS

The current version of WIDS does not yet include chemical or radionuclide inventory data. Data which existed before WIDS was revised are still available, and were incorporated by this task. Updates to solid waste burial grounds have been made using SWITS data from Anderson and Hagel (1996) (*and will be updated directly from more current SWITS data*). Updates to liquid disposal site inventories will be updated with information from the latest Environmental Release Summary System report, “Cumulative Decayed Inventories for Hanford Waste Disposal Sites” (Diediker 1999).

For many sites, there is no inventory data. In those cases for SAC, Rev. 0, a generic inventory may be selected based on the type of site, and scaled by the estimated release of inventories available for similar sites. Alternatively, the cumulative inventory for all similar sites may be generated, for which the overall uncertainty may be lower than for the individual sites. For this scoping study, the inventories of selected major sites were added (e.g., K Basins, WESF), others were assumed to be sufficiently small as to not affect the overall scoping result.

Although a large number of sites identified in WIDS have little or no information, this should not be construed as implying that large quantities of material are potentially unaccounted for. Hanford Site records pertaining to overall inventories are good; the majority of waste sites in WIDS are judged to have very small amounts of waste.

2.6.2 Best-Basis Inventory

The technical approach to developing the Best Basis Inventory is the strongest found for any Hanford cleanup operation. The projections are being based on a combination of monitoring and process history modeling, using all available data. However, even this program has limitations, most of which have been enumerated in project reports (Harmsen et al. 1998; Cammann et al. 1999):

- The HDW model predicts chemical inventories better than radionuclide inventories due to trace chemistry effects and variables of fuel exposure not captured in the model (megawatt-days, fuel design, co-precipitation, solubility, complexants, etc.).
- The Supernate Mixing Model incorrectly models in-tank precipitation processes adversely impacting double-shell tank estimates.
- HDW model “defined wastes” do not match sample data or flowsheets in all cases.
- HDW model incorrectly identifies waste layers and volumes at times due to incomplete waste transaction records and incorrect assumptions about analyte solubility, volume percent solids precipitated, and plant partitioning factors.
- HDW model solubility assumptions could significantly affect predictions of chemicals and radionuclides previously discharged to soils.

Current Hanford Constituent Inventory

- HDW model uncertainties do not accurately represent discrepancies found when comparing sample results to model predictions.
- Limited data are available to compare with HDW model predictions.
- HDW model inventory estimates for Sr-90 and Cs-137 often fall within one order of magnitude of measured values (measured range is six orders of magnitude).
- HDW model inventory estimates for Tc-99 often fall within two orders of magnitude of measured values (measured range is four orders of magnitude).
- Fuel activity record averaging methodology obscures trends in fuel exposure and process improvements (1,300 fuel activity records averaged into seven waste types).
- Updated fuel activity records are not yet incorporated into latest version of HDW model.
- Simplified solubility assumption was used for 40 radionuclides (50/50 liquid-solid split).
- Sample data indicate errors due to solubility assumptions.
- Processing split factors are approximate.
- Sludge compositions are held constant throughout tank waste cascades.
- Uncertainties exist in waste transactions (approximately 40% are not verified).
- Decay functions for certain minor transuranic daughters are oversimplified.
- Chemical inventory estimates are mostly sample-based or extrapolated from other tanks using engineering assessment-based methods.
- HDW model tank estimates for bismuth often fall within a factor of 2-3 of the measured value.
- HDW model was not designed to predict chemical compounds likely to precipitate in tank waste.
- HDW model does not predict sludge wash/leach performance.
- Environmental Simulation Program model and laboratory data are being used to estimate chemical compounds and sludge wash/leach performance.
- Multiple flowsheets are represented as a single flowsheet for some waste types.

Current Hanford Constituent Inventory

- Startup and rework chemical usage is estimated from plant discharge volume records.
- HDW model assumes large volumes of residual metal waste in tanks despite known success of sluicing operations.
- HDW model assumes mercury is distributed to cladding waste instead of HLW as indicated in REDOX/PUREX flowsheets.
- Carbonate formation from carbon dioxide absorption and organic degradation is not modeled.
- Aluminum precipitation is not well understood or represented in the HDW model (e.g., residence time of: supernatant in tank and effect on aluminum precipitation).

2.6.3 100 Area Characterization

The waste sites in the Hanford 100 Areas are being characterized during the process of site remediation. Thus, there are no good projections of waste quantities in sites that have not yet been remediated, and there are no plans to create any before the sites are remediated. In the long term, assuming the sites are in fact cleaned up with disposal to the Environmental Restoration Disposal Facility (ERDF), this will not result in problems for 100 Area estimates (but see the discussion of ERDF inventory). However, it makes the projection of potential hazard difficult for current conditions. When all the sites are cleaned up, some contamination will remain, and an estimate of residual concentrations will be possible on the basis of sampling. Residual waste inventory estimates have been made for those sites that have been remediated.

2.6.4 ERDF

The waste constituent inventory of the ERDF is being developed as the facility is filled. Samples are taken from each waste site for which materials are disposed in ERDF, and the inventory is conservatively estimated by multiplying the volume of material emplaced by the highest measured concentration. This results in an overall overestimate of the inventory, since not all the materials will be at the highest concentration. However, since sampling is limited, a more accurate method may not exist. In addition, there is no way to estimate future disposals, other than to extrapolate from past disposals. If waste sites are encountered that differ significantly from those already remediated, the future projections may misrepresent the ultimate site contents.

2.7 HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION RIVER RELEASE INVENTORIES

The Hanford Environmental Dose Reconstruction (HEDR) Project estimated radiation doses from radionuclides released to the Columbia River that individuals could have received from Hanford operations between 1944 and 1971. The primary source of release was operation of plutonium production reactors. Beginning in September 1944 with the initial startup of B Reactor, eight single-pass production reactors were operated at the Hanford Site. Single-pass

Current Hanford Constituent Inventory

reactors used Columbia River water to cool the fuel elements in the reactor core. The cooling water flowed past the fuel elements in the process tubes, was stored temporarily in retention basins, then was released to the river. (A ninth reactor, N, did not discharge directly to the Columbia River and so was not considered in the HEDR study.) Operation of the single-pass reactors continued until the last one was shut down in 1971.

2.7.1 Routine Reactor Releases

Radionuclides were created when neutrons in the reactor core activated native elements present in the inlet cooling water from the Columbia River, as well as elements added to the water by water treatment processes. Reactor neutrons also produced radionuclides by activating elements in the alloys used for process tubes and fuel cladding and activating materials held in the films deposited on the tube and jacket surfaces. The resulting radionuclides were released in the cooling water discharged to the Columbia River.

Although a large number of different radionuclides were discharged, most of them had very small inventories and/or very short half-lives. As a result of a study done by Napier (1993a), the following eleven radionuclides, as well as gross nonvolatile beta, were designated by the Technical Steering Panel of the HEDR Project to be studied: sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, gallium-72, arsenic-76, yttrium-90, iodine-131, and neptunium-239.

To estimate the radionuclides discharged to the Columbia River, the actual quantities were reconstructed for each month using reactor operating history and measurements of radionuclide concentrations, where the latter were available. Missing data were reconstructed using statistical analysis of existing data coupled with Monte Carlo modeling techniques. The radionuclides reported to be released by the HEDR Project are presented in Table 2-6 (Heeb and Bates 1994).

Table 2-6. Cumulative Radionuclide Release to the Columbia River from Hanford Once-Through-Cooled Plutonium Production Reactors (from Heeb and Bates 1994).

Radionuclide	Half-Life	Cumulative Release, Ci
Sodium-24	15.0 hours	12,600,000
Phosphorus-32	14.3 days	229,000
Scandium-46	83.7 days	120,000
Chromium-51	27.7 days	7,191,000
Manganese-56	2.5 hours	79,600,000
Zinc-65	245.0 days	491,000
Gallium-72	14.0 hours	3,685,000
Arsenic-76	26.3 hours	2,520,000
Yttrium-90	64.0 hours	444,718
Iodine-131	8.0 days	47,900
Neptunium-239	2.4 days	6,310,000
Gross beta (includes above)	--	66,300,000

Current Hanford Constituent Inventory

All of the listed releases have very short half-lives, and are no longer detectable in Columbia River waters or sediments. However, the Np-239 has decayed into about 2 Ci of long-lived Pu-239.

2.7.2 Fuel Element Failures

Nearly 2,000 fuel-element failures occurred in the eight original Hanford reactors. A failure occurred when the aluminum cladding on the fuel element was breached, allowing coolant water direct access to the irradiated uranium. The uranium-water reaction proceeds rapidly at process temperatures. The result was a release of fission products and actinides to the effluent water.

Every attempt was made to remove the ruptured slug as soon as possible. The reactor was shut down as soon as a rupture was indicated. With the development of scintillation counting in 1951, the primary detection system in place was a gamma spectrometer set to detect the presence of specific fission products in the effluent water. The instrument sequentially sampled water from each tube row during operation. Thus, when a fuel-element failure was detected, the tube row containing the failed element was usually known at shutdown. A radiation survey along the suspected tube row was conducted soon after shutdown. The radiation reading from the ruptured tube was usually high enough above the general background level within the reactor to permit identification. Attempts were then made to discharge the tube. However, the initial attempt sometimes failed when uranium oxide buildup had caused the slug to swell, lodging it securely in the process tube. Most of these "stuck ruptures" were discharged within the following 24 hours by applying higher forces than were routinely available from the normal charging machines.

Information on the reactor, the date, and the rupture classification for each rupture was extracted from Hanford reports (Gydeson 1993). This information was used to estimate the release contributions of all radionuclides from fuel-element failures using information from Heeb and Bates (1994) and Napier (1991). The complete calculation is shown in Appendix B. The cumulative releases, decayed to the present, for all of the radionuclides in the Candidate Set are presented in Table 2-7. The only insoluble radionuclides likely to be still detectable in the Columbia River sediments from these releases are the plutonium isotopes, which can be detected in Columbia River sediments, increasing the amount present over fallout background by about 30 percent.

**Table 2-7. Radionuclides Released to the Columbia River
From Fuel Failures. (2 Pages)**

Radionuclide	Total Ci 1,963 Failures	Approx. Ci Remaining Today
Hydrogen 3 (Tritium)	1.43E+00	2.00E-01
Actinium 227	1.23E-11	4.04E-12
Americium 241	2.67E-03	2.52E-03
Americium 242M	2.50E-05	2.13E-05
Cadmium 113M	1.38E-01	2.33E-02
Carbon 14	3.00E-07	2.99E-07
Cesium 135	5.84E-04	5.84E-04
Cesium 137	2.66E+02	1.19E+02

Current Hanford Constituent Inventory

**Table 2-7. Radionuclides Released to the Columbia River
From Fuel Failures. (2 Pages)**

Radionuclide	Total Ci 1,963 Failures	Approx. Ci Remaining Today
Chlorine 36	0.00E+00	0.00E+00
Cobalt 60	5.34E+04	5.31E+02
Curium 243	1.05E-06	4.93E-07
Curium 244	4.51E-05	1.18E-05
Europium 152	5.01E-03	8.85E-04
Europium 154	1.77E+00	7.89E-02
Iodine 129	7.17E-05	7.17E-05
Krypton 85	2.92E+01	3.05E+00
Lead 210	0.00E+00	0.00E+00
Neptunium 237	6.51E-04	6.51E-04
Nickel 59	1.43E-04	1.43E-04
Nickel 63	1.84E-02	1.41E-02
Palladium 107	1.54E-04	1.54E-04
Protactinium 231	6.01E-09	6.00E-09
Plutonium 238	2.50E-01	1.90E-01
Plutonium 239/240	1.07E+01	1.07E+01
Plutonium 241	4.84E+01	8.87E+00
Plutonium 242	2.34E-05	2.34E-05
Radium 226	2.84E-16	2.79E-16
Radium 228	1.50E-17	2.21E-19
Samarium 151	4.81E+00	3.70E+00
Selenium 79	1.13E-03	1.13E-03
Strontium 90	2.21E+02	9.55E+01
Technetium 99	3.50E-02	3.50E-02
Tellurium 123	2.34E-17	2.34E-17
Thorium 229	1.03E-13	1.03E-13
Thorium 230	1.43E-11	1.43E-11
Thorium 232	3.17E-15	3.17E-15
Tin 121M	3.50E-04	2.55E-04
Tin 126	2.17E-03	2.17E-03
Uranium 232	1.45E-07	1.04E-07
Uranium 234	2.34E-05	2.34E-05
Uranium 235	2.17E-03	2.17E-03
Uranium 236	9.18E-04	9.18E-04
Uranium 238	5.01E-02	5.01E-02
Zirconium 93	5.01E-03	5.01E-03

Current Hanford Constituent Inventory

2.8 EXISTING GROUNDWATER PLUMES

Certain contaminants now in soil or groundwater distant from the Columbia River within Hanford may some time in the future pose a source of contamination to the river. Some distant contaminants are essentially certain to reach the river, and others are, at this time, only potential, in part because planned remedial actions will either immobilize or remove them. Those contaminants contained in Hanford Site tank farms or burial grounds may/may not pose a future hazard. The contaminants that are already in groundwater are quite likely to reach the Columbia River in the future. High priority plumes are being remediated with pump-and-treat technology for this reason.

More than 120 plumes, containing more than 20 contaminants, are readily observable in groundwater beneath the Hanford Site (Ford 1993; DOE-RL 1994; Hartman et al. 1999). A summary of the nature of the existing groundwater contaminant plumes, their general locations, and maximum measured concentrations is given in Table 2-8 (adapted from CRCIA [DOE-RL 1998] using 1998 data from Dirkes et al. 1999). Maps of these plumes are provided in Ford (1993), DOE-RL (1994), Dirkes et al. (1999), and Hartman et al. (1999). (Note that each of the authors of these reports draws the outlines of the plumes somewhat differently, depending on the purpose of the reports.)

The window for future concern varies depending both on the location of the plumes and the material in them. Groundwater travel times from the current location to discharge in the river vary by location. Travel times in the 100 Areas generally can be less than 1 year. Travel times for groundwater carrying the plumes in the 200 East Area are generally in the range of 20 to 200 years. Travel times for the contaminants in the 600 Area evolving from the 600 Area Solid Waste Landfill Site are probably about 10 years. Travel times for plumes in the 200 West Area may be as long as 80 to 300 years (Freshley and Graham 1988). All of these estimated times depend on future groundwater conditions and influences such as quantity of water discharged from Hanford operating facilities.

Table 2-8. Peak Concentrations in Groundwater Plumes on the Hanford Site. (2 Pages)

Contaminant	Number of Plumes	Maximum Concentrations	Units
100 Area			
Tritium	4	80,000	pCi/L
Carbon-14	2	35,000	PCi/L
Strontium-90	8	26,000	pCi/L
Nitrate	10	280,000	ppb
Chromium (+6)	3	2,200	ppb
Trichloroethylene	2	24	Ppb
Uranium	2	57	Ppb

Current Hanford Constituent Inventory

Table 2-8. Peak Concentrations in Groundwater Plumes on the Hanford Site. (2 Pages)

Contaminant	Number of Plumes	Maximum Concentrations	Units
200 West Area			
Arsenic	4	24	ppb
Chromium	5	180	ppb
Fluoride	3	5,000	ppb
Nitrate	5	1,673,000	ppb
Carbon Tetrachloride	1	7000	ppb
Chloroform	3	120	ppb
Trichloroethylene	2	23	ppb
Tritium	3	3,210,000	pCi/L
Technetium-99	5	22,600	pCi/L
Iodine-129	2	81	pCi/L
Uranium	4	2800	pCi/L
200 East Area			
Arsenic	4	24	ppb
Chromium	4	2820	ppb
Cyanide	2	347	ppb
Nitrate	7	491,000	ppb
Chloroform	1	7	ppb
Tritium	5	3,870,000	pCi/L
Cobalt-60	2	66	pCi/L
Strontium-90	5	10,800	pCi/L
Technetium-99	2	7030	pCi/L
Iodine-129	3	13	pCi/L
Cesium-137	1	1,840	pCi/L
Uranium	1	282	pCi/L
Plutonium-239/240	1	66	pCi/L
600 Area (Solid Waste Landfill, NRDWL, FFTF)			
1,1,1-trichloroethane	1	50	ppb
Trichloroethene	1	10	ppb
Tetrachloroethene	2	38	ppb
1,1-dichloroethane	1	7	ppb
Chloroform	1	0.5	ppb
Uranium	1	91	ppb
300 Area			
1,2-dichloroethylene	1	80	ppb
Trichloroethylene	1	8	ppb
Uranium	2	252	ppb

Current Hanford Constituent Inventory

Most of the contaminants observed in groundwater are relatively mobile in groundwater. However, actinides, strontium-90, and cesium-137 have significant chemical interactions with the soil and move much more slowly than the groundwater. (They exist in the groundwater in the 200 Areas because they were essentially injected there directly during waste disposal rather than arriving via percolation from a surface source.) The chemical interactions add to the delay that these materials will experience, particularly those in the distant 200 Areas, before the plumes begin to discharge to the Columbia River. Because the half-lives of cobalt-60 (5.3 years), strontium-90 (28.8 years), and cesium-137 (30.2 years) are relatively short compared to the travel time from the 200 Areas to the Columbia River, they will decay before reaching the river. The strontium-90 in the 100 Areas will likely reach the river, or continue to enter the river as is the case at the 100-N Area; however, only the strontium-90 inventory within a relatively short distance of the Columbia River shoreline has sufficient time to be transported to the river because of its moderate sorption and short half-life.

2.9 DIFFUSE ATMOSPHERIC SOURCES AND FALLOUT RUN-OFF

In response to the requirements of the *Clean Air Act*, the Hanford Site has provided estimates of radiation dose to the regional population resulting from diffuse and/or unmonitored sources on the Hanford Site for the last several years (e.g., DOE-RL 1998a). The requirements are published in the *Code of Federal Regulations* (CFR), Title 40, Protection of the Environment, Part 61, "National Emissions Standards for Hazardous Air Pollutants," Subpart H "National Emissions Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities." The estimates are based on the results of atmospheric sampling around the site. Diffuse sources and fugitive emissions include all radioactive emissions that are not actively ventilated or are not routinely sampled (e.g., passively ventilated tanks vents, outdoor surface contamination areas, cracks between cover blocks, dust from remediation activities, etc.)

Currently, all nuclear material production facilities on the Hanford Site are shutdown or are in standby mode. Only waste minimization and stabilization processes continue to operate. In the past, when the Hanford Site was operating at or near full capacity, point source emissions were easily detected. Now, however, emissions from point sources have diminished in most instances to background levels. Passively ventilated point sources, breather vents and other openings on tanks, vaults, and other structures are potential conduits of radioactive emissions. Airborne radionuclides inside vented structures can be released via passive air exchanges, typically attributed to ambient temperature and pressure changes. However, it is difficult to accurately assess radionuclide releases that might occur under such conditions, particularly when the vent opening is irregularly shaped, or when multiple openings are in close proximity. Passively ventilated point sources are not routinely sampled, therefore, the Hanford Site has elected to use environmental surveillance ambient air monitoring data collected at the site perimeter to estimate the dose from diffuse and fugitive emissions sources. This method is preferred for two reasons: (1) these data most accurately represent the actual exposures of an offsite individual to airborne radioactivity and (2) there is currently insufficient information about the extent and characteristics of soil contamination on the Hanford Site to use resuspension estimates in conjunction with estimating emissions from other sources of diffuse and fugitive emissions. The ambient air sampling results consisted of measured air concentrations for radionuclides that may

Current Hanford Constituent Inventory

be released from site operations and diffuse and fugitive sources. Radionuclides sampled and analyzed for include: ^3H , ^{60}Co , ^{90}Sr , ^{106}Ru , ^{125}Sb , ^{129}I , ^{134}Cs , ^{137}Cs , ^{154}Eu , ^{155}Eu , ^{234}U , ^{235}U , ^{238}U , ^{238}Pu , and $^{239/240}\text{Pu}$.

For the last several years, the radiation dose estimate for diffuse sources has averaged about 0.04 mrem/year (Woodruff, Hanf, and Lundgren 1993; Dirkes et al. 1994; Dirkes and Hanf 1995; Dirkes and Hanf 1996; Dirkes and Hanf 1997; Dirkes and Hanf 1998). A radiation dose of this magnitude proffers an annual health risk of 3×10^{-8} , or a lifetime risk of about 2×10^{-6} . Because this risk is occurring during a period of active site cleanup, with considerable physical moving of dirt, transferring of radioactive material, and cleanup of contaminated facilities, it seems probable that the dose in the future, when sites will be cleaned up and stabilized, will be less. Thus, the airborne release pathway is probably of minimal importance.

Past testing of nuclear explosives in the atmosphere has resulted in worldwide contamination. Past fallout in the overall drainage basin of the Columbia River totals around 25,000 Ci of ^{90}Sr , 40,000 Ci of ^{137}Cs , and 1000 Ci of ^{239}Pu (NATO 1998). As a result, measurable concentrations of these radionuclides are transported through runoff into the Columbia River. The Hanford monitoring programs regularly measure these radionuclides upstream of the Hanford Site (e.g., Dirkes and Hanf 1998). From these measurements, it can be shown that the Columbia River transports around 8 Ci of ^{90}Sr , 0.13 Ci of ^{137}Cs , and 0.008 Ci of ^{239}Pu per year through the Hanford Site from upriver washout sources.

Estimates of past Hanford Site releases of radionuclides to the atmosphere were prepared by the HEDR Project (Heeb 1994; Napier 1992). The HEDR estimates of atmospheric release for selected long-lived radionuclides are shown in Table 2-9, as estimated and radioactively decayed to today. In comparison with the fallout quantities, Hanford Site releases are very small.

Hanford Site lands are all within about 30 km (20 miles) of the Columbia River. Most of the Columbia Basin is within similar distances of surface streams.

The transport of these radionuclides through the Hanford Site, compared to the total fallout deposition, gives a useful estimate of the transfer rates from land surface into the Columbia River. As can be seen from Table 2-9, these transfer rates are quite low. They indicate that nearly all of the ^{90}Sr and ^{137}Cs will decay before it is washed into the Columbia, and that the decay rate of the ^{239}Pu is nearly three times faster than its washout rate, indicating that most of the ^{239}Pu will also decay before being moved through the river system. From this evidence, it appears that atmospheric transport-deposition-washout is a negligible pathway for contamination of the Columbia River from Hanford contaminants.

Current Hanford Constituent Inventory

Table 2-9. Comparison of Bomb-Testing Fallout and Hanford Releases of Selected Radionuclides.

Radionuclide	Cumulative Fallout Deposition in Basin, Ci	Cumulative Hanford Release, Ci		Annual Columbia River Fallout Transport, Ci/Year	Approximate Land-to-River Transfer Rate, Year ⁻¹
		Released	Decayed to 1999		
Strontium-90	25,000	64	31	8	3.00E-04
Cesium-137	40,000	42	21	0.13	3.00E-06
Plutonium-239	1,000	1.8	1.8	0.008	1.00E-05

2.10 SUMMARY INVENTORIES

Tables 2-10 to 2-15 were created to summarize the SAC inventory database. Table 2-10 summarizes the total number of each Waste Group Types in the 100, 200, and All Other Areas of the Hanford Site. Then the table displays the number of sites within an Area-Waste Group combination for which an inventory value currently resides in the DRAFT database. Radiological and chemical inventory counts are shown separately.

Then, Tables 2-11 to 2-12 indicate the total quantities of each inventoried radioactive material in each Area-Waste Group combination for which there is data. These preliminary activities are not decayed to the same date. The youngest inventory values are decayed to 1985 (all other decayed to a more recent date), so the shorter half-lives isotopes (e.g., some Co-60, H-3) values may be rather conservative.

Tables 2-13 to 2-15 indicate the total quantities of each hazardous chemical in each Area-Waste Group combination for which there is data.

Table 2-10. Site Inventories Available in the SAC Database by Waste Site Grouping Type. (3 Pages)

Waste Group Type	100 Areas			200 Areas			All Other Areas		
	Total Sites	Rad Inventory Sites	Chemical Inventory Sites	Total Sites	Rad Inventory Sites	Chemical Inventory Sites	Total Sites	Rad Inventory Sites	Chemical Inventory sites
Physical Plant									
1A Miscellaneous contaminated structure	66	1	1	42	1	0	45	0	0
1B Tunnels	4	0	0	2	2	0			
1C Fuel storage basins	4	1	1				1	1	0
1D Reactor cooling water storage basin	8	7	0						
1E Reactor structures with cores	9	8	8				1	0	1
1F BiPO4 process				3	0	0			
1G U extraction process				6	0	0			
1H REDOX process				14	0	0			
1I PUREX process				13	0	0			
1J Cs/Sr recovery process				18	1	0			
1K Thoria (PUREX) process									
1L PFP process				9	2	2			
1M Waste throughput structures	36	2	3	127	0	70	12	0	0
1P Evaporation and waste condensate processes				15	0	1			
HLW Tanks									
2A Leaking SST leaks				67	67	67			
2B Nonleaking SST leaks				84	82	82			
2C Double-shell Tanks				28	28	28			

Table 2-10. Site Inventories Available in the SAC Database by Waste Site Grouping Type. (3 Pages)

Waste Group Type	100 Areas			200 Areas			All Other Areas		
	Total Sites	Rad Inventory Sites	Chemical Inventory Sites	Total Sites	Rad Inventory Sites	Chemical Inventory Sites	Total Sites	Rad Inventory Sites	Chemical Inventory sites
High Volume Liquid Disposal									
3A Evaporator and tank condensates				20	14	18			
3B Plant steam condensate	1	0	0	2	2	1			
3C Plant cooling water crib				12	5	1			
3D Reactor cooling water crib	30	22	19				1	1	0
3E Misc high volume cribs/french drains	14	3	0	26	12	10	19	8	3
3F BiPO4 process waste crib/french drain				38	31	31			
3G U extraction process waste crib/french drain				40	38	37			
3H REDOX process waste crib/french drain				18	15	14			
3J PUREX process waste crib/french drain				30	20	23			
3K Cs/Sr recovery waste crib/french drain				6	5	3			
3L Thoria (PUREX) waste crib/french drain									
3M PFP waste crib/french drain				14	12	9			
Solid Waste Disposal									
4A Radioactive pre-Sep1988	64	24	0	30	26	0	22	2	0
4B Radioactive post-Sep1988									
4C Mixed post-Sep1988				1	0	0	1	1	0
4D Hazardous	13	0	0	8	0	0	31	0	0
4E Inert	4	0	0	4	0	0	3	0	0
4F Low volume/incidental (rad and/or haz)	23	3	0	12	0	0	38	0	1

Table 2-10. Site Inventories Available in the SAC Database by Waste Site Grouping Type. (3 Pages)

Waste Group Type	100 Areas			200 Areas			All Other Areas		
	Total Sites	Rad Inventory Sites	Chemical Inventory Sites	Total Sites	Rad Inventory Sites	Chemical Inventory Sites	Total Sites	Rad Inventory Sites	Chemical Inventory sites
Misc. and Low Volume Liquids									
5A Laboratory	6	1	0	18	12	9	7	0	1
5B Decontamination liquid effluent to ground	11	5	5	14	3	3			
5C Misc. underground storage tank	13	0	0	15	0	0	10	0	0
5D Misc. liquid ground disposal (low volume)	46	1	1	56	1	4	12	0	0
5E Soil residuals	20	2	1	7	0	0	15	0	0
5F Sanitary sewer	52			56			26	0	0
Atmospheric									
6A Airborne release (non-UPR)	1			6					
Unplanned releases									
7U Unplanned release (non-single-shell tank leak)	77			286	1	0	81		
Rejected									
RR No further analyses	81			79			463		
Total	583			1226			787		

Table 2-11. 100 Area Radionuclide Inventory Summary by SAC Waste Type Grouping (Curies).

Isotope	1A	1C	1D	1E	1M	3D	3E	4A	4F	5A	5B	5D	5E	TOTAL
Am241		3.77E+05		3.40E+00										3.77E+05
C14		6.93E+02		4.69E+04		1.06E+00	2.20E+02	8.50E+00	2.00E-02					4.78E+04
Cl36				7.50E+01										7.50E+01
Cm244		1.44E+03												1.44E+03
Co60	1.46E-03	3.96E+03	6.69E+00	7.43E+04	2.32E-01	1.07E+03	1.86E-01	6.65E+03	2.00E+00		9.51E-01		5.38E-03	8.60E+04
Cs135		7.75E+00												7.75E+00
Cs137	4.74E-03	1.32E+07	2.00E+01	2.67E+02	9.18E+00	2.59E+03	9.36E-02	1.53E+01			3.05E-01	5.74E-06	1.11E+00	1.32E+07
Eu152	5.57E-03	9.45E+02	4.50E+01	3.41E+02	1.38E+00	4.08E+02	3.94E-01	1.38E+02			4.35E-01	2.48E-05	4.67E-02	1.88E+03
Eu154	4.07E-04	1.07E+05	9.84E+00	1.81E+02	1.97E-01	7.84E+01	1.85E-01	2.48E+02			7.48E-02	4.07E-04	1.47E-02	1.08E+05
H3	1.63E-02	3.72E+04	1.98E+00	9.81E+04	5.02E-01	1.97E+02	9.24E+01	4.83E+03	8.00E-01		4.01E-01		8.29E+01	1.40E+05
I129		6.37E+00												6.37E+00
Kr85		5.91E+05												5.91E+05
Ni59				8.66E+01										8.66E+01
Ni63		4.56E+03		1.09E+04		1.41E+02		7.64E+02						1.64E+04
Np237		5.72E+01												5.72E+01
Pu238	0.00E+00	1.11E+05	2.44E-02	1.50E-01	6.08E-04	3.61E-01					1.30E-04		4.67E-04	1.11E+05
Pu239	6.46E-05	2.18E+05	7.49E-01	1.01E+01	3.72E-02	2.58E+01	6.30E-03	5.16E-01			7.10E-03	2.47E-05	3.35E-02	2.18E+05
Pu240	1.62E-05	1.20E+05	1.87E-01		9.30E-03	6.45E+00	7.00E-04	1.38E-02			1.76E-03	6.18E-06	8.38E-03	1.20E+05
Pu241		6.69E+06												6.69E+06
Pu242		5.49E+01												5.49E+01
Ra226					9.88E-16	4.68E-13							7.58E-16	4.70E-13
Se79		8.62E+01												8.62E+01
Sm151		1.76E+05												1.76E+05
Sn126		1.56E+02												1.56E+02
Sr90	4.11E-05	1.01E+07	3.17E+00	1.01E+02	2.97E-01	1.77E+03	1.96E+00	2.57E+01		1.04E+01	6.61E-01	9.84E-06	7.53E-01	1.01E+07
Tc99		2.89E+03		1.11E-01										2.89E+03
U-gross											3.40E-04			3.40E-04
U234		8.74E+02			4.35E-08	2.06E-05							3.34E-08	8.74E+02
U235		3.37E+01			1.05E-09	2.01E-05					4.72E-11	7.02E-13	2.00E-05	3.37E+01
U236		1.27E+02												1.27E+02
U238		6.96E+02		1.30E-02	1.88E-02	7.40E-01	1.10E-04				9.20E-04		4.36E-03	6.97E+02
Zr93		4.00E+02		2.10E+01										4.21E+02

Current Hanford Constituent Inventory

Table 2-12. 200 Area Radionuclide Inventory Summary by SAC Waste Type Grouping (Curies). (2 Pages)

Isotope	1A	1B	1J	1L	2A	2B	2C	3A	3B	3C	3D	3E	3F	3G	3H	3J	3K	3M	4A	5A	5B	5D	Totals
Ac227					1.22E-01	8.73E+01	5.76E-02												4.20E+01				1.29E+02
Am241					1.14E+04	2.74E+04	6.90E+04	1.33E-03	1.02E-01	4.21E+00		5.29E-01		7.15E-01	1.87E-02	1.79E+00	1.39E-01	1.04E+00	1.64E+03	9.61E-04	6.35E-03		1.10E+05
Am242m																			1.66E-01				1.66E-01
Cl14					5.91E+02	1.94E+03	1.34E+03												5.78E+03				9.65E+03
Cd113m				1.63E-09	2.47E+03	6.20E+03	8.13E+03	1.95E-06	9.78E-09	1.98E-05	9.04E-10	1.31E-05	7.27E-06	6.08E-05	1.31E-04	5.88E-05	2.39E-06	1.97E-07	5.38E-05	6.75E-06	1.04E-07	4.35E-10	1.68E+04
Cl36																			4.92E+00				4.92E+00
Cm243	4.67E-07				1.89E+00	6.21E+00	2.00E+01												2.07E-03				2.81E+01
Cm244					4.90E+01	1.31E+02	4.98E+02												1.31E+00				6.79E+02
Co60	5.90E-04				2.04E+03	6.32E+03	1.21E+04	4.79E-02		1.08E+00		1.19E-01	1.37E-01	5.71E-01	6.55E-01	3.72E+00	1.14E-01	1.90E-02	8.55E+05	2.05E-01	9.53E-03		8.76E+05
Cs135				1.48E-06				9.53E-04	2.49E-06	7.40E-03	6.07E-07	5.12E-03	4.78E-03	3.39E-02	7.40E-02	2.12E-02	7.50E-04	6.79E-05	1.96E-06	2.38E-03	3.76E-05	1.46E-07	1.51E-01
Cs137	1.51E+01	8.23E+03	4.77E+07	2.95E+00	7.28E+06	1.62E+07	3.03E+07	5.33E+03	2.02E-01	2.45E+02	7.14E-02	1.91E+02	4.12E+03	4.85E+03	1.86E+03	1.40E+03	7.01E+02	1.67E+02	1.30E+06	2.34E+02	4.15E-01	1.16E+01	1.03E+08
Eu152				3.78E-07	3.20E+02	4.38E+02	7.20E+02	5.03E-04	5.10E-06	6.25E-03	2.20E-07	3.48E-03	1.78E-03	1.53E-02	3.28E-02	1.58E-02	7.09E-04	5.37E-05	1.25E+03	1.83E-03	2.81E-05	1.19E-07	2.73E+03
Eu154	8.96E-07				5.55E-05	2.61E+04	5.21E+04	1.13E+05	1.53E-02	6.28E-01	2.96E-05	3.99E-01	2.37E-01	1.95E+00	4.19E+00	1.78E+00	9.80E-01	5.94E-03	2.60E+03	2.04E-01	3.15E-03	1.31E-05	1.93E+05
H3					4.07E+03	1.38E+04	6.66E+03	1.06E+03	4.08E+00	6.31E+02		1.98E+02		1.69E+02		1.38E+04	1.18E+01		2.57E+05	1.13E-01	1.13E-03		2.98E+05
H129					1.56E+01	2.59E+01	5.67E+01	4.26E-03				2.66E-03				1.27E-01			6.58E+00				1.05E+02
Kr85																			9.52E+02				9.52E+02
Ni59					2.33E+02	4.72E+02	1.73E+02												8.98E+03				9.86E+03
Ni63					2.28E+04	4.61E+04	1.76E+04												1.11E+06				1.20E+06
Np237					1.54E+01	5.28E+01	1.16E+02												3.46E-01				1.85E+02
Pa231					2.48E-01	1.55E+02	2.11E-01												5.24E+01				2.08E+02
Pb210																			2.88E+02				2.88E+02
Pd107				2.18E-07				1.40E-04	3.66E-07	1.09E-03	8.94E-08	7.53E-04	7.03E-04	4.99E-03	1.09E-02	3.12E-03	1.10E-04	1.00E-05		3.50E-04	5.52E-06	2.15E-08	2.22E-02
Pu238					3.11E+02	9.73E+02	1.39E+03			3.34E-03						3.17E-01		2.23E-02	9.29E+04				9.56E+04
Pu239					1.06E+04	3.58E+04	1.02E+04	1.61E-04	3.14E-02	7.68E-01		9.77E-02		1.34E-01	6.54E-03	2.95E+00	1.56E-02	2.76E+02	4.57E+03	1.59E-04	9.84E-03		6.16E+04
Pu240					1.67E+03	6.48E+03	3.15E+03	4.02E-05	7.86E-03	1.92E-01		5.23E-03		3.34E-02	1.63E-03	7.36E-01	3.90E-03	7.44E+01	2.02E+03	3.98E-05	2.46E-03		1.34E+04
Pu241					1.77E+04	6.65E+04	8.00E+04									2.82E+01	1.79E+00	1.79E+00	2.13E+03				1.66E+05
Pu242					1.01E-01	2.80E-01	6.28E-01												2.39E+02				2.40E+02
Ra226				5.82E-13	1.56E-02	3.28E-02	1.02E-02	3.90E-09	3.31E-10	1.11E-07		5.29E-09	2.60E-08	2.28E-07	5.42E-08	2.64E-07	1.25E-07	5.00E-10	2.57E+06	1.53E-09	1.19E-08		2.57E+06
Ra228					1.41E+01	5.00E+01	1.34E+01												2.09E+02				2.87E+02
Sr79				1.28E-06	1.46E+02	3.24E+02	2.47E+02	8.27E-04	2.17E-06	6.43E-03	5.27E-07	4.45E-03	4.15E-03	2.94E-02	6.42E-02	1.85E-02	6.52E-04	5.90E-05	5.16E-03	2.07E-03	3.26E-05	1.27E-07	7.18E+02
Sm151				3.28E-03	5.18E+05	1.20E+06	9.02E+05	2.32E+00	7.27E-03	1.89E+01	1.41E-03	1.29E+01	1.11E+01	1.77E+02	5.46E+01	1.97E+00	1.97E+00	1.76E-01	1.17E+00	6.13E+00	9.64E-02	3.79E-04	2.62E+06
Sn11m																			1.57E+01				1.57E+01
Sn126					2.20E+02	5.13E+02	4.48E+02												1.31E-03				1.18E+03
Sr90	1.37E+01	7.53E+03	2.07E+07	1.38E+00	2.07E+07	2.29E+07	1.58E+07	1.33E+02	2.79E-01	7.59E+02	6.27E-02	2.33E+02	3.20E+03	7.46E+03	2.47E+03	1.32E+03	1.32E+02	1.64E+02	9.17E+05	2.38E+02	4.53E+01		8.10E+07

Current Hanford Constituent Inventory

Table 2-12. 200 Area Radionuclide Inventory Summary by SAC Waste Type Grouping (Curies). (2 Pages)

Isotope	1A	1B	1J	1L	2A	2B	2C	3A	3B	3C	3D	3E	3F	3G	3H	3J	3K	3M	4A	5A	5B	5D	Totals
Tc99				7.38E-05	4.49E+03	1.48E+04	9.26E+03	4.75E-02	1.24E-04	3.69E-01	3.03E-05	4.27E-01	2.39E-01	1.69E+00	3.69E+00	1.06E+00	3.75E-02	3.40E-03	6.98E+01	1.19E-01	1.87E-03	7.28E-06	2.87E+04
Th229					3.15E-01	1.18E+00	3.07E-01												2.62E-04				1.80E+00
Th230																			1.86E+00				1.86E+00
Th232				1.25E-17	5.94E-01	2.43E+00	1.38E+00	8.36E-14	7.09E-15	2.38E-12		1.13E-13	5.59E-13	4.88E-12	1.16E-12	5.66E-12	2.68E-12	1.07E-14	2.45E+02	3.28E-14	2.56E-13		2.50E+02
U-gross				3.32E-05				2.23E-01	1.89E-02	6.33E+00		2.21E+00	1.72E+00	1.30E+01	3.09E+00	1.51E+01	7.14E+00	2.85E-02		8.74E-02	6.80E-01		4.96E+01
U232					4.28E+01	7.60E+01	8.97E+00												5.54E-02				1.28E+02
U233								6.89E-15	5.24E-13	4.85E+00		1.88E-13		3.70E-12	9.45E-14	4.54E+00	7.20E-13	5.29E-12		4.56E-15	3.29E-14		9.40E+00
U234					1.14E+02	1.48E+02	8.11E+01		5.13E-08	1.04E-03						8.36E-06		5.19E-07	4.00E-01				3.43E+02
U235					4.80E+00	6.01E+00	3.10E+00	1.78E-12	3.47E-10	1.90E-05		2.30E-10		1.48E-09	6.90E-11	3.27E-08	1.63E-10	1.82E-08	7.18E-01	1.63E-12	1.09E-10		1.46E+01
U236					2.53E+00	2.92E+00	6.26E+00													1.70E-03			1.17E+01
U238					1.07E+02	1.41E+02	5.76E+01		2.50E-03	7.40E-04									5.20E+01				3.58E+02
Zr93				1.66E-05	6.82E+02	1.55E+03	1.25E+03	1.07E-02	2.79E-05	8.31E-02	6.82E-06	5.74E-02	5.37E-02	3.80E-01	8.31E-01	2.38E-01	8.43E-03	7.63E-04	2.56E+00	2.67E-02	4.21E-04	1.64E-06	3.49E+03

Table 2-13. 100 Area Chemical Inventory Summary (kg).

Chemical Name	SAC Waste Type Groupings								
	1A	1C	1E	1M	3D	4F	5B	5D	5E
Aluminum		1.8E+03							
Beryllium		1.6E+02							
Cadmium		6.1E-01	4.8E+02						
Chromium		2.9E+02							
Copper		1.7E+02							
Copper sulfate					5.0E+02				
Iron		9.4E+02							
Lead		1.6E+01	8.2E+05	4.5E+01					
Manganese		6.0E+01							
Mercury	2.0E+02								7.0E+02
Nickel		3.0E+02							
PCBs		4.5E+00							
Potassium borate								3.0E+03	
Silicon		2.8E+02							
Sodium		3.0E+00							
Sodium dichromate				1.0E+02	3.0E+05		5.1E+03		
Sodium hydroxide					1.0E+05				
Sodium oxylate					3.0E+03		5.2E+03		
Sodium sulfamate					3.0E+03		1.0E+04		
Strontium		1.5E+02							
Sulfamic Acid				1.0E+04	1.3E+04				
Sulfuric acid					1.1E+05	1.0E+05			
Uranium		2.1E+06							
Zirconium		1.5E+05							

Current Hanford Constituent Inventory

Table 2-14. 200 Area Chemical Inventory Summary. (2 Pages)

Chemical Name	SAC Waste Site Groupings																Grand Total						
	1L	1M	1P	2A	2B	2C	3A	3B	3C	3E	3F	3G	3H	3J	3K	3M		5A	5B	5D	RR		
Aluminum				2.55E+06	3.96E+06	1.55E+06																8.06E+06	
Aluminum nitrate																							8.70E+05
Ammonium carbonate							5.41E+05																5.41E+05
Ammonium nitrate							2.88E+04			4.00E+03	3.66E+05		6.00E+02	7.30E+05	1.89E+06								3.02E+06
Bismuth				3.17E+05	3.10E+05	2.02E+03																	6.29E+05
Calcium nitrate																2.60E+05							2.60E+05
Carbon tetrachloride																2.60E+05							2.60E+05
Chloride				2.03E+05	4.37E+05	2.96E+05																	9.35E+05
Chromium				1.41E+05	4.04E+05	1.03E+05																	6.48E+05
Dibutyl butyl phosphonate (DBBP)																1.50E+04							1.50E+04
Dibutyl phosphate (BP assume)							2.20E+05																2.20E+05
Ferrocyanide (assume sodium)											6.00E+03	8.39E+04											8.99E+04
Fluoride				2.84E+05	5.83E+05	3.07E+05	9.00E+04			4.00E+04	7.56E+05					4.91E+05							2.55E+06
Iron				5.75E+05	6.44E+05	1.68E+05																	1.39E+06
Iron Nitrate (hexahydrate)																	7.70E+04						7.70E+04
Lanthanum				1.66E+04	2.13E+04	1.32E+04																	5.11E+04
Lead		1.56E+03	2.26E+01	3.13E+04	3.72E+04	1.44E+04																	8.45E+04
Magnesium(II) nitrate																	3.50E+05						3.50E+05
Manganese				6.54E+04	9.45E+04	3.18E+04																	1.92E+05
Mercury				5.21E+02	1.27E+03	1.58E+01																	1.81E+03
Methyl isobutyl ketone (hexone)													6.20E+05										6.20E+05
Nickel				6.32E+04	9.38E+04	1.64E+04																	1.73E+05
Nitrate	1.00E+05			1.67E+07	2.61E+07	9.38E+06	3.05E+06		1.00E+00	3.00E+05	9.96E+06	3.18E+07	1.95E+05	1.36E+06	2.00E+03	2.62E+06	2.31E+04	1.30E+03	1.08E+03	1.00E+02			1.02E+08
Nitric acid									2.30E+04	1.90E+04	2.00E+05		3.80E+05	1.00E+00		7.60E+04							6.98E+05
Nitrite				1.89E+06	5.52E+06	3.15E+06	3.40E+05									2.82E+05							1.32E+07

Current Hanford Constituent Inventory

Table 2-14. 200 Area Chemical Inventory Summary. (2 Pages)

Chemical Name	SAC Waste Site Groupings																Grand Total					
	1L	1M	1P	2A	2B	2C	3A	3B	3C	3E	3F	3G	3H	3J	3K	3M		5A	5B	5D	RR	
NPH (normal paraffin hydrocarbon)							7.60E+04			2.40E+04		4.00E+04		3.05E+05								4.45E+05
Oxalate											7.80E+04	1.00E+03										7.90E+04
Phosphate				2.08E+06	3.03E+06	3.16E+05	7.50E+05			2.10E+04	1.91E+06	1.67E+06						3.00E+01				9.78E+06
Potassium				9.38E+04	2.03E+05	5.82E+05				6.00E+04	7.70E+05											1.71E+06
Silicon				3.90E+05	4.75E+05	5.70E+04																9.21E+05
Sodium	1.00E+05			1.26E+07	2.32E+07	1.26E+07	2.29E+06			2.50E+05	7.75E+06	1.36E+07	2.40E+04	2.10E+04		1.48E+06	4.00E+02					7.40E+07
Sodium aluminate							3.80E+05				2.89E+05											6.69E+05
Sodium dichromate							2.00E+00				4.10E+02		1.00E+04	6.10E+02								1.10E+04
Sodium hydroxide				6.37E+06	1.07E+07	6.29E+06	1.58E+05	1.00E+04		1.00E+03	2.14E+05					1.00E+03	1.00E+01					2.37E+07
Sodium oxybate										9.00E+03	8.60E+04											9.50E+04
Sodium silicate							1.50E+05				1.27E+05											2.77E+05
Strontium				2.36E+04	2.03E+04	9.82E+02																4.48E+04
Sulfate				1.03E+06	1.75E+06	4.98E+05	1.59E+05			2.40E+03	3.06E+05	2.25E+06	2.90E+04		2.00E+04							6.05E+06
Sulfuric acid											2.10E+04											2.10E+04
Total organic carbon				3.48E+05	6.67E+05	6.32E+05																1.65E+06
Tributyl phosphate (TBP)												1.30E+04		1.73E+05								2.08E+05
Tributyl phosphonate										1.40E+04												1.40E+04
Uranium				3.22E+05	4.24E+05	1.73E+05																9.18E+05
Zirconium				5.09E+03	1.40E+05	3.25E+05																4.70E+05

Current Hanford Constituent Inventory

Table 2-15. All Other Area Chemical Inventory Summary.

Chemical Name	SAC Waste Site Groupings			
	1E	3E	5A	Grand Total
Beryllium		70	10	80
Cadmium		140	20	160
Chromium		8000	1000	9000
Copper		110000	20000	130000
Fluoride		12000	2000	14000
Lead		6000	600	6600
Mercury		100	10	110
Methyl isobutyl ketone (hexone)		3000		3000
Nickel		18000	3000	21000
Nitrate		1801000		1801000
Nitric acid		1900000		1900000
Nitrite		1600000		1600000
Silver		1900	300	2200
Sodium	2600	3000000		3000000
Sodium aluminate		4000000		4000000
Sodium hydroxide		1800000		1800000
Sodium silicate		190000		190000
Trichloroethylene		200000		200000
Uranium		72000	10000	82000
Zinc		8000	1000	9000

3.0 SCOPING MODEL FOR ENVIRONMENTAL TRANSPORT

A simplified groundwater transport model was prepared for this scoping analysis. This was necessary to the evaluation of wastes from the near-shore groundwater/river environment and those from the central plateau, and to permit the scoping analyses to be based on future concentrations predicted from existing inventories. The model is intended to be conservative (that is, to overpredict expected concentrations of contaminants in the environment).

3.1 THEORETICAL DESCRIPTION

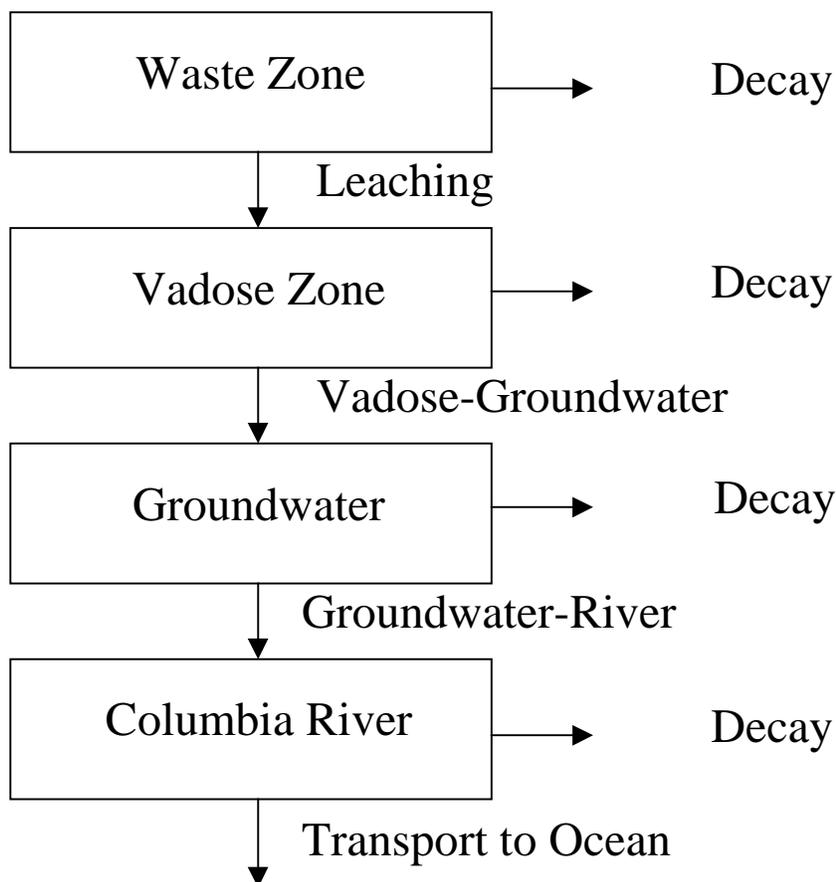
A conservative method of estimating the concentration of radionuclides in a groundwater aquifer is to use a simple leach-rate model. Leach rates are dependent on the chemical properties of the radionuclides and soil and the rate of local water movement. For this model, it was assumed that radionuclides would be transferred to the groundwater because of contact with infiltrating water. To account for potential *saturated* and *unsaturated* conditions, a four-box compartmental model is used for this study to estimate the transfer of activity from the surface to the groundwater aquifer over time, and thence into the Columbia River. The model used is an expansion of the U.S. Nuclear Regulatory Commission (NRC) model developed for evaluating exposures from residual radioactivity following decommissioning of nuclear facilities, presented in Kennedy and Strenge (1992). This very simple model uses a minimum of Hanford-specific data and parameters. The results must be evaluated in the sense of *screening* assessments. The results are strictly for comparison to limiting values and are not intended to represent estimates of actual exposures to individuals.

A conceptual representation of the four-box model is shown in Figure 3-1. This figure shows the four boxes and indicates the flow of water through the system with infiltration being the driving force for transfer from the surface soil to the groundwater aquifer. The following assumptions are implied by this model:

- Initial radioactivity is contained within the waste zone (box 1).
- All material is assumed to be available for release.
- The unsaturated-soil layer (box 2) and the aquifer (box 3) are initially free of contamination.
- The vertical saturated hydraulic conductivity is greater than the infiltration rate.
- The activity in the vadose zone and in the aquifer is diluted by the volume of water in these compartments.
- The volume of water in the aquifer volume is considered to be the pore volume of a stream tube 5 meters deep (minimal vertical mixing), 1 km wide by the time it reaches the shores of the Columbia River from the 200 Areas or 100 m wide from the 100 Areas, and 10 km long from the 200 Areas and 1 km from the 100 Areas.

Scoping Model for Environmental Transport

Figure 3-1. Simple Scoping Contaminant Transport Model.



- The annual infiltration volume is the product of the infiltration rate and the area of land contaminated, assumed to be a 100 square meter area for all waste sites.
- Water is removed from the aquifer at a constant rate during all years of interest in the analysis, corresponding to 1/travel time. The travel times for the 200 Areas are assumed to be 20 years, and for the 100 Areas to be 1 year.

The initial activity is assumed to be contained within the first soil layer as a reasonable approach for a waste site model. While some sites may exist that have contamination spread through all layers and even into the aquifer, these cases should be evaluated on a site-specific basis, rather than by using this generic model.

The assumption regarding the vertical saturated hydraulic conductivity means that the soil conditions will allow water to move vertically downward faster than the infiltration rate (expressed as distance per year).

Figure 3-1 represents the movement of material in the simple four-box leach model. Box 1 in the figure represents the initial inventory in a surface layer, with removal of material by either

Scoping Model for Environmental Transport

radioactive decay or leaching into box 2, an unsaturated zone. The initial quantity of material in box 1, $Q_1(0)$ is defined for each radionuclide or chemical of interest in total activity, Ci or kg. The initial quantities of material in box 2, $Q_2(0)$, box 3, $Q_3(0)$, and box 4, $Q_4(0)$ are all zero. The material in box 2 is transferred to the aquifer (box 3). The material in box 3 is transported to the Columbia River (box 4). The material in box 3 is used to determine the annual average concentration in the groundwater system. The groundwater concentration is evaluated for the year in which the dose via a scenario reaches a maximum.

The material entering box 4 is assumed to be uniformly mixed with the average flow of the Columbia River. Thus, this model does not explicitly incorporate a "mixing zone" region but more accurately represents the concentrations downstream beyond about the City of Richland. For the SAC analyses, the concentrations within the riparian zone are all assumed to be represented by the undiluted groundwater concentration.

Figure 3-1 includes a simple representation of radionuclide decay. In this representation, each radionuclide has its own radioactive decay constant and transfer rate constant between boxes. Chain decay is neglected in this simple approach. Evaluation of the year which the maximum annual concentration occurs requires that annual concentrations be calculated over a number of years until all radionuclides have reached a maximum concentration in the third and fourth boxes. The following discussion gives the mathematical description of the box model for the scenario.

The amounts of each contaminant are represented as the total amount present, represented either as kilograms or curies. The concepts involved in accounting for the quantity of contaminant in box 1 at time t are described in the word equation below:

[Rate of change of contaminant in Box 1 at time t] = -[Rate of removal of contaminant by decay at time t] - [Rate of removal of contaminant by leaching at time t]

The basic differential equation for box 1 has the following form, accounting for original quantities and for radioactive decay (λ term), and the rate of leaching (L term). The equations are the same for chemical constituents, with the decay term set to zero:

$$\frac{dQ_1}{dt} = -\lambda Q_1 - L_{12} Q_1.$$

Where:

- Q_1 = Activity of radionuclide in box 1 at time t
- L_{12} = Rate constant for movement of radionuclide from box 1 to box 2 (1/yr)
- λ = Decay rate constant for decay of radionuclide j (1/yr).

For box 2, the concepts involved in accounting for the quantity of radionuclide at time t are described in the word equation shown below:

[Rate of Change in Box 2 at Time t] = [Rate of Transfer by Leaching from Box 1 at Time t] - [Rate of Removal from Box 2 by Decay at Time t] - [Rate of Removal from Box 2 by Leaching at Time t].

Scoping Model for Environmental Transport

For box 2, the basic differential equation accounts for not only original quantities, radioactive decay, and leaching, also for quantities entering from box 1:

$$\frac{dQ_2}{dt} = L_{12} Q_1 - \lambda Q_2 - L_{23} Q_2.$$

Where:

- Q_2 = Activity of radionuclide in box 2 at time t (Ci)
- L_{23} = Rate constant for movement from box 2 to box 3 (1/yr).

and other terms are as defined above.

For box 3, the concepts involved in accounting for the quantity at time t are described in the word equation shown below:

$$\begin{aligned} [\text{Change in Box 3 at Time t}] = & [\text{Rate of Transfer by Leaching from Box 2 at Time t}] \\ & - [\text{Rate of Removal from Box 3 by Decay at Time t}] \\ & - [\text{Rate of Transfer from Box 3 to Box 4 at Time t}]. \end{aligned}$$

The differential equation for box 3 is similar to box 2:

$$\frac{dQ_3}{dt} = L_{23} Q_2 - \lambda Q_3 - L_{34} Q_3.$$

Where:

- Q_3 = Activity of radionuclide in box 3 at time t (Ci)
- L_{34} = Rate constant for movement from box 3 to box 4 (1/yr)

and other terms are as defined above.

The input to box 4 is the material released from box 3. In this application, rather than explicitly represent the loss rate constants, which would have very fast transfer rates compared to the groundwater system (the Columbia River is very fast-flowing compared to groundwater), the concentrations in the Columbia River are approximated assuming that the annual releases are diluted in the annual water flow, and decay is neglected. The equation for concentration in Columbia River water is then

$$C_4 = Q_3 L_{34} / R.$$

Where:

- C_4 = The concentration in Columbia River water, Ci/L
- R = The flow rate of the river, L/yr.

and other terms are as defined above.

Scoping Model for Environmental Transport

The rate constants for movement between compartments are evaluated as follows. The leach rate from the waste zone is

$$L_{12} = \frac{I}{H_w \theta_1 R_t}.$$

Where:

- I = The infiltration rate, m/yr
- H_w = The assumed thickness of the waste zone layer containing the residual radioactive material (m)
- θ₁ = Volumetric water content of the surface-soil layer (dimensionless)
- R_t = Retardation factor for movement of contaminant from the surface-soil layer to the unsaturated layer (dimensionless).

The retardation factor is calculated from the partition coefficient for the radionuclide in the soil, the density of the soil layer, and the volumetric water content as follows:

$$R_t = 1 + \frac{K_d \rho}{\theta_1}.$$

Where:

- K_d = The partition coefficient for radionuclide in the surface-soil layer (mL/g)
- ρ = The bulk density of waste zone layer (g/mL).

The transfer rate from the vadose zone into the aquifer, L₂₃, is calculated in a manner analogous to the rate from the waste zone:

$$L_{23} = \frac{I}{H_v \theta_1 R_t}.$$

Where

- H_v = The thickness of the vadose zone (m).

The transfer parameter from the groundwater to the Columbia River, L₃₄, is assumed to be the reciprocal of the groundwater travel time, TT (yr). That is, the release is assumed to be related to plug flow of the groundwater mass into the river, retarded with the K_d. Thus,

$$L_{34} = 1 / (TT R_t).$$

The equation for contaminant concentration in groundwater C₃ (Ci or kg/m³), is the quantity in the groundwater divided by the water volume of the streamtube

$$C_3 = Q_3 / D_1 D_2 D_3 (\theta_2 + K_d (1 - \theta_2)).$$

Scoping Model for Environmental Transport

Where:

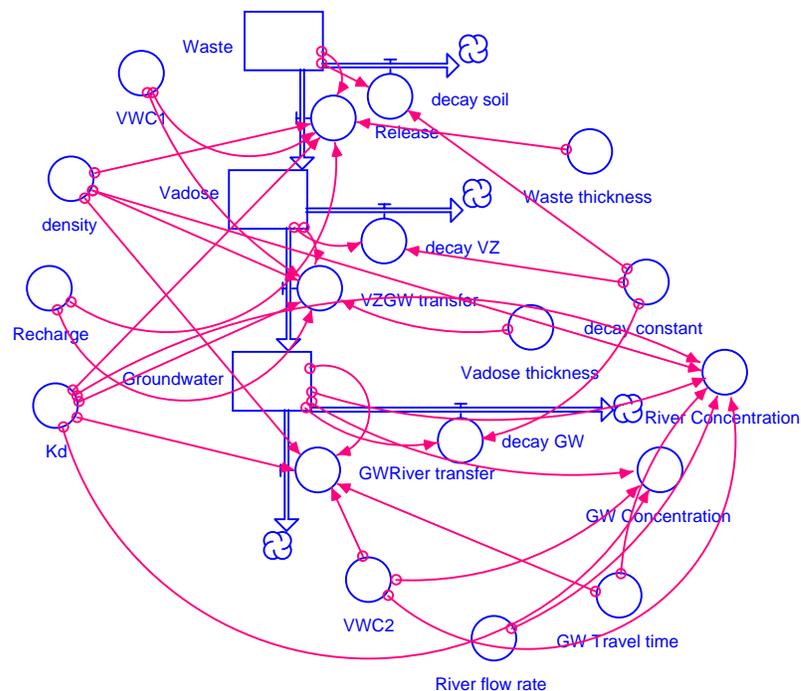
D_1 , D_2 , and D_3 are the dimensions of the streamtube, m, and
 θ_2 is the saturated zone porosity or saturated water content (dimensionless).

3.2 STELLA APPLICATION

The series of coupled differential equations defined above does not have an analytical solution for the quantities Q_1 , Q_2 , and Q_3 , from which the other concentrations can be derived (e.g., these are the Bateman equations common in the calculation of radioactive decay (Bateman 1910)). However, these equations become very complex for the third and fourth boxes in the series. A simpler solution technique is available using the computer modeling environment STELLA II (High Performance Systems 1994). STELLA is a multi-level, hierarchical environment for constructing and running complex models. The benefit to STELLA is that it allows input of the basic differential equations, which it then solves numerically, while providing graphical output and control.

The scoping groundwater transport model described above was implemented in STELLA. A graphical representation of the resulting model is presented in Figure 3-2. The differential equations for the waste zone, vadose zone, and groundwater are evident as rectangular boxes. The Transfer of material to the Columbia River is the circle at the lower right of the figure. The various other parameters defined in the equations above are also evident as circles throughout the figure. The STELLA language implementation of this figure is presented in Appendix A.

Figure 3-2. STELLA Representation of Contaminant Scoping Transport Model.



Scoping Model for Environmental Transport

Model Parameters

The parameters used in the model for the near-river and plateau sites are provided in Table 3-1.

Results

In order to be of use in the scoping calculations, predicted concentrations in groundwater and Columbia River water for unit releases of each potential contaminant from both the 100 and 200 Areas were computed. The raw results for radionuclides are presented in Table 3-2. The raw results for chemicals are presented in Table 3-3.

Table 3-1. Common Parameters use in Transport Modeling.

	100 Areas	200 Areas
Infiltration, m/year	0.01	0.01
Volumetric Water Content, Vadose Zone	0.02	0.02
Volumetric Water Content, Aquifer	0.35	0.35
Waste Zone Thickness, m	5	5
Vadose Zone Thickness, m	1	50
Streamtube Width, m	100	1000
Streamtube Length, m	1,000	10,000
Streamtube Depth, m	5	5
Travel Time, years	1	20

Some insight may be gained into the behavior of materials in the groundwater-river system by investigating the concentration changes in response to changes of parameters. For instance, as the sorption coefficient is increased, the peak concentration decreases and time to occurrence of the peak increases. These effects are illustrated in Figures 3-3 and 3-4.

Figure 3-3. Influence of K_d on Peak Release Concentration for a Unit Inventory of Nondecaying Material in the 200 Areas.

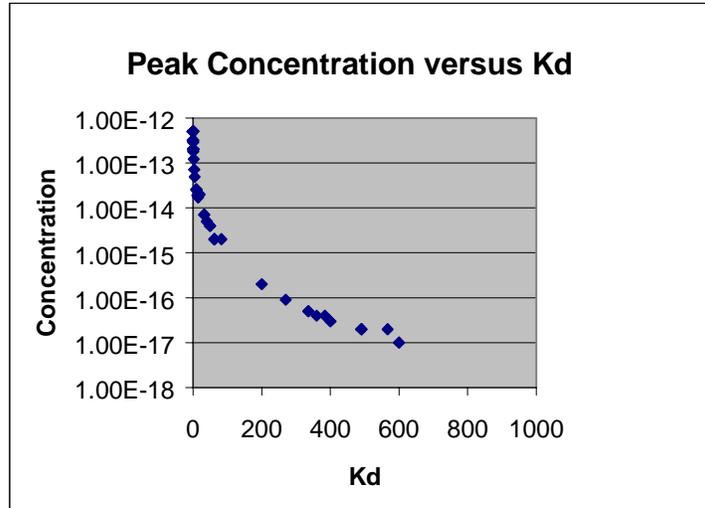
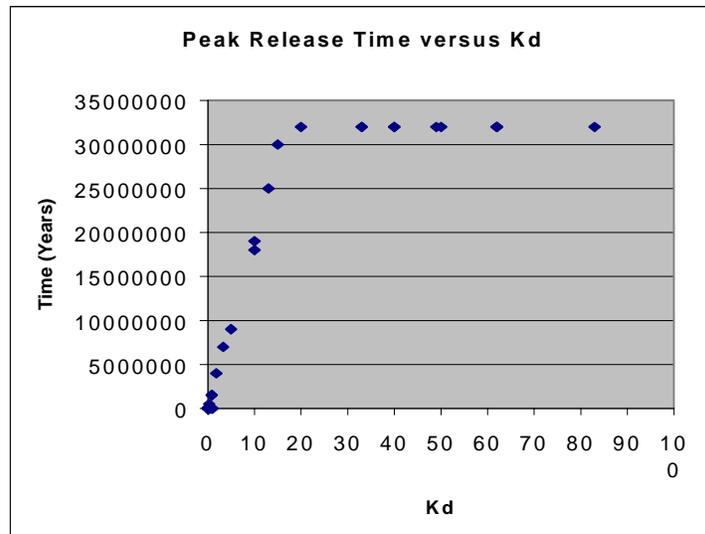


Figure 3-4. Influence of K_d on Time to Peak Release for a Nondecaying Material in the 200 Areas.



**Table 3-2. Peak Groundwater and Surface Water Concentrations for Unit Releases
in the 100 and 200 Areas (Radionuclides). (3 Pages)**

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ^{1/2} (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)				
Radionuclides			Ci/L per Ci				
Actinium 227	100	21.7	7.20E-24	5.50E-33	1.40E-27	5.50E-36	*
Americium 241	100	433	2.90E-21	2.20E-30	5.80E-25	2.20E-33	
Americium 242M	100	152	3.50E-22	2.70E-31	7.10E-26	2.70E-34	
Cadmium 113M	74	13.6	7.00E-24	5.30E-33	1.40E-27	5.30E-36	
Carbon 14	0	5730	3.70E-10	6.40E-16	7.30E-12	6.40E-17	
Cesium 135	540	2.30E+06	2.60E-16	1.90E-25	9.80E-21	3.70E-28	~7E6
Cesium 137	540	30.2	8.90E-26	6.80E-35	1.80E-29	6.80E-38	
Chlorine 36	0	3.07E+05	3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Cobalt 60	1200	5.26	2.50E-28	1.90E-37	4.90E-32	1.90E-40	
Curium 243	100	32	1.60E-23	1.20E-32	3.10E-27	1.20E-35	
Curium 244	100	18.1	5.00E-24	3.80E-33	1.00E-27	3.80E-36	
Europium 152	100	14	3.00E-24	2.30E-33	6.00E-28	2.30E-36	
Europium 154	100	7.8	9.30E-25	7.10E-34	1.90E-28	7.10E-37	
Iodine 129	0.3	1.60E+07	1.40E-11	3.00E-20	3.20E-14	3.40E-21	~1E6
Krypton 85	0	10.74	0	0	0	0	
Lead 210	2000	22	9.30E-28	7.10E-37	1.90E-31	7.10E-40	
Neptunium 237	10	2.14E+06	5.70E-13	4.60E-22	3.10E-16	1.20E-23	~3E6
Nickel 59	50	8.00E+04	5.70E-16	4.40E-25	1.50E-20	5.90E-28	
Nickel 63	50	92	1.00E-21	7.90E-31	2.10E-25	7.90E-34	~5E5

**Table 3-2. Peak Groundwater and Surface Water Concentrations for Unit Releases
in the 100 and 200 Areas (Radionuclides). (3 Pages)**

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ^{1/2} (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)				
Radionuclides			Ci/L per Ci				
Palladium 107	55	7.00E+06	9.10E-14	6.90E-24	3.20E-17	1.20E-24	~13e6
Protactinium 231	10	3.24E+04	8.70E-15	6.90E-24	9.80E-21	3.70E-28	~7E6
Plutonium 238	80	87.4	2.30E-22	1.70E-31	4.60E-26	1.70E-34	
Plutonium 239/240	80	24390	1.70E-17	1.30E-26	3.50E-21	1.40E-29	~75,000
Plutonium 241	80	14.3	6.10E-24	4.70E-33	1.20E-27	4.60E-36	
Plutonium 242	80	3.87E+05	2.10E-15	1.60E-24	8.40E-19	3.20E-27	~1E6
Radium 226	8	1602	6.80E-17	5.60E-26	1.40E-20	5.80E-29	
Radium 228	8	5.75	9.30E-22	7.50E-31	1.90E-25	7.50E-34	
Samarium 151	240	93	9.60E-24	7.30E-33	1.90E-27	7.30E-36	
Selenium 79	0	650000	3.30E-09	5.80E-15	7.40E-12	6.50E-17	
Strontium 90	8	28.9	2.40E-20	1.90E-29	4.70E-24	1.90E-32	
Technetium 99	0	213000	3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Tellurium 123	150	1.20E+13	7.40E-14	5.60E-23	3.70E-16	1.40E-24	>32E6
Thorium 229	40	7340	1.20E-17	9.40E-27	2.60E-21	9.80E-30	
Thorium 230	40	78000	9.90E-16	7.60E-25	2.80E-19	1.10E-27	~5E5
Thorium 232	40	1.41E+10	2.90E-13	2.20E-22	5.00E-15	1.90E-23	>32E6
Tin 121M	50	76	7.00E-22	5.40E-31	1.40E-25	5.40E-34	
Tin 126	50	2.50E+05	3.40E-15	2.60E-24	1.40E-17	5.50E-27	~750,000
Tritium (Hydrogen 3)	0	12.3	2.80E-10	4.90E-16	1.40E-13	1.20E-17	

Table 3-2. Peak Groundwater and Surface Water Concentrations for Unit Releases in the 100 and 200 Areas (Radionuclides). (3 Pages)

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ^{1/2} (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)				
Radionuclides			Ci/L per Ci				
Uranium 232	0.6	72	1.90E-16	2.70E-25	3.90E-20	2.80E-28	
Uranium 234	0.6	2.47E+05	6.90E-12	9.90E-21	5.40E-14	3.90E-22	~750,000
Uranium 235	0.6	7.10E+08	1.00E-11	1.50E-20	2.40E-13	1.70E-21	~1.5E6
Uranium 236	0.6	2.42E+07	1.00E-11	1.50E-20	2.30E-13	1.70E-21	~1.5E6
Uranium 238	0.6	4.51E+09	1.00E-11	1.50E-20	2.40E-13	1.70E-21	~1.5E6
Zirconium 93	40	9.50E+05	2.80E-14	2.20E-23	3.30E-17	1.30E-25	~2E6

**Table 3-3. Peak Groundwater and Surface Water Concentrations for Unit Releases
in the 100 and 200 Areas (Chemicals). (4 Pages)**

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ^{1/2} (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)				
Chemicals	K _d (IAEA 1994, Kincaid et al.)		kg/L per kg				
Aluminum	35300		3.00E-19	2.20E-28	6.30E-23	2.40E-31	>32E6
Ammonia/Ammonium	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Ammonium Carbonate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Ammonium Nitrate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Benzene	1		7.60E-12	8.90E-21	1.80E-13	1.00E-21	
Benzo[a]Pyrene	75900		3.00E-20	2.00E-29	6.00E-24	2.00E-32	>32E6
Beryllium	1400		2.00E-15	1.00E-24	9.00E-19	4.00E-27	>32E6
Bismuth	270		3.00E-14	2.00E-23	9.00E-17	3.00E-25	
Cadmium	74		1.60E-13	1.20E-22	2.00E-15	6.00E-24	>32E6
Carbon Tetrachloride	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Cerium	100		1.20E-13	8.90E-23	9.00E-16	4.00E-24	>32E6
Chloroform	0.4		1.20E-11	2.20E-17	2.90E-13	2.60E-21	
Chromium	67		1.70E-13	1.30E-22	2.00E-15	8.00E-24	>32E6
Chrysene	2760		3.00E-16	2.00E-25	1.00E-19	5.00E-28	>32E6
Copper Sulfate	92		1.30E-13	9.70E-23	1.00E-15	4.00E-24	>32E6
Copper	92		1.30E-13	9.70E-13	1.00E-15	4.00E-24	>32E6
Cyanide	0.007728		2.50E-11	1.50E-19	4.40E-13	1.30E-20	
Dibutyl Butyl Phosponate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	

**Table 3-3. Peak Groundwater and Surface Water Concentrations for Unit Releases
in the 100 and 200 Areas (Chemicals). (4 Pages)**

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ^{1/2} (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)				
Chemicals	K _d (IAEA 1994, Kincaid et al.)		kg/L per kg				
Dibutyl Phosphate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Dichloroethylene, 1,2-	0.8		8.80E-12	1.10E-20	2.00E-13	1.30E-21	~1.5E6
Diesel Fuel	62		1.90E-13	1.40E-22	2.00E-15	9.00E-24	>32E6
Ferrocyanide	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Ferrous Sulfamate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Fluoride	0.3		1.40E-11	3.00E-20	3.20E-13	3.40E-21	
Iron	15		7.60E-13	5.90E-22	1.80E-14	6.90E-23	~30E6
Kerosene	62		1.90E-13	1.40E-22	2.00E-15	9.00E-24	>32E6
Lanthanum	100		1.20E-13	8.90E-23	9.00E-16	4.00E-24	>32E6
Lead	270		3.00E-14	2.00E-23	9.00E-17	4.00E-25	>32E6
Manganese	49		2.40E-13	1.80E-22	3.00E-15	1.00E-23	>32E6
Mercury	580		9.00E-15	6.00E-24	1.00E-17	4.00E-26	>32E6
Methyl Isobutyl Ketone (Hexone)	10		1.10E-12	8.90E-22	2.60E-14	1.00E-22	~19E6
NPH (Normal Parafin Hydrocarbon)	62		1.90E-13	1.40E-22	2.00E-15	9.00E-24	>32E6
Nickel	50		2.30E-13	1.80E-22	4.00E-15	1.00E-23	>32E6
Nitrate	0.3		1.40E-11	3.00E-20	3.20E-13	3.40E-21	
Nitrite	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	

**Table 3-3. Peak Groundwater and Surface Water Concentrations for Unit Releases
in the 100 and 200 Areas (Chemicals). (4 Pages)**

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ½ (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)				
Chemicals	K _d (IAEA 1994, Kincaid et al.)		kg/L per kg				
Oxalate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
PCBs (Arochlor)	384		2.00E-14	1.00E-23	4.00E-17	1.00E-25	>32E6
Phosphate	50		2.30E-13	1.80E-22	4.00E-15	1.00E-23	>32E6
Potassium	0.2		1.60E-11	4.50E-20	3.70E-13	5.20E-21	~1.5E6
Potassium Borate	0.2		1.60E-11	4.50E-20	3.70E-13	5.20E-21	~1.5E6
Silicon	33		3.50E-13	2.70E-22	7.00E-15	3.00E-23	>32E6
Silver (I)	90		1.30E-13	9.90E-23	1.00E-15	4.00E-24	>32E6
Silver Chloride	90		1.30E-13	9.90E-23	1.00E-15	4.00E-24	>32E6
Sodium	0.2		1.60E-11	4.50E-20	3.70E-13	5.20E-21	~1.5E6
Sodium Aluminate	35300		3.00E-19	2.00E-28	6.00E-23	2.00E-31	>32E6
Sodium Dichromate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Sodium Hydroxide	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Sodium Nitrate	0.3		1.40E-11	3.00E-20	3.20E-13	3.40E-21	~500,000
Sodium Oxylate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Sodium Silicate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Sodium Sulfamate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Strontium	8		1.40E-12	1.10E-21	3.20E-14	1.30E-22	~16E6
Sulfamic Acid	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	

Table 3-3. Peak Groundwater and Surface Water Concentrations for Unit Releases in the 100 and 200 Areas (Chemicals). (4 Pages)

Peak Releases for Unit Inventories Summary of Scoping Transport Model Results							
Name of Analyte	K _d (ml/g)	T ^{1/2} (Years)	Unit Inventories				Time Years
			100 Area Peaks		200 Area Peaks		
	GW	River	GW	River			
	(IAEA 1994)		(1 m vadose, 1 yr travel)		(50 m vadose, 20 yr travel)		
Chemicals	K _d (IAEA 1994, Kincaid et al.)		kg/L per kg				
Sulfate (Sulfur)	0.3		1.40E-11	3.00E-20	3.20E-13	3.40E-21	
Sulfuric Acid	0.3		1.40E-11	3.00E-20	3.20E-13	3.40E-21	
Tetrachloroethane 1,1,1,2-	10		1.10E-12	8.90E-22	2.60E-14	1.00E-22	~20E6
Tetrachloroethylene	5		2.10E-12	1.80E-21	4.90E-14	2.10E-22	~10E6
Tributyl Phosphate (TBP)	83		1.40E-13	1.10E-22	1.00E-15	5.00E-24	>32E6
Tributyl Phosphonate	0		3.70E-10	6.40E-16	7.40E-12	6.50E-17	
Trichloroethylene	1.8		5.00E-12	4.90E-21	1.20E-13	5.70E-22	~4e6
Uranium	0.6		1.00E-11	1.50E-20	2.40E-13	1.70E-21	~1E6
Xylene	3.3		3.00E-12	2.70E-21	7.10E-14	3.10E-22	~7E6
Zinc	200		5.00E-14	4.00E-23	2.00E-16	7.00E-25	>32E6
Zirconium	40		2.90E-13	2.20E-22	5.00E-15	2.00E-23	>32E6

* Unmarked times are within 1,500 years.

Scoping Model for Environmental Transport

3.3 VALIDATION OF SCOPING MODEL PREDICTIONS

The simple scoping model contains a number of simplifying assumptions, but because of its structure should give conservative transport results. In order to test this hypothesis, known Hanford releases were simulated, and the resulting predicted concentrations compared to site measurements.

The Best Basis Inventory suggests that, in 1994 curies, 71,600 curies of tritium should be somewhere at the Hanford Site, and about 34,000 curies of it should be in the 200 Area tank farms. This means that 37,600 curies are outside the tanks in some form or other. This is in correspondence with the amounts reported in the site annual reports for the years when PUREX was operating; 37,180 curies between 1983 and 1988.

Because the tritium was discharged to cribs with large volumes of water, the simple model parameter for recharge was increased to 2 meters/year. With this single change, the model predicts groundwater concentrations downgradient of PUREX of about 600,000 pCi/L. This region is described in the 1998 Hanford Site annual report (Dirkes and Hanf 1998) as having a plume in excess of 200,000 pCi/L extending southeast that extended as far as the Central Landfill area in the recent past. It is now shrinking back toward the 200 East area because radioactive decay is exceeding the transport velocity. This corresponds with the model prediction. A small area exceeds the concentration predicted by the simple model, at peak concentrations up to 2,000,000 pCi/L, but since the simple model applies to the entire plume downgradient towards the river, it appears to be a reasonable but conservative description of the contamination.

In the 100 Areas, sodium dichromate was added to cooling water as a corrosion inhibitor, and some residual chromium remains from that use. The SAC inventory indicates that 3,690 kg of sodium dichromate exists in the 100-H Area, through past disposals near the H Reactor, disposal to the 107-H Liquid Waste Disposal Trench, and chromium in acid wastes stored in the former 183-H Basins. At least some of these wastes were disposed of with water, so the recharge used in the simple scoping model should be greater than the natural value of 1 cm/year. Using the natural recharge rate of 1 cm/year, the model predicts groundwater concentrations of about 80 µg/L. Using an enhanced value of 1 m/year, the model predicts about 5,500 µg/L. Measurements at the site indicate values in 100-H Area as high as 277 µg/L. Thus, it is likely that the model is within an order of magnitude of the appropriate value, probably on the high side, if the appropriate recharge rate were known.

The simple model used here is appropriate for very dilute materials flowing with groundwater. Concentrated, dense, or nonaqueous materials, such as the carbon tetrachloride plume in the 200 West Area, will not be as well modeled using this simple formulation.

4.0 SCOPING BENCHMARKS

Benchmark values are needed to compare to the scoping criteria elaborated in Section 1. The human risk estimates require estimates of exposure. These are provided using a Native American Subsistence Resident scenario derived from the CRCIA, Part 1. Ecological benchmarks are based on world-wide regulatory or other minimum allowable concentrations in surface water. Socio-cultural impacts are based on comparisons of predicted future concentrations in groundwater to Hanford-specific background values. Each of these is elaborated below.

4.1 NATIVE AMERICAN HUMAN EXPOSURE SCENARIO

Because humans affected by the Columbia River are involved in a wide range of activities, various scenarios have been developed on which to base the risk assessments. The scenarios illustrate the range of activities possible by members of the public coming in contact with the Columbia River so that the impact of contaminants in the river on human health can be assessed. Each scenario illustrates particular activity patterns by a specific group. The Columbia River Comprehensive Impact Assessment introduced a Native American Subsistence Resident scenario, that under most situations tends to bound the exposures to most other groups. This scenario has been selected as the basis for the human risk analysis in the scoping analysis. This section defines the scenario and the exposure factors used as the basis for estimating the potential risk to human health from Hanford-derived radioactive as well as nonradioactive contaminants associated with Hanford Site groundwater and the Columbia River.

The range of potential Native American activities on the Hanford Site is very broad. They include activities specifically delineated in the treaties and also include a range of unlisted but reserved rights related to traditional lifestyles and to preservation of natural and cultural resources. Specific activities or activity categories include but are not limited to collecting, fishing, gathering, hunting, and processing of the catch along the shoreline, and pasturing of livestock, as well as ceremonial, educational, seasonal, social, and trade activities. Some of these activities are analogous to common suburban activities with respect to environmental contact rates, but some are unique and have no suburban surrogate. Initial estimates of exposure factors for a range of activities are presented here based on their use in CRCIA, Part 1.

This report describes an initial version of a Native American subsistence scenario specifically developed for Columbia Basin climatic conditions (hot and dry), ecosystems (high desert, river), and indigenous activity patterns (high fish consumption, seasonally active lifestyles). The Subsistence Resident Scenario is a composite year-round scenario that crosses all habitats. This habitat approach to human activity patterns was taken because of the potential for these scenarios to be used to answer questions about whether particular areas are safe to use, and therefore it seemed reasonable to combine activities that a person might pursue in different areas into separate scenarios. It should be noted that the subsistence scenario is an unrestricted use scenario. The specific activities presented here reflect several, but not all, treaty-reserved rights (fishing, gathering, hunting, and pasturing). In traditional communities, different people tend to specialize in different activities, and therefore they spend more time at their special activities than a subsistence person would be able to allocate. The Subsistence Resident Scenario is a

Scoping Benchmarks

composite scenario in which a person must divide her/his time throughout a full year among all the specific activities rather than specializing in one or two. The Subsistence Resident Scenario is intended to represent a reasonable set of activities that reflect a traditional lifestyle with activities occurring for a full 70-year lifetime on what is now the Hanford Site. It is a composite scenario that includes a mix of representative but not all-inclusive activities spread over the entire year. This is a moderately active lifestyle with access to both the shoreline and to seeps/springs as well as upland areas near the river. Seep/spring water is assumed to be used for ingestion and biotic uptake directly from in situ groundwater and around the springs. A full diet of meat (game and pastured livestock), fish, and plants is assumed. It can be considered an almost completely unrestricted scenario, but it does not include maxima for fishing, gathering, or hunting and does not necessarily include visits to special areas or sites for nonfood purposes such as ceremonies or teaching.

In this scenario, a person spends full time (365 days, 24 hours/day) on the site for a lifetime of 70 years. Activities include collecting, fishing, gathering, hunting, and pasturing of livestock. Pasturing of livestock, such as cattle, is included here because human exposure could result, but pasturing of horses would be considered part of an ecological assessment because the horse is not part of the human food chain. Exposures related to these activities can occur from ingestion of food and water as well as from contact with environmental media during gathering, preparation, and noningestion uses. Access to seep/spring water for all uses including irrigation of pasture and crops or native plants growing around springs, and access to the shoreline are assumed. Preliminary assumptions and selection of exposure factors are described below. They are summarized in Table 4-1.

- **Soil: Ingestion** – A person is assumed to continue a child's soil ingestion rate of 200 milligrams/day (EPA 1991a) throughout life. Resuspension of dust with deposition on plants and pasture is included. If soil is contaminated, a soil-plant-animal-human pathway would also exist. If contaminated soil or dust deposits on plants and pasture, an additional exposure route would exist.
- **Soil: External Radiation Exposure** – Because this scenario assumes full-time residence, the person is assumed to be on site 24 hours/day, and, for this example, the time is not divided among location types (shoreline, boating, and upland). A shielding reduction factor of 0.8 (a reduction in the dose rate by building walls and other deviations from a uniformly-contaminated, flat surface) is applied per the *Hanford Site Risk Assessment Methodology* (HSRAM) (DOE-RL 1995), which assumes that the person is standing on contaminated soil during the entire exposure period.
- **Soil: Dermal Contact** – Dermal contact is assumed to occur at the rate of one event per day with soil adhering to the skin at a rate of 1 mg/cm² per day, which is a multiple of the 0.2 mg/cm² default (EPA 1991a) value. The duration of the event is not used because dermal absorption is time-independent. Contact would occur over a skin surface area of 5,000 cm². This value represents 25 percent of the total skin surface area (EPA 1991a). The skin absorption fraction is contaminant specific. The increased soil adherence rate needs to be reviewed to ensure that it adequately represents not only initial contact during gathering but also cleaning and preparation.

Scoping Benchmarks

**Table 4-1. Exposure Factors for the Native American Subsistence Resident Scenario.
(2 Pages)**

Pathways Media	Exposure Factors					
	Exposure Route	Intake/ Contact Rate (per day)	Exposure Frequency (days/year)	Exposure Duration (years)	Other Factors	Other Factor Definitions
Soil	Ingestion ^a	200 mg	365	70	--	--
	External	24 hr	365	70	0.8	Shielding factor
	Dermal	1 mg/cm ²	365	70	5000 cm ²	Skin surface area
	Inhalation	30 m ³	365	70	100 µg/m ³	Air mass loading
Air	Inhalation	30 m ³	365	70	--	--
Seep/Spring Water	Ingestion	3 L	365	70	--	--
	External	12 hr	365	70	0.8	Shielding factor
	Dermal ^b	1 hr	365	70	20,000 cm ²	Skin surface area
	Inhalation ^c	15 m ³	365	70	0.1 L/m ³	See footnote d
Surface Water	Ingestion	3 L	365	70	--	--
	External	2.6 hr	70	70	0.5	Geometry correction
	Dermal ^e	2.6 hr	70	70	20,000 cm ²	Skin surface area
	Inhalation ^f	15 m ³	70	70	0.1 L/m ³	See footnote d
Sediment	Ingestion	200 mg	270	70	--	--
	External	12 hr	270	70	0.2	Geometry correction
	Dermal	1 mg/cm ²	270	70	5000 cm ²	Skin surface area
Biota ^g	Fish ^h	540 g	365	70	--	--
	Fruit and vegetation	660 g	365	70	--	--
	Animal protein ⁱ	150 g	365	70	--	--
	Other Organs ^j	54 g	365	70	--	--
	Milk	0.6 L	365	70	--	--
	Upland Birds	18 g	365	70	--	--
	Waterfowl	70 g	365	70	--	--
	Wild bird eggs	45 g	365	70	--	--

Scoping Benchmarks

**Table 4-1. Exposure Factors for the Native American Subsistence Resident Scenario.
(2 Pages)**

Pathways Media	Exposure Factors					
	Exposure Route	Intake/Contact Rate (per day)	Exposure Frequency (days/year)	Exposure Duration (years)	Other Factors	Other Factor Definitions
Cultural ^k	Inhalation	1 hr	365	70	0.075 L/m ³	See footnote k
	Dermal	1 hr	365	70	20,000 cm ²	Skin surface area

^a Soil ingestion is typically separated into child (200 mg/d) and adult (100 mg/d) factors, but considering the activities included in these scenarios, it seems reasonable to assume that the higher rate would persist throughout a lifetime.

^b The dermal factor for seep/spring water in HSRAM reflects bathing. For this scenario, it is assumed that seep/spring water is encountered regularly while gathering roots.

^c In HSRAM, seep/spring water use is a household scenario where inhalation comes from volatilization during showering and other household use. To the extent that analogous activities occur, this factor is retained.

^d Based on volatilization equivalent to 0.1 L water per m³ of air (Andleman 1990).

^e For surface water, only swimming (2.6 hours/day) is included.

^f As for seep/spring water, exposures may still occur that are the equivalent of suburban household exposures.

^g Foodchain pathways include deposition, soil uptake and seep/spring water uptake, as well as aquatic pathways. There are also additional factors relevant to human ingestion, such as additional plant parts used or eaten (and multiple parts per plant that rotate through the seasons), medicinal uses (infusions, teas, poultices, etc.), other potential contact with people or their foods (food storage basketry, sleeping mats, extensive contact during basketmaking, use of bones, feathers and sinews), etc.

^h Fish consumption includes multiple species and parts eaten, prepared both fresh and dried. Equivalent fresh weight is given here.

ⁱ The animal protein consumption rate includes meat, fat, and marrow, prepared fresh or dried. The equivalent fresh weight is given here.

^j Approximated as 10 percent of the fish ingestion value.

^k The unique pathway related to volatilization of contaminants from water during sweat bathing is included here. The absolute humidity is based on saturated conditions at a temperature of 80 degrees Centigrade (180 degrees Fahrenheit).

- **Soil: Resuspended Soil Inhalation** – Resuspension of soil with subsequent inhalation of the dust in the air is assumed to occur at all times while the person is on site. The amount of resuspension is determined by use of the mass loading approach based on an ambient air mass loading value of 100 $\mu\text{g}/\text{m}^3$, which is twice the U.S. Environmental Protection Agency (EPA) recommended value for suburban areas (40 CFR 50.6(b)). The pollutant concentration in the particulate matter is assumed to be the same as the pollutant concentration in the soil. The person is assumed to inhale 30 m³ of air during the 24 hours s/he is onsite. This is 150 percent of the average value to account for a more active outdoor lifestyle (EPA 1989).
- **Air: Inhalation** – The person is assumed to inhale 150 percent of the default volume of air per day (30 m³/day) to account for a more active lifestyle (EPA 1989). If there is an airborne radiological plume, immersion of people, plants and animals in that plume is also included.
- **Seep/Spring Water: Ingestion** – For this scenario, the person is assumed to drink 3 liters/day of seep/spring water, which is assumed to be undiluted groundwater. No decay of radionuclides between withdrawal of seep/spring water and ingestion is assumed, and no filtration of particulate matter is assumed. In other words, the concentration of contaminant

Scoping Benchmarks

in unfiltered groundwater is the appropriate comparison value. In addition, deliberate irrigation of pasture and some amount of domestic crops is assumed to occur, resulting in a pathway from groundwater to plants via direct uptake by the roots of domestic and/or native plants (for example, cattails growing in contaminated seeps). In the present example, game animals are also assumed to drink from the springs, and groundwater or springs are used as the source of drinking water for pastured animals. If the seeps form a wetland, several of the exposure assumptions will need to be revised to construct a true wetland scenario.

- **Seep/Spring Water: External Radiation Exposure** – A person is assumed to be close enough to the spring or to soil dampened by spring water to receive exposure to external radiation 12 hours every day.
- **Seep/Spring Water: Dermal Contact** – On the average, 1 hour every day is assumed to be spent in activities associated with groundwater, seeps or springs, including bathing, digging for roots, collecting medicines, or drawing water. The complete skin surface area is assumed to be exposed to the water. In addition, sediment or groundwater-soaked soil is assumed to adhere to the skin during one contact event every day.
- **Seep/Spring Water: Inhalation** – The inhalation rate of 15 m³/day represents volatilization of pollutants from seep/spring water into a relatively small space or short distance. This pathway typically includes year-round indoor activities such as showering and cooking. Because these activities or analogues of these activities could be expected to occur during subsistence living, the default factor is included here unchanged (EPA 1991a). The quantity of water in indoor air is based on the absolute humidity (Andelman 1990).
- **Surface Water: Ingestion** – For this scenario, the person is assumed to drink 3 liters/ day of surface water. A person is also expected to inadvertently ingest water during swimming at a rate of 0.01 liter/hour x 2.6 hours/swim) (DOE-RL 1995), but this is not expected to add significantly to his total daily water intake and so is not listed separately. In the present example, no irrigation is assumed to occur, but it is assumed that game and domestic animals would drink from the river, and that fish might bioconcentrate some contaminants.
- **Surface Water: External Radiation Exposure** – Swimming and boating are assumed to occur for 2.6 hours/day for 70 days/year, and shoreline use is assumed to occur for 12 hours/day for 270 days/year. During boating, the dose rate at the water surface is one-half that of immersion (Jaeger et al. 1968), while the shoreline geometry is expected to reduce the dose by 20 percent. There is no shielding while directly swimming in the river.
- **Surface Water: Swimming Dermal Contact** – The dermal contact during swimming assumed 2.6 hours of swimming (EPA 1991a) for 70 days with dermal contact with water over 20,000 cm² skin surface area (EPA 1991a). The absorption coefficient is contaminant specific. In addition, swimming is also assumed to result in dermal contact with sediment over 5000 cm² skin surface area (EPA 1991a).

Scoping Benchmarks

- **Surface Water: Inhalation** – The person is assumed to inhale near-surface volatiles year-round as in conventional indoor surface water use (EPA 1991a).
- **Sediment: Ingestion, External Radiation Exposure, Dermal Contact** – The rates used for contact with sediment are similar to soil except the contact is assumed to be 12 hours/ day because the individual lives permanently above the high water line. Also the exposure frequency per year is lower (270 days instead of 365 days) because inclement weather, high water, or other activities are assumed to reduce the overall time spent on or near sediments.
- **Biota: Ingestion** – A fish consumption rate of 540 grams/day was chosen to represent a reasonable maximum intake (CRITFC 1994, DOI 1942, Hunn 1990). Tribal input indicates that fresh fish and dried fish are consumed in roughly equal ratios, so the overall consumption rate was estimated as follows. One quarter of the 540-gram daily consumption (135 g/d or 3.5 oz.) is assumed to be fresh, and three quarters (405 g/d) is assumed to be dried. The 405 grams/day that is dried is estimated to lose about two-thirds of its mass during drying, resulting in a dry weight of about 135 grams. Thus, a person is assumed to eat 135 grams/day fresh and 135 grams/day dry, which is equivalent to 540 grams of wet weight.
 - On the basis of tribal input, the ingestion rate for fruits and vegetables was set at 660 grams/day based on the same principle of 50 percent fresh and 50 percent dried. It will not be useful to investigate specific ingestion rates of roots, fruits, etc. unless uptake factors to specific plant parts (roots versus leaves) or specific plant species are available. Medicinal and other uses of plant material may provide reason to increase in this ingestion rate.
 - The HSRAM value for meat and game intake is superseded with a single animal protein consumption rate based on tribal input of 75 grams/day of animal protein (which may include flesh, fat, marrow, etc.), of which 50 percent is fresh and 50 percent is dried. Conversion to fresh weight, assuming a wet-to-dry ratio of 3, gives the equivalent fresh weight of 150 grams/day. The waterfowl and upland game bird consumption rates are assumed to be the same for subsistence as they are for the Upland Hunter Scenario. This needs to be reviewed for seasonal take, length of season, and special hunting privileges. Again, since contaminant concentration among animal/fowl species is currently modeled solely on the basis of proportional animal body weight, it will not be useful to determine consumption rates of specific species or animal organs/tissues unless information about contaminant uptake and tissue distribution is available.
 - The caloric content of fresh salmon is approximately 500 Kcal/275 grams (chinook) or 400 Kcal/275 grams (sockeye). The rate of 540 grams/day therefore represents about 800-1,000 Kcal/day depending on the type of salmon. The caloric requirements for moderately active adults is approximately 3,000 Kcal/day for males, 2,200 Kcal/day for females, with an additional 500 Kcal/day for pregnant or lactating females (or 80,000 Kcal per pregnancy). If the daily protein requirement is about 75 grams for a 75 kilogram male (about 165 lbs) for a sedentary lifestyle and 25 percent more for a moderately active lifestyle, and salmon contains 17 grams protein per 100 grams wet weight, then the salmon would provide close to the required daily amount of protein and one third to one half of the caloric requirement (100 g = 3 oz.). Hunn (1990) estimated

Scoping Benchmarks

that a traditional diet is composed of 1300 grams/day roots (or 1830 Kcal/day) plus 1,400 grams/day of other vegetation (or 1390 Kcal/day) plus 500 grams/day salmon (or 850 Kcal/day) plus 240 grams/day venison (or 300 Kcal/day) for a total of 2,500 Kcal/day. This varies somewhat from the estimates used in this report, especially for the amount of venison and the amount versus caloric content of native plants, although the overall caloric estimates are close.

- For the screening-level risk assessment, ingestion pathways for milk from locally grazing cattle and for eggs collected from local nests have also been included. However, the values in Table 5-6 are approximations requiring additional tribal staff input.
- Organs or than meat are also consumed, such as fish eggs and liver. For this screening scenario, this category is identified as a data gap, and uses as a placeholder value a value equal to one-tenth of the fish ingestion. This is a critical data gap that may be addressed in the future.
- **Cultural: Inhalation, Dermal** – For the screening level risk assessment, sweat bathing is explicitly added. Based on tribal descriptions, a nominal time of 1 hour/day is assumed to be spent inside a sweat lodge kept at 80 °C (180 °F). Air inside the sweat lodge is assumed to be saturated with groundwater (equivalent to 0.3 kilograms of water per m³ of air, and 0.3 L/m³ of semivolatiles), which are then available for inhalation and dermal absorption over the entire body. During the 1 hour of use, 4 liters of water is used.
- **Cultural: Other Media** – Two potential pathways have been added to the CRCIA Native American Subsistence Resident scenario for this application. Both involve exposures to cultural items made from contaminated natural materials. These items are assumed to be made of clay (soil or sediment) and vegetation (such as reeds). Exposures are assumed for 1 hour per day to each. The primary exposure pathways from these materials in this exercise are direct exposure to radiation incorporated in the materials.

The contaminants assessed fall into one of three categories: carcinogenic chemicals, toxic chemicals, and radionuclides. Because the three categories of contaminants result in different types of risk, the estimates for each category are reported differently. The estimates for carcinogenic chemicals are reported as the probability of the incidence of cancer. The estimates for toxic chemicals are reported as a ratio between the reference dose determined by the EPA to be safe and the dose that has been estimated (a hazard index). The estimates for radionuclides are reported as radiation dose.

Exposure Equations

The exposure equations described in this section were used to assess human risk at a screening level. The parameters in the various scenarios were used in these equations. The equations are based on the exposure routes: external radiation, dermal, inhalation, and ingestion. These exposure equations were adapted and expanded from those in Appendix D of the HSRAM (DOE-RL 1995). The same notation and terminology have been used for consistency with HSRAM. Additions have been made to the equations to make them more directly applicable to the scoping study scenario.

Scoping Benchmarks

The following equations represent the total exposure of a person to radionuclides or chemicals. These equations describe just the exposure or intake not the risk from those exposures.

External Radiation Exposure

$$\begin{aligned} \text{Dose}_{\text{ext}} = & [(C_{\text{soil}} \times \text{ET}_{\text{soil}} \times \text{RF}_{\text{soil}} \times \text{EF}_{\text{soil}} + C_{\text{sed}} \times \text{ET}_{\text{sed}} \times \text{EF}_{\text{sed}}) \times \text{DF1} + \\ & C_{\text{river}} \times \text{ET}_{\text{swim}} \times \text{EF}_{\text{swim}} \times \text{DF2} + C_{\text{river}} \times \text{ET}_{\text{boat}} \times \text{EF}_{\text{boat}} \times \text{DF3} + \\ & C_{\text{items}} \times \text{ET}_{\text{items}} \times \text{EF}_{\text{items}} \times \text{DF4}] \times \text{ED}. \end{aligned}$$

Where:

C_{river}	=	Radionuclide concentration in river water (pCi/L)
C_{sed}	=	Radionuclide concentration in sediment (pCi/g)
C_{soil}	=	Radionuclide concentration in soil (pCi/g)
C_{items}	=	Radionuclide concentration in household items (pCi/g)
DF1	=	Dose conversion factor for soil and sediment (rem/hr per pCi/g)
DF2	=	Dose conversion factor for swimming (rem/hr per pCi/L)
DF3	=	Dose conversion factor for boating (rem/hr per pCi/L)
DF4	=	Dose conversion factor for small items, taken to be 1% of the infinite plane source (rem/hr per pCi/g)
Dose_{ext}	=	Dose from external radionuclides (rem)
ED	=	Exposure duration (year)
EF_{boat}	=	Exposure frequency for boating (days/year)
EF_{items}	=	Exposure frequency to household items (days/year)
EF_{sed}	=	Exposure frequency for sediment (days/year)
EF_{soil}	=	Exposure frequency for soil (days/year)
EF_{swim}	=	Exposure frequency for swimming (days/year)
ET_{boat}	=	Exposure time for boating (hours/day)
ET_{items}	=	Exposure time for household items (hours/day)
ET_{sed}	=	Exposure time for sediment (hours/day)
ET_{soil}	=	Exposure time for soil (hours/day)
ET_{swim}	=	Exposure time for swimming (hours/day)
RF_{soil}	=	Soil shielding factor (dimensionless).

Scoping Benchmarks

Dermal Exposure (Carcinogenic, Noncarcinogenic, Nonradioactive)

$$\begin{aligned} \text{DAD} = & [C_{\text{soil}} \times \text{AF}_{\text{soil}} \times \text{ABS} \times \text{SA}_{\text{soil}} \times \text{EF}_{\text{soil}} \times \text{CF1} + \\ & C_{\text{sed}} \times \text{AF}_{\text{sed}} \times \text{ABS} \times \text{SA}_{\text{sed}} \times \text{EF}_{\text{sed}} \times \text{CF1} + \\ & (C_{\text{other}} \times K_p \times \text{SA}_{\text{other}} \times \text{ET}_{\text{other}} \times \text{EF}_{\text{other}} + \\ & C_{\text{seep}} \times K_p \times \text{SA}_{\text{seep}} \times \text{ET}_{\text{seep}} \times \text{EF}_{\text{seep}}) \times \text{CF3} + \\ & C_{\text{river}} \times K_p \times \text{SA}_{\text{river}} \times \text{ET}_{\text{river}} \times \text{EF}_{\text{river}} \times \text{CF3}] \times \text{ED}/(\text{BW} \times \text{AT}). \end{aligned}$$

Where:

ABS	=	Material-specific absorption factor (unitless)
AF _{sed}	=	Adherence factor for sediment (mg/cm ² per day)
AF _{soil}	=	Adherence factor for soil (mg/cm ² per day)
AT	=	Averaging time (year x 365 days/year)
BW	=	Body weight (kg)
C _{other}	=	Contaminant concentration in household items (mg/L)
C _{river}	=	Contaminant concentration in river water (mg/L)
C _{sed}	=	Contaminant concentration in sediment (mg/kg)
C _{seep}	=	Contaminant concentration in seep/spring water (mg/L)
C _{soil}	=	Contaminant concentration in soil (mg/kg)
CF1	=	Unit conversion factor (1E-6 kg/mg)
CF3	=	Unit conversion factor (1E-3 L/cm ³)
DAD	=	Dose from dermal absorption (mg/kg per day)
ED	=	Exposure duration (year)
EF _{other}	=	Exposure frequency to cultural activities (sweat lodge) (days/year)
EF _{river}	=	Exposure frequency to river water (days/year)
EF _{sed}	=	Exposure frequency to sediment (days/year)
EF _{seep}	=	Exposure frequency to seep/spring water (days/year)
EF _{soil}	=	Exposure frequency to soil (days/year)
ET _{other}	=	Exposure time to household items (hours/day)
ET _{river}	=	Exposure time to river water (hours/day)
ET _{seep}	=	Exposure time to seep/spring water (hours/day)
K _p	=	Permeability coefficient for a chemical in water through skin (cm/hour)
SA _{other}	=	Body surface area exposed to household items (cm ²)
SA _{river}	=	Body surface area exposed to river water (cm ²)
SA _{sed}	=	Body surface area exposed to sediment (cm ²)
SA _{seep}	=	Body surface area exposed to seep/spring water (cm ²)
SA _{soil}	=	Body surface area exposed to soil (cm ²).

Scoping Benchmarks

Inhalation Exposure (Nonradioactive)

$$\text{INH} = (\text{C}_{\text{soil}} \times \text{ML} \times \text{ET}_{\text{soil}} \times \text{EF}_{\text{soil}} + \text{C}_{\text{seep}} \times \text{VF} \times \text{ET}_{\text{seep}} \times \text{EF}_{\text{seep}} + \text{C}_{\text{river}} \times \text{VF} \times \text{ET}_{\text{river}} \times \text{EF}_{\text{river}} + \text{C}_{\text{other}} \times \text{CF}_{\text{other}} \times \text{ET}_{\text{other}} \times \text{EF}_{\text{other}}) \times \text{ED} \times \text{BR} / (\text{BW} \times \text{AT} \times \text{CF}_4).$$

Where:

AT	=	Averaging time (year x 365 days/year)
BW	=	Body weight (kg)
C _{other}	=	Contaminant concentration in household materials made airborne (mg/L)
C _{river}	=	Contaminant concentration in river water (mg/L)
C _{seep}	=	Contaminant concentration in seep/spring water (mg/L)
C _{soil}	=	Contaminant concentration in soil (mg/kg)
CF ₄	=	Unit conversion factor (24 hours/day)
CF _{other}	=	Factor relating cultural materials to air concentration (L/m ³)
ED	=	Exposure duration (year)
EF _{other}	=	Exposure frequency to materials resuspended from cultural activities (day/year)
EF _{river}	=	Exposure frequency to volatilized river water (day/year)
EF _{seep}	=	Exposure frequency to volatilized seep/spring water (day/year)
EF _{soil}	=	Exposure frequency to resuspended dusts (day/year)
ET _{other}	=	Exposure time for breathing materials suspended from cultural activities (hours/day)
ET _{river}	=	Exposure time for breathing volatilized river water (hours/day)
ET _{seep}	=	Exposure time for breathing volatilized seep/spring water (hours/day)
ET _{soil}	=	Exposure time for breathing resuspended dusts (hours/day)
INH	=	Chronic daily inhalation intake (mg/kg per day)
BR	=	Inhalation (Breathing) rate (m ³ /day)
ML	=	Mass loading of soil in air (kg/m ³)
VF	=	Volatilization factor for sweat lodges (L/m ³).

Inhalation Exposure (Radioactive)

$$\text{Dose}_{\text{inh}} = (\text{C}_{\text{soil}} \times \text{ML} \times \text{ET}_{\text{soil}} \times \text{EF}_{\text{soil}} \times \text{CF}_5 + \text{C}_{\text{seep}} \times \text{VF} \times \text{ET}_{\text{seep}} \times \text{EF}_{\text{seep}} + \text{C}_{\text{river}} \times \text{VF} \times \text{ET}_{\text{river}} \times \text{EF}_{\text{river}} + \text{C}_{\text{other}} \times \text{CF}_{\text{other}} \times \text{ET}_{\text{other}} \times \text{EF}_{\text{other}} \times \text{CF}_5) \times \text{ED} \times \text{BR} \times \text{DF}_5 / \text{CF}_4.$$

Where:

C _{other}	=	Radionuclide concentration in household materials made airborne (pCi/g)
C _{river}	=	Radionuclide concentration in river water (pCi/L)
C _{seep}	=	Radionuclide concentration in seep/spring water (pCi/L)

Scoping Benchmarks

C_{soil}	=	Radionuclide concentration in soil (pCi/g)
CF_4	=	Unit conversion factor (24 hours/day)
CF_5	=	Unit conversion factor (1000g/kg)
CF_{other}	=	Factor relating cultural materials to air concentration (g/m^3)
DF_5	=	Dose conversion factor for inhalation (rem/pCi)
Dose_{inh}	=	Dose from inhalation of radionuclides (rem)
ED	=	Exposure duration (year)
EF_{other}	=	Exposure frequency to materials resuspended during cultural activities (days/year)
EF_{river}	=	Exposure frequency to volatilized river water (days/year)
EF_{seep}	=	Exposure frequency to volatilized seep/spring water (days/year)
EF_{soil}	=	Exposure frequency to resuspended dusts (days/year)
ET_{other}	=	Exposure time for breathing materials suspended during cultural activities (hours/day)
ET_{river}	=	Exposure time for breathing volatilized river water (hours/day)
ET_{seep}	=	Exposure time for breathing volatilized seep/spring water (hours/day)
ET_{soil}	=	Exposure time for breathing resuspended dusts (hours/day)
BR	=	Inhalation rate (m^3/day)
ML	=	Mass loading of soil in air (kg/m^3)
VF	=	Volatilization factor for sweat lodges (L/m^3).

Ingestion Exposure (Nonradioactive)

$$\text{ING} = (C_{\text{soil}} \times \text{IR}_{\text{soil}} + C_{\text{sed}} \times \text{IR}_{\text{sed}} + C_{\text{river}} \times \text{IR}_{\text{river}} + C_{\text{seep}} \times \text{IR}_{\text{seep}} + C_{\text{fish}} \times \text{IR}_{\text{fish}} + C_{\text{leafy}} \times \text{IR}_{\text{leafy}} + C_{\text{root}} \times \text{IR}_{\text{root}} + C_{\text{meat}} \times \text{IR}_{\text{meat}} + C_{\text{bird}} \times \text{IR}_{\text{bird}}) \times EF \times ED / (\text{AT} \times \text{BW}).$$

Where:

AT	=	Averaging time (year x 365 days/yr)
BW	=	Body weight (kg)
C_{bird}	=	Contaminant concentration in domestic and wild birds (mg/kg)
C_{fish}	=	Contaminant concentration in fish (mg/kg)
C_{leafy}	=	Contaminant concentration in above-ground vegetation (mg/kg)
C_{meat}	=	Contaminant concentration in meat (mg/kg)
C_{river}	=	Contaminant concentration in river water (mg/kg)
C_{root}	=	Contaminant concentration in root vegetables (mg/kg)
C_{sed}	=	Contaminant concentration in sediment (mg/kg)
C_{seep}	=	Contaminant concentration in seep/spring water (mg/kg)
C_{soil}	=	Contaminant concentration in soil (mg/kg)
ED	=	Exposure duration (year)
EF	=	Exposure frequency (days/year)
ING	=	Chronic daily ingestion rate (mg/kg per day)
IR_{bird}	=	Ingestion rate of domestic and wild birds (kg/day)

Scoping Benchmarks

IR_{fish}	=	Ingestion rate of fish (kg/day)
IR_{leafy}	=	Ingestion rate of above-ground vegetation (kg/day)
IR_{meat}	=	Ingestion rate of meat (kg/day)
IR_{river}	=	Ingestion rate of river water (kg/day)
IR_{root}	=	Ingestion rate of root vegetables (kg/day)
IR_{sed}	=	Ingestion rate of sediment (kg/day)
IR_{seep}	=	Ingestion rate of seep/spring water (kg/day)
IR_{soil}	=	Ingestion rate of soil (kg/day).

Ingestion Exposure (Radioactive)

$$\begin{aligned} Dose_{ing} = & (C_{soil} \times IR_{soil} + C_{sed} \times IR_{sed} + C_{river} \times IR_{river} + C_{seep} \times IR_{seep} + \\ & C_{fish} \times IR_{fish} + C_{leafy} \times IR_{leafy} + C_{root} \times IR_{root} + C_{meat} \times IR_{meat} + \\ & C_{bird} \times IR_{bird}) \times EF \times ED \times CF5 \times DF6. \end{aligned}$$

Where:

C_{bird}	=	Radionuclide concentration in domestic and wild birds (pCi/g)
C_{fish}	=	Radionuclide concentration in fish (pCi/g)
C_{leafy}	=	Radionuclide concentration in above-ground vegetation (pCi/g)
C_{meat}	=	Radionuclide concentration in meat (pCi/g)
C_{river}	=	Radionuclide concentration in river water (pCi/g)
C_{root}	=	Radionuclide concentration in root vegetables (pCi/g)
C_{sed}	=	Radionuclide concentration in sediment (pCi/g)
C_{seep}	=	Radionuclide concentration in seep/spring water (pCi/g)
C_{soil}	=	Radionuclide concentration in soil (pCi/g)
CF5	=	Unit conversion factor (1000 g/kg)
DF6	=	Dose conversion factor for ingestion (rem/pCi)
$Dose_{ing}$	=	Dose from ingestion (rem)
ED	=	Exposure duration (year)
EF	=	Exposure frequency (days/year)
IR_{bird}	=	Ingestion rate of domestic and wild birds (kg/day)
IR_{fish}	=	Ingestion rate of fish (kg/day)
IR_{leafy}	=	Ingestion rate of above-ground vegetation (kg/day)
IR_{meat}	=	Ingestion rate of meat (kg/day)
IR_{river}	=	Ingestion rate of river water (kg/day)
IR_{root}	=	Ingestion rate of root vegetables (kg/day)
IR_{sed}	=	Ingestion rate of sediment (kg/day)
IR_{seep}	=	Ingestion rate of seep/spring water (kg/day)
IR_{soil}	=	Ingestion rate of soil (kg/day).

Scoping Benchmarks

Estimate of Environmental Concentrations of Contaminants

The equations defined in the previous section require both the concentrations of contaminants in seep water and surface water and also in food products, such as fish, meat, and vegetables that become contaminated through contact with these media. The human exposure model used transfer coefficients, to determine the concentrations in vegetation. The same transfer coefficients are assumed to apply to all terrestrial vegetation, therefore concentrations estimated for riparian vegetation are assumed to be the same as those estimated for food products. In this way, the human and ecological models are directly connected and thus consistent. The estimate of concentrations in these food products is described here.

Soil and sediment. For this scoping analysis, a simple relationship between soil, sediments, and river water is assumed. It is assumed that the soil and sediments are in reversible equilibrium with the river water as described by a linear sorption isotherm (K_d). Thus,

$$C_{\text{soil}} = C_{\text{sediment}} = C_{\text{river}} * K_d.$$

Fish. The contaminant concentration in fish for a segment is related to the contaminant concentration in Columbia River water in that segment as

$$C_{\text{fish}} = C_{\text{river}} * \text{BIO}_{\text{fish}}.$$

Where:

$$\begin{aligned} C_{\text{fish}} &= \text{Analyte concentration in fish, pCi or } \mu\text{g per kg} \\ C_{\text{river}} &= \text{Analyte concentration in river water, pCi or } \mu\text{g per L} \\ \text{BIO}_{\text{fish}} &= \text{Analyte-specific bioaccumulation factor, L/kg.} \end{aligned}$$

Foods. The contaminant concentrations in terrestrial foods are related to the concentrations of analytes in soil.

$$\begin{aligned} C_{\text{leafy}} &= C_{\text{soil}} * \text{CR}_{\text{veg}} \\ C_{\text{root}} &= C_{\text{soil}} * \text{CR}_{\text{veg}} = C_{\text{leafy}} \\ C_{\text{meat}} &= C_{\text{leafy}} * \text{TF}_{\text{deer}} = C_{\text{soil}} * \text{CR}_{\text{veg}} * \text{TF}_{\text{deer}} \\ C_{\text{bird}} &= C_{\text{leafy}} * \text{TF}_{\text{bird}} = C_{\text{soil}} * \text{CR}_{\text{veg}} * \text{TF}_{\text{bird}}. \end{aligned}$$

Where:

$$\begin{aligned} C_{\text{bird}} &= \text{Analyte concentration in wild bird flesh, pCi or } \mu\text{g per kg} \\ C_{\text{leafy}} &= \text{Analyte concentration in leafy vegetables, pCi or } \mu\text{g per kg} \\ C_{\text{meat}} &= \text{Analyte concentration in animal protein, pCi or } \mu\text{g per kg} \\ C_{\text{root}} &= \text{Analyte concentration in root vegetables, pCi or } \mu\text{g per kg} \\ C_{\text{soil}} &= \text{Analyte concentration in soil, pCi or } \mu\text{g per kg} \end{aligned}$$

Scoping Benchmarks

CR_{veg}	=	Sediment-to-vegetation concentration ratio derived from ecosystem model
TF_{bird}	=	Feed-to-wild-bird transfer factor derived from ecosystem model
TF_{deer}	=	Feed-to-animal-protein transfer factor derived from ecosystem model.

Native American Cultural Materials. The only unique Native American pathway defined in the CRCIA scenarios is that involving a sweat lodge. The assumption for the sweat lodge was that water would be collected and poured over hot rocks to create steam. Therefore,

$$C_{\text{sweat lodge}} = C_{\text{seep}} \text{ or } C_{\text{river}}.$$

Household items are assumed to be equal in concentration to either soil or vegetation.

Parameters

A large number of parameters were required by the equations defined in the preceding sections in addition to those that describe the human activities in the scenarios (Section 5.1). The parameters fall into the categories of environmental transfer factors, radiation dose conversion factors, chemical risk and reference doses, dermal absorption rate constants, and miscellaneous other parameters. Each parameter used in the assessment is defined here and its source given.

The equations described in the previous Section for estimating potential contaminant concentrations in fish, birds, meat, and vegetation (plants consumed by humans or animals), and irrigated soil require parameters that relate the ratios of a contaminant in one medium to that in another. The transfer factor, also known as the concentration ratio or bioaccumulation factor, is the ratio of the concentration of an element in an organism of interest to the concentration in the source medium. The transfer factor applies to long-term, chronic exposure of plants and animals and is ideally measured at equilibrium. Transfer factors relate the concentration of an element in soil to the element's concentration in plant products and the concentration in animal feed to animal products; the fish transfer factor relates the concentration in water to the concentration in fish muscle tissue. Transfer factors are used in risk assessments to estimate the amount of radioactivity that could be present in a food crop or organism based on the calculated concentration in the source medium (i.e., soil or animal feed). By calculating the concentration in the food, the total intake can be estimated and a dose calculated as a result of the annual intake. In terms of radionuclides, the transfer factor is used to calculate how many curies per kilogram of soil are transferred to the edible dry plant product (pCi per kg). For vegetation, the units are kg soil/kg edible dry plants. For animal products, the transfer factor relates the daily intake to that of the animal product. Units for milk are pCi/L per pCi intake/d. For animal and fish meat products, transfer factors are measured in wet weight animal product: pCi/kg muscle per pCi/d intake for meat and pCi/kg muscle per pCi/L for fish. For nonradioactive chemicals, the same definitions apply, but the pCi may be replaced with kg.

Numerous studies have been undertaken to quantify transfer factors for specific chemical elements as a function of food type. These studies have been compiled in several publications. This document was written to compile a list of those transfer factors which best describe the commonly accepted factors, and to document the data sources by providing the original as well as the compilation references. In some cases, this listing contains values for elements that are

Scoping Benchmarks

not included in other compilations. Transfer factors for such elements were extrapolated from experimental data based on chemical similarities.

Transfer factors for this report were generally selected from recommended values compiled by national or international organizations for use in radiological food chain transport calculations. (In some cases, where newer data were available, very recent references for specific values were preferred to compiled recommendations.) In general, the recommended values from more recent compilations were selected rather than those in older publications. The primary data sources are also cited where identified in the compilation document. In many cases, where neither a primary source of data nor a recommended value in a compilation was available, other methods were used to estimate transfer factors, as described in the following sections. The selections made and their rationale are presented in Appendix C.

The sorption coefficient K_d is the ratio of radionuclides in solid and liquid phases (the units are pCi/kilogram of soil per pCi/liter of water = L/kg). One of the applications of K_d is in its use as a retardation factor. For this application, conservatively small values of K_d were selected representing sandy soil. This will tend to minimize retardation, and simulate fast release of materials to the environment.

A number of transfer factors can be seen to be set to zero. For most contaminants for which this is true, the ecological modeling indicated that plants or animals did not take up these chemical compounds without first breaking them down to other biological components (for example, nitrates are metabolized to other forms of nitrogen, sulfates to sulfur, etc.).

Radiation Dose Conversion Factors

The translation of radionuclide concentration in soil, or water to radiation dose rate was performed using dose rate conversion factors. Such factors are available from a number of sources and are very similar regardless of the source. Those used in this analysis were taken from Federal Guidance Report No. 12 (EPA 1993).

Soil and sediment factors relate concentration in soil and sediment in picocuries/kilogram to the external dose rate above a large, flat contaminated area in rem/hour.

Swimming dose factors relate the concentration of radionuclides in water in picocuries/liter to the dose rate in rem/hour. These were calculated using an assumption of immersion in what is effectively an infinite medium. This worked because the range of radiation in water is relatively short, on the order of a meter. The dose rate then was calculated by assuming that the energy emitted in a volume of water is equal to the energy absorbed in that same volume, and the presence of a person or a fish does not noticeably perturb the dose rate field.

Dose conversion factors for boating were derived from those for swimming. It can be shown that the dose rate at the surface of a body of contaminated water is exactly half that of a point immersed within the water (see, for example, Morgan and Turner 1973). For this analysis, that fact was used with no additional modifications (such as shielding from the boat, distance above the water line, etc.).

Scoping Benchmarks

Dose conversion factors for ingestion and inhalation were taken from Federal Guidance Report No. 11 (EPA 1988). These factors relate the amount of a radionuclide in rem/picocurie taken in to the body to the ultimate expressed dose over a period of 50 years following the intake. Internal doses such as these are more variable between individuals than are the external doses discussed above. Individual radiation doses depend on the amount of a radionuclide taken in to the body and absorbed in the bloodstream, in which organs the contaminants accumulate and how long they remain there, and on the masses of the individual's organs as well as the age and sex of the individual. The values used are for a reference adult.

The exposure models were set up with separate pathways and parameters for the Native American cultural media exposures. In the development of the scenarios, the sweat lodge was identified as a distinct Native American practice requiring analysis. The pathway of exposure in the sweat lodge is inhalation of contaminants volatilized from seep water in steam. This was represented in the model using the standard inhalation dose conversion factors.

All radionuclide parameters are presented in Appendix E.

Chemical Exposure Risk Factors

The calculations outlined above require a large number of input parameters for every chemical. Distributions of parameter values for the cancer potency factor, reference dose, skin absorption factor, and skin permeability coefficient are presented in Appendix E for the nonradioactive chemicals of interest in this scoping assessment. The information in this appendix is derived from several sources. The preferred source is EPA's Integrated Risk Information System (IRIS) (EPA 1996). IRIS is a database available through EPA's Environmental Criteria Assessment Office in Cincinnati, Ohio, and from various commercial electronic sources. The preferred secondary source is EPA's HEAST (EPA 1995). HEAST, prepared by EPA's Office of Solid Waste and Emergency Response, is a compilation of toxicity values published in health effects documents issued by EPA. It is intended for use in the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) and *Resource Conservation and Recovery Act* (RCRA) programs.

Periodically, EPA announces changes in toxicity factors for individual chemicals as new information becomes available. In some instances, reference doses or other factors listed in IRIS or HEAST for some chemicals are withdrawn. For some of the chemicals in the table, older references were used to approximate the potential health risk because specific values are no longer included in IRIS or HEAST.

For benzene, the ingestion cancer potency factor was taken from IRIS (EPA 1996) and the inhalation cancer potency factor, which has the same numerical value, was taken from HEAST (EPA 1995). The inhalation cancer potency factor for chromium is from HEAST. Neither HEAST nor IRIS provides an ingestion factor, so the ingestion factor is assumed to be the same as the inhalation factor. The inhalation and ingestion reference doses for ammonia are the same from HEAST or IRIS. IRIS provides an ingestion reference dose for chromium (assumed here to be soluble chromium VI). The inhalation value is assumed to be equal. The human toxicity of copper is equivocal. Recent versions of IRIS and HEAST have not provided values of reference

Scoping Benchmarks

dose. However, in 1992 IRIS did provide a value for ingestion, and EPA (1984a) has older documents that discuss the inhalation toxicity. Reference doses are not provided by EPA for diesel fuel. An effective reference dose was estimated from the acute toxicity data available in the *Registry of Toxic Effects of Chemical Substances* (RTECS), published by the National Institute for Occupational Safety and Health (NIOSH 1996). A difficulty similar to that for diesel fuel was encountered for kerosene. A slightly different approach was used, based on the threshold limit value (TLV) defined by the American Conference of Government Industrial Hygienists (ACGIH 1987) to estimate an effective reference dose for inhalation. Values of the reference dose for lead were taken from EPA documents (EPA 1984, EPA 1986). The reference dose for inhalation of mercury is from IRIS, the reference dose for ingestion of mercury is from HEAST. For nickel, the reference dose for inhalation is assumed to be the same as that for ingestion. For nitrate and nitrite ions, reference doses are presented in IRIS for ingestion. The same values were assumed for the inhalation route. Reference doses are not available for phosphate ion. The same technique based on RTECS LD₅₀ data as used for diesel fuel was used for phosphate. The estimate for reference dose for sulfate inhalation is based on TLV using the same technique as described for diesel fuel. For ingestion, rather than assume the same value as derived for inhalation, an estimate was made using EPA's Secondary Drinking Water Standard (40 CFR 143). The drinking water standard for sulfates is 250 milligrams/liter. Because the secondary standards are based on aesthetics rather than human health risk, the value thus derived was increased by a factor of 10. The IRIS database provides an ingestion reference dose for xylenes. The ingestion value was assumed to also apply to inhalation. Zinc is listed in the IRIS database for ingestion; the ingestion value was assumed to also apply to inhalation.

Values for the skin absorption coefficient ABS are difficult to obtain because very few measurements have been made. A metal, cadmium, has been evaluated (Wester et al. 1991), and the organics, benzene (Skowronski et al. 1988) and xylene (Skowronski et al. 1990), in experiments that are not completely consistent with exposure conditions in the environment. For cadmium applied at 20 and 40 mg/cm² to the skin of the abdomen for 16 hours, between 0.08 and 0.2 percent of the applied dose was absorbed. The average of twelve samples was 0.1 percent. EPA recommends an upper range of 0.1 to 1.0 percent (EPA 1992a).

The concentrations for dermal absorption of benzene (Skowronski et al. 1988) were up to 21 percent of the soil mixture. In addition, the area of application was covered during the experiment, which prevented evaporation. A model based on fugacity was developed by McKone (1990) and applied by Burmaster and Maxwell (1991) for benzene, predicting 1 to 2 percent uptake for skin loadings of 0.1 to 10 mg/cm². McKone (1990) also made some generalizations for organics on the basis of Henry's Law constant and the octanol-water partition coefficient K_{ow}, which indicated that for xylenes the absorption should be less than about 5 percent in 12 hours.

On the basis of the cadmium measurement, the default skin absorption factor for metals was established at 10⁻³, and the default for other organics was set at 10⁻², with uncertainty ranges of one order of magnitude larger and smaller.

The equations and parameters discussed above were programmed into an EXCEL spreadsheet. (This spreadsheet was actually prepared in support of the verification efforts of the CRCIA,

Scoping Benchmarks

Part 1 human risk computer code.) This spreadsheet was used to prepare unit risk factors for unit concentrations of contaminants in seep water and river water. These were then coupled with the predictions of future concentrations made with the source term and simple transport model to provide estimates of risk.

4.2 ECOSYSTEM BENCHMARKS

Ecological limits for radionuclides are currently based on radiation dose rates. Most regulations that deal with the subject require that doses to aquatic biota be less than 1 rad/day. To accommodate potential multiple contaminants, a limit of 0.001 rad/day was selected. Radiation doses were calculated using the approach of Baker and Soldat (1992). The equation for radiation dose to biota, D_{biota} (rad/day), is

$$D_{biota} = 5.12 \times 10^{-8} C_w BCF EE .$$

Where:

- 5.12×10^{-8} = Unit conversion factor (disintegration-kg-rad per pCi-day-MeV)
- BCF = The bioconcentration factor for the biota (L/kg)
- EE = The effective absorbed energy rate per unit activity in biota (MeV/disintegration).

Tabulated values of EE were taken from Baker and Soldat (1992).

A major review of the literature on effects of contaminants on aquatic life was undertaken recently at Pacific Northwest National Laboratory (PNNL) for another project. This other project developed a large database of contaminant concentration limits on surface water used by various governmental agencies around the world. This database was reviewed for the SAC analysis, and the most limiting value of surface freshwater concentration selected. These concentrations, the promulgating agency, the basis of the value, and references are provided in Table 4-2. Most entries initially were identified from an Internet-accessible database prepared at the University of Waterloo in Canada.

Table 4-2. Surface Water Concentration Values and References Used as Benchmarks for the Scoping Analysis, µg/L. (3 Pages)

Chemical Name	Guideline	Application	Jurisdiction	Reference 1	Reference 2
Aluminum (dissolved)	50	30-day Average Concentration; pH >=6.5	British Columbia	U Waterloo Summary	BCMOELP 1994
Ammonia	5	Guide value for salmonid and cyprinid waters, monthly sampling (as un-ionized)	Europe	U Waterloo Summary	CEC 1987
Benzene	1.2	For Consumption of: Water & Organisms	US	Federal Register Vol. 57 No. 246 December 22, 1992	
Benzo(a)Pyrene	0.0028	For Consumption of: Water & Organisms	US	Federal Register Vol. 57 No. 246 December 22, 1992	
Beryllium	5.3	Chronic Criteria; Lowest Observed Effect Level	Netherlands	U Waterloo Summary	Stortelder et al. 1989
Bismuth	5	1/10 toxic level		OHM/TADS	
Cadmium	0.01	Draft Guideline	Canada	U Waterloo Summary	CCREM 1987
Carbon Tetrachloride	13	Interim Maximum Criterion	British Columbia	U Waterloo Summary	BCMOELP 1994; CCREM 1987
Cerium	0.3	derived from lanthanides		OHM/TADS	
Chloroform	2	Interim Guideline	Canada	U Waterloo Summary	BCMOELP 1994; CCREM 1987; MENVIQ 1990
Chromium	2	Maximum for phyto- and zooplankton	Quebec	U Waterloo Summary	MENVIQ 1990
Chrysene	0.003	Related to Benzo(a)pyrene		HSDB	
Copper	0.04	30-day Average; Hardness >50 mg/L CaCO3 average	British Columbia	U Waterloo Summary	BCMOELP 1994
Cyanide	5	Chronic criterion	Quebec	U Waterloo Summary	MENVIQ 1990; OMEE 1994; CCREM 1987
Dibutyl phosphate	40	related to xylene		HSDB	
Dibutyl phosphonate	40	related to xylene		HSDB	
Dichloroethylene, 1,2-	200	Provincial Water Quality Guideline	Ontario	U Waterloo Summary	OMEE 1994
Diesel fuel	40	as xylene			
Ferrous sulfamate	240	see sulfamate			

Table 4-2. Surface Water Concentration Values and References Used as Benchmarks for the Scoping Analysis, µg/L. (3 Pages)

Chemical Name	Guideline	Application	Jurisdiction	Reference 1	Reference 2
Fluoride	200	Chronic criterion	Quebec	U Waterloo Summary	MENVIQ 1993
Iron	300	Chronic criterion	Quebec	U Waterloo Summary	MENVIQ 1993
Kerosene	40	see xylene			
Lanthanum	0.3	chemical similarity to cerium			
lead	1	Chronic	US	State of Louisiana Department of Environmental Quality Title 33 Water Quality Regulations; OMEE 1994; CCREM 1987	
Manganese	1000	Criterion	Netherlands	U Waterloo Summary	Stortelder et al. 1989
Mercury	0.006	Chronic criterion for protection of commercial fish species.	Quebec	U Waterloo Summary	MENVIQ 1990; MDEWPSH 1988
Methyl Isobutyl ketone	123,000	TLM		OHM/TADS	
Normal Parafin Hydrocarbon	123,000	related to MIBK			
Nickel	9.3	Ecotoxicological value.	Netherlands	U Waterloo Summary	Stortelder et al. 1989
Nitrate	40000	Average, as N	British Columbia	U Waterloo Summary	Pommen 1989
Nitrite	10	Guide value for salmonid waters	Europe	U Waterloo Summary	CEC 1987
Oxalates	2000	1/10 toxic level		OHM/TADS	
PCBs	0.00008	Fish consumption only, human health criterion reported at 10 ⁻⁶ risk level	USA	U Waterloo Summary	USEPA 1990
Phosphate	10	Lakes only	British Columbia	Pommen 1989	
Potassium	10000	1/10 LC50		CRCIA	
Silver	0.4	1/10 LC50		CRCIA	
Sodium aluminate	50	as aluminum			
Sodium dichromate	2	as chromium			
Sodium hydroxide	1000	TLM		OHM/TADS	

Table 4-2. Surface Water Concentration Values and References Used as Benchmarks for the Scoping Analysis, µg/L. (3 Pages)

Chemical Name	Guideline	Application	Jurisdiction	Reference 1	Reference 2
Sodium nitrate	40000	as nitrate			
Sodium oxalate	2000	as oxalate			
Sodium silicate	25000	TLM		OHM/TADS	
Sodium sulfamate	240	1% of LD50		OHM/TADS	
Strontium	7	Proposed Provincial Water Quality Guideline	Ontario	U Waterloo Summary	OMEE 1994
Sulfamic acid	240	see sodium sulfamate			
Sulfate (dissolved)	100000	Maximum Criterion (SO4); Tentative, effects on some species/life stages	British Columbia	U Waterloo Summary	BCMOELP 1994
Sulfuric acid	100000	as sulfate			
Tetrachloroethane	7	1/10 Drinking Water Standard	Provincial Water Quality Guideline	Ontario	OMEE 1994
Tetrachloroethylene	50	Provincial Water Quality Guideline	Ontario	U Waterloo Summary	OMEE 1994
Tributyl phosphate	40	see xylene			
Tributyl phosphonate	40	see xylene			
Trichloroethylene	1	Ecotoxicological value.	Netherlands	U Waterloo Summary	Stortelder et al. 1989
Uranium	300	Maximum	British Columbia	U Waterloo Summary	Pommen 1989
Xylene	40	Chronic criterion	Quebec	U Waterloo Summary	MENVIQ 1990
Zinc	10	Maximum allowable concentration in water of fish-breeding reservoirs	USSR	U Waterloo Summary	UNEP 1985
Zirconium	300	low toxicity, set = iron		HSDB	

Scoping Benchmarks

4.3 BACKGROUND/DETECTABILITY AS A SURROGATE FOR SOCIO-CULTURAL IMPACTS

For socio-cultural impact, the concepts of loss-of-use, loss of religious or spiritual value, and intangible mental stress are all related to the possible contamination of environmental materials. Because these are not directly connected to health or risk metrics, the ability to detect materials above background concentrations is considered as the benchmark; predicted environmental contaminant concentrations in groundwater, as prepared for the human health and ecological health calculations, are compared to background values. Those materials for which predicted Hanford-related incremental concentrations exceed the background are included in the Study Set.

Because the concentrations are several orders-of-magnitude higher in the groundwater than the surface water, the comparisons are made for that medium.

Groundwater background concentrations have been evaluated for the Hanford Site (DOE 1996). Because background levels can vary across locations, the 90th percentile value is selected as the benchmark. Various percentiles of background values are presented in DOE(1996). These values are based on numerous measurements of groundwater made at a range of uncontaminated locations on the Hanford Site. Unfortunately, this particular reference contains an error in the presented values for radionuclides, which has been recognized by the report authors but which, to date, has not been corrected for financial reasons. A corrected version of the report results was obtained from the report author (personal communication, S. Petersen to B. Napier, May 1999). Because the uncorrected version of this report is available on the Hanford Site internet web site, it is recommended that this mistake be corrected or the report removed from electronic access.

Not all contaminants in the Candidate Set are listed in the available data. For those that are not, fractions of the current measured levels of gross beta, gross alpha, or total organic carbon have been used as surrogate measures. It is assumed that future measurements that do not indicate increases in these commonly-measured values will not be rigorously examined with expensive speculative techniques. A fraction of 1% is used.

The background levels used for comparison are presented in Table 4-3 for radionuclides, and in Table 4-4 for chemicals.

Scoping Benchmarks

**Table 4-3. Background Levels of Radionuclides
in Hanford Site Groundwater, fCi/L. (2 Pages)**

Radionuclides	Background Level
Actinium 227	27
Americium 241	1.91
Americium 242m	81
Cadmium 113m	81
Carbon 14	81
Cesium 135	81
Cesium 137	8.43
Chlorine 36	81
Cobalt 60	3.41
Curium 243	27
Curium 244	27
Europium 152	21.8
Europium 154	13.6
Iodine 129	0.0939
Krypton 85	81
Lead 210	27
Neptunium 237	27
Nickel 59	81
Nickel 63	81
Palladium 107	81
Protactinium 231	27
Plutonium 238	0.221
Plutonium 239/240	0.949
Plutonium 241	27
Plutonium 242	27
Radium 226	33.2
Radium 228	64.9
Samarium 151	81
Selenium 79	81
Strontium 90	14.6
Technetium 99	81
Tellurium 123	81
Thorium 229	27
Thorium 230	27
Thorium 232	27
Tin 121M	81

Scoping Benchmarks

Table 4-3. Background Levels of Radionuclides in Hanford Site Groundwater, fCi/L. (2 Pages)

Radionuclides	Background Level
Tin 126	81
Tritium (Hydrogen 3)	14.5
Uranium 232	27
Uranium 234	27
Uranium 235	108
Uranium 236	27
Uranium 238	1630
Zirconium 93	81

Table 4-4. Background Concentrations of Chemicals in Hanford Site Groundwater. (2 Pages)

Chemicals	µg/L	Chemicals	µg/L
Aluminum	7.11	Nickel	1.56
Ammonia/Ammonium	113	Nitrate	26871
Ammonium Carbonate	113	Nitrite	93.7
Ammonium Nitrate	26871	Oxalate	287
Benzene	27	PCBS (Arochlor)	27
Benzo[a]Pyrene	27	Phosphate	162
Beryllium	2.29	Potassium	9122
Bismuth	0.4	Potassium Borate	36
Cadmium	0.916	Silicon	33949
Carbon Tetrachloride	27	Silver	5.28
Cerium	135	Silver Chloride	5.28
Chloroform	27	Sodium	26998
Chromium	2.4	Sodium Aluminate	7.11
Chrysene	27	Sodium Dichromate	2.4
Copper Sulfate	0.81	Sodium Hydroxide	147127
Copper	0.81	Sodium Nitrate	26871
Cyanide	8.41	Sodium Oxalate	287
Dibutyl Butyl Phosponate	27	Sodium Silicate	33949
Dibutyl Phosphate	27	Sodium Sulfamate	27
Dichloroethylene, 1,2-	27	Strontium	323
Diesel Fuel	27	Sulfamic Acid	27
Ferrocyanide	8.41	Sulfate (Sulfur)	47014
Ferrous Sulfamate	27	Sulfuric Acid	47014

Scoping Benchmarks

**Table 4-4. Background Concentrations of Chemicals in Hanford Site Groundwater.
(2 Pages)**

Chemicals	µg/L	Chemicals	µg/L
Fluoride	1047	Tetrachloroethane 1,1,1,2-	27
Iron	570	Tetrachloroethylene	27
Kerosene	27	Tributyl Phosphate (TBP)	27
Lanthanum	80	Tributyl Phosphonate	27
Lead	0.917	Trichloroethylene	27
Manganese	38.5	Uranium	9.85
Mercury	0.003	Xylene	27
Methyl Isobutyl Ketone (Hexone)	27	Zinc	21.8
NPH (Normal Parafin Hydrocarbon	27	Zirconium	25

5.0 REGULATORY DRIVERS

A number of Federal and Washington State regulations and treaties pertain to waste management, disposal, and cleanup operations at the Hanford Site. These are listed with annotations in Table 5-1 for the Federal regulations and treaties and Table 5-2 for the Washington State regulations.

Several of the laws and regulations are directly applicable to the selection of criteria, and indirectly to the selection of contaminants for the Study Set. The Federal CERCLA, 42 USC 9602-9604, as amended, is applicable. It leads to the selection of a human risk level of concern of 10^{-6} , which was used in the scoping analyses as the level of interest.

The National Primary Drinking Water Standards, 40 CFR 141, are applicable in that they set maximum contaminant levels (MCLs), as well as a 4 mrem/year radiation dose rate limit from the drinking water pathway. The ecological screening levels were all set at or below the MCLs, and the individual dose limit was set at 1 mrem/70 years; both are at or below the standards.

DOE Order 5400.5 also sets requirements on the radiation doses to offsite individuals. The scoping dose cutoff was set well below the order limit.

The NRC's LLW disposal rule 10 CFR 61 is written in terms of radionuclide concentration acceptance levels. Several radionuclides have specific individual limits. All of these contaminants were considered in the scoping analyses.

The EPA's HLW disposal rule 40 CFR 191 sets individual dose limits, cumulatively and via the groundwater ingestion pathway. The scoping cutoffs were set below the limits of this rule.

The *Toxic Substances Control Act of 1976* (TSCA), 15 USC 2601 et seq., sets limits on polychlorinated biphenyls. PCBs are included in the scoping study, although ultimate predicted concentrations are well below the limits specified in this rule.

The *Clean Air Act of 1977*, as amended, 42 USC 7401, et seq. Sets requirements on radiation doses and other exposures from atmospheric releases. In the scoping studies, the potential for fugitive and/or unmonitored emissions is considered.

The *Endangered Species Act of 1973*, 16 USC 1531, et seq. prohibits federal agencies from jeopardizing threatened or endangered species or adversely modifying habitats essential to their survival. Partially for this reason, the scoping studies focus on the interface between the Hanford Site groundwater and the Columbia River in the riparian zone of the Hanford Reach.

For the Washington State regulations, the *Model Toxics Control Act* (MTCA) specifies methods for determining compliance that include use of human exposure scenarios and transport parameters. A modified version of this approach is embodied in the use of the Native American Subsistence Resident scenario for determination of human health impacts. Similarly to CERCLA, MTCA sets the human risk level of concern to 10^{-6} . It also requires the use of MCLs,

Regulatory Drivers

and nonzero MCL goals, which were incorporated as the ecological screening levels were all set at or below the MCLs.

Like the *Clean Air Act*, *Washington Administrative Code* (WAC) 173-480 and WAC 246-247 set requirements on atmospheric emissions. In the scoping studies, the potential for fugitive and/or unmonitored emissions is considered.

WAC 246-252 specifies that the radionuclides ^{226}Ra and ^{228}Ra be evaluated. Both of these are included in the Candidate Set evaluated in the scoping.

None of the regulations and applicable or relevant and appropriate requirements (ARARs) specifically define which contaminants must be included in the SAC evaluations. The intent of the combination of the requirements of all the rules has been met with the approach taken for the scoping analyses.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
<p>Treaty between the United States and Walla Walla, Cayuses, and Umatilla Tribes, June 9, 1855, ratified 1859</p> <p>Treaty between the United States and the Yakama Nation of Indians, June 9, 1855, ratified 1859</p> <p>Treaty between the United States and the Nez Perce Tribe of Indians, June 11, 1855, ratified 1859</p> <p>Treaty between the United States and the Nez Perce Tribe of Indians, June 9, 1863, ratified 1867</p>	<p>Ceded lands, including the current Hanford Site, retaining rights to be exercised at usual and accustomed places and on open and unclaimed lands.</p>	<p>The Federal government and implementing agencies have an obligation to safeguard natural resources in consultation with Tribal governments.</p>
<p>Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9602-9604, as amended</p> <p>National Oil and Hazardous Substances Pollution Contingency Plan, Subpart E, 40 CFR 300.400</p> <p>Designation, Reportable Quantities, and Notification, 40 CFR 302</p>	<p>Establishes the process to be followed upon discovery of a release of a hazardous substance, including notification, site evaluation, and remedial response. Establishes CERCLA remediation criteria consisting of a risk range of 10^{-4} to 10^{-6} for carcinogens and a hazard index of less than 1 for noncarcinogens.</p> <p>Defines the comprehensive list of hazardous substances regulated under CERCLA. Imposes reporting requirements in the event of a release in excess or reportable quantities.</p>	<p>CERCLA hazardous substances have been released to the vadose zone and groundwater and, as a result, the 100, 200, and 300 Areas are identified on the National Priorities List for action under CERCLA.</p> <p>CERCLA hazardous substances are present in the vadose zone and groundwater.</p>
<p>Safe Drinking Water Act of 1974, 42 USC 300, et seq.</p> <p>National Primary Drinking Water Standards, 40 CFR 141</p>	<p>Establishes maximum contaminant levels (MCLs) and maximum contaminant level goals (MCLGs) that are drinking water criteria designed to protect human health from the potential adverse effects of contaminants in drinking water.</p>	<p>Groundwater at the Hanford Site is not a current drinking water source, but it is considered a potential future source of drinking water using EPA's groundwater classification strategy. In addition, Hanford groundwater is hydraulically connected to groundwater that is used for drinking water and to the Columbia River. MCLs and MCLGs should be considered in establishing cleanup levels that are protective of groundwater, points of compliance, and institutional controls.</p>

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
National Secondary Drinking Water Standards, 40 CFR 143	Establishes secondary drinking water standards for use in establishing cleanup levels.	Federal secondary standards are not enforceable standards and are not typically applicable or relevant and appropriate requirements; however, the State of Washington Model Toxics Control Act requires that these standards be considered in establishing cleanup levels protective of groundwater.
Clean Water Act of 1977, 33 USC 1251, as amended Water Quality Standards, 40 CFR 131	Establishes the requirements and procedures for states to develop and adopt water quality standards based on federal water quality criteria that are at least as stringent as the federal standards. Provides EPA authority to review and approve state standards. Washington State has received EPA approval and has adopted more stringent standards under WAC 173-201A.	Not applicable (the requirement to develop standards applies to the states, not individual facilities) but relevant in establishing the basis for state regulation.
Atomic Energy Act of 1954, as amended, 42 USC 2011, et seq. Department of Energy Occupational Radiation Protection, 40 CFR 835 DOE Order 5400.5, Radiation Protection of the Public and the Environment, and 10 CFR 834 (Proposed)	These requirements set occupational dose limits for adults. Total effective dose equivalent is equal to 5 rem/yr This DOE order sets radiation standards for protection of the public in the vicinity of DOE facilities. The order set limits for the annual effective dose equivalent of 100 mrem, but allows temporary limits of 500 mrem if avoiding the higher exposures is impractical. The standard sets annual dose limits for any organ at 5 mrem. The order sets an annual dose equivalent from drinking water supplies operated by DOE at 4 mrem, and states that liquid effluent from DOE activities will not cause public drinking water systems to exceed EPA MCLs. The proposed rule, Radiation Protection of the Public and the Environment (10 CFR 834), in the March 23, 1993 Federal Register (58 FR 16268), promulgates the standards presently found in DOE Order 5400.5.	These standards are applicable when performing any assessment or response actions. Both the DOE order and the proposed rule are relevant in assessing risks associated with existing contamination and identifying appropriate response actions.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
<p>DOE Order 5400.5, Radiation Protection of the Public and the Environment, and 10 CFR 834 (Proposed) (continued)</p> <p>DOE Order 5820.2a, Radioactive Waste Management</p>	<p>The proposed rule identifies DCGs not as “acceptable” discharge limits, but to be used as reference values for estimating potential dose and determining compliance with the requirements of the proposed rule. Where residual radioactive materials remain, the proposed rule states that various disposal modes should address impacts beyond the 1,000-year time period identified in the existing DOE Order.</p> <p>These guidelines set performance objectives to limit the annual effective dose equivalent beyond the facility boundary to 25 mrem. Selected disposal methods must be sufficient to limit the annual effective dose equivalent to 100 mrem for continuous exposure, or 500 mrem for acute exposures when active institutional controls are removed.</p>	<p>The order is applicable to any radioactive waste that is present in Hanford Site waste management units, or for waste that might be generated during assessment or response actions.</p>
<p>Nuclear Regulatory Standards for Protection Against Radiation, 10 CFR 20</p>	<p>The regulation establishes standards for protection of the public against radiation arising from the use of regulated materials. Limits external and internal exposure from releases to levels that do not exceed 100 mrem/yr total effective dose equivalent, or 2 mrem/hr from external exposure in unrestricted areas. These requirements also establish criteria for closing NRC-licensed sites, including a standard of 25 mrem/yr from all sources, and reducing residual radioactivity to levels that are as low as reasonably achievable (ALARA).</p>	<p>The regulation is not strictly applicable at the Hanford Site because it applies to NRC-licensed facilities. However, it is relevant and appropriate because it establishes standards for protection of the public against radiation.</p>
<p>EPA Memorandum, Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination,” OSWER No. 9200.4-18</p>	<p>This memorandum provides guidance on cleanup levels at CERCLA sites. EPA has determined in this directive that dose limits established by the NRC in 10 CFR 20 (25 mrem/yr and ALARA) are generally not protective at CERCLA sites, and instead states that a cleanup level of 15 mrem/yr is protective of human health and the environment. EPA dose limits are to generally achieve risk levels in the 10^{-4} to 10^{-6} risk range.</p>	<p>The standard established in this memorandum is considered protective by EPA in lieu of the NRC standards and is relevant in establishing cleanup levels.</p>

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
Licensing Requirements for the Land Disposal of Radioactive Waste, 10 CFR 61	Requires that disposal systems be designed to limit the annual dose equivalent beyond the facility boundary below 25 mrem to the whole body, 75 mrem to the thyroid, or 25 mrem to any other organ. The systems must be relevant and appropriate to remedial actions that include land disposal or release radioactive effluent. Inadvertent intruder requirements for land disposal units are also contained in this regulation.	The regulation is not strictly applicable because it applies to NRC facilities and land disposal of radioactive wastes containing byproduct, source, and special nuclear material received from other persons. However, it is relevant and appropriate if radioactive waste will be left in place following remediation. Requirements to protect inadvertent intruders may also be relevant and appropriate in assessing risks and determining appropriate response actions.
Packaging and Transportation of Radioactive Material, 10 CFR 71	These requirements apply to the packaging, preparation for shipment, and transportation of licensed radioactive material.	The regulation is not strictly applicable because the Hanford Site is not NRC-licensed. However, radioactive waste might be generated during assessment or response actions, and subparts of this regulation are relevant and appropriate for packaging, testing, and preparation of packages containing radioactive material.
Environmental Radiation Protection Standards for Nuclear Power Operations, 40 CFR 190	Specifies the levels below which normal operations of the uranium fuel cycle are determined to be environmentally acceptable. The standard sets dose equivalents from facility operations that are not to exceed 25 mrem/yr to whole body, 75 mrem/yr to thyroid, or 25 mrem/yr to any other organ.	These standards are not strictly applicable at the Hanford Site, because the standard excludes operations at disposal sites and uses a definition of the uranium fuel cycle that focuses on those processes that result in generation of electrical power. However, the standards are relevant and appropriate in the assessment because they address acceptable dose to the public.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes, 40 CFR 191	Establishes standards for management and disposal of spent nuclear fuel, high-level waste, and transuranic wastes at facilities operated by the DOE. The standard addresses all disposal methods. Subpart A sets the maximum committed effective dose of 15 mrem/yr for any member of the public. Environmental standards set in Subpart B address protection of individual members of the public and groundwater at disposal facilities. Appendix A provides numeric standards for potential future releases.	The requirements are not directly applicable because DOE does not intend to dispose of spent nuclear fuel, high-level- or transuranic-wastes at Hanford. However, they are relevant and appropriate because high-level wastes and transuranic wastes are present at the Hanford Site, and must be addressed during closure of waste units and/or remediation of environmental media.
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings, 40 CFR 192	Standards for cleanup are set under this program, including groundwater protection requirements for radium-226, radium-228, and gross alpha particle activity, which are set at levels established under state and federal water quality criteria programs.	The standard is not strictly applicable because the Hanford Site is not a uranium or thorium milling site. However, standards for cleanup set under this program are relevant and appropriate to assessment and response actions conducted at the Hanford Site.
Resource Conservation and Recovery Act, 42 USC 6901, et seq. Criteria for Classification of Solid Waste Disposal Facilities and Practices, 40 CFR 257	Criteria specified under this standard are used to determine which solid waste disposal facilities and practices pose a reasonable possibility of adverse risk to human health and the environment.	Although Hanford has solid waste disposal facilities, most of the provisions of this chapter have been delegated to the state. (See Table B-2, Hazardous Waste Management Act.)
Identification and Listing of Wastes, 40 CFR 261	This part establishes the framework for determining whether a waste is hazardous, including testing methods, criteria for characteristic waste, and definitions of listed wastes.	Although hazardous waste is present at the Hanford Site, and might be generated during assessment and response actions, most of the provisions relative to designation have been delegated to the state.
Generator Standards, 40 CFR 262, Standards Applicable to Transporters of Hazardous Waste, 40 CFR 263, Standards for Owners and Operators of TSD Units, 40 CFR 264 and 265	Establishes specific requirements for facilities that generate, transport, store, treat, and/or dispose of hazardous waste. Requirements cover such items as permitting, waste unit design and operation, training, and emergency preparedness planning.	Although hazardous waste is present at the Hanford Site and might be generated during assessment and response actions, most of the provisions relative to waste generation and management have been delegated to the state.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
Groundwater Protection Standards, 40 CFR 264.92	Three remediation levels of groundwater protection established by this section are background, MCLs, and ACLs. MCLs are set at the same levels as SDWA MCLs. Where no SDWA MCL has been set, health-based ACLs may be established that are protective of human health and environment.	Groundwater restoration goals established by this section are relevant and appropriate in establishing soil cleanup levels that are protective of groundwater.
Corrective Action for Solid Waste Management Units, 40 CFR 264, Subpart S (proposed)	Identifies a process for implementing corrective action under RCRA, and establishes chemical-specific soil cleanup levels that are protective based on direct exposure.	Releases from solid waste management units will be considered in the assessment and in identifying response actions. Soil remediation goals established by this section may be pertinent to the establishment of soil cleanup levels. Because this is a proposed rule, it is not strictly applicable at this time.
Land Disposal Restrictions, 40 CFR 268	These requirements prohibit the placement of restricted RCRA hazardous wastes in land-based units until treated to standards considered protective for disposal. Specific treatment standards are included in the requirements.	These requirements are applicable if restricted waste is generated during assessment or response actions.
Toxic Substances Control Act (TSCA), 15 USC 2601 et seq. Regulation of PCBs, 40 CFR 761	These requirements identify standards applicable to the handling and disposal of PCBs above 50 ppm. Spills that occurred before May 4, 1987, are to be decontaminated to requirements established at the discretion of the EPA.	PCBs are known to have been used at the Hanford Site and might be present in waste units and/or might have been released to the environment. TSCA requirements for remediation, treatment, and disposal of PCBs are applicable in developing response actions if the PCBs are present at regulated levels.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
Guidance on Remedial Actions for Superfund Sites with PCB Contamination, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response	This document provides guidance for evaluating and selecting a remedy for sites contaminated with PCBs. The guidance presents a range of preliminary remediation goals for the cleanup of PCB-contaminated sites that are protective of human health and intended to meet the goals of the NCP and TSCA. EPA guidance notes that in selecting a response action under CERCLA, cleanup levels and disposal methods should be selected based on the form and concentration found at the site.	PCBs might be present at CERCLA waste sites at the Hanford Site.
Clean Air Act of 1977, as amended 42 USC 7401, et seq. National Ambient Air Quality Standards, 40 CFR 50	Requirements of these regulations are applicable to airborne releases of criteria pollutants specified under the statute. Specific release limits for particulates are set at 50 µg/m ³ annually or 150 µg/m ³ per 24-hour period.	Applicable to airborne releases of criteria pollutants that might be generated during assessment or response actions.
Ambient Air Quality Monitoring, 40 CFR 58	This regulation presents the criteria and requirements for ambient air quality monitoring and reporting for local air pollution control agencies and operators of new sources of air pollutants.	Applicable to assessment or response actions that meet the regulatory definition of a new source. Also, these requirements may be considered relevant and appropriate to response actions that have the potential to emit air contaminants, even if they are not a new source.
Standards of Performance for New Stationary Sources, 40 CFR 60	These requirements provide standards for new stationary sources or modifications of existing sources.	Applicable if assessment or response actions include stationary sources.
National Emission Standard for Hazardous Air Pollutants (NESHAP), 40 CFR 61	40 CFR 61 provides general requirements and listings for actions that will generate regulated emissions at a regulated facility.	These requirements are applicable to assessment or response actions that release air emissions into unrestricted areas.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
<p>Subpart H, National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities, 40 CFR 61</p>	<p>Subpart H sets emissions limits to ambient air from the entire facility, not to exceed an amount that would cause any member of the public to receive an effective dose equivalent of 10 mrem/yr. The definition of “facility” for the Hanford Site includes all buildings, structures, and operations collectively as one contiguous site. Radionuclide emission from stacks shall be monitored and effective dose equivalent values to members of the public calculated.</p>	<p>These requirements are applicable to assessment and response actions that have the potential to release air emissions to unrestricted areas.</p>
<p>National Emission Standards for Asbestos, Standard for Demolition and Renovation, 40 CFR 61.145 – 150</p>	<p>This section specifies that facilities are to be inspected for the presence of asbestos prior to demolition. The standard defines regulated asbestos-containing materials and establishes removal requirements based on the quantity present and handling requirements. These requirements also specify handling and disposal requirements for regulated sources having the potential to emit asbestos. Specifically, no visible emissions are allowed during handling, packaging, and transport of asbestos-containing materials.</p>	<p>These requirements are applicable if response actions require demolition of buildings or structures containing regulated asbestos-containing materials.</p>
<p>Hazardous Materials Transportation Act, 49 USC 1801, et seq. Hazardous Materials Regulation, 49 CFR 171</p>	<p>These requirements state that no person may offer to accept hazardous material for transportation in commerce unless the material is properly classed, described, packaged, marked, labeled, and in condition for shipment.</p>	<p>These requirements are applicable to hazardous material generated during assessment or response actions, which is sent offsite for disposal.</p>

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
<p>Hazardous Materials Tables, Hazardous Materials Communications Requirements, and Emergency Response Information Requirements, 49 CFR 172</p>	<p>Tables are used to identify requirements for labeling, packaging, and transportation based on categories of waste types. Small quantities of radioactive wastes are not subject to the requirements of the standard if activity levels are below limits established in paragraph 173.421, 173.422, or 173.424. Specific performance requirements are established for packages used for shipping and transport of hazardous materials.</p>	<p>These requirements are applicable if hazardous materials are transported offsite during assessment or response actions. In the event of a discharge of hazardous waste during transportation from the treatment facility to the disposal facility, this section is applicable.</p>
<p>Executive Order 12856, Federal Compliance with Right- to-Know Laws and Pollution Prevention Requirements</p>	<p>Requires that federal agencies will comply with Emergency Planning and Community Right-To-Know Act of 1986 (EPCRA) and the Pollution Prevention Act of 1990 (PPA) to the extent that private entities would. The EO incorporates, by reference, all implementing regulations of EPCRA and the PPA. EPCRA requires tracking and reporting information on the storage, use, and release of extremely hazardous substances, hazardous substances, listed chemicals, and toxic chemicals to inform the public about the presence of such hazards in their community and to provide emergency planners and emergency response organizations with information needed to provide appropriate response to potential emergencies at the facilities. The PPA requires entities to implement practices that reduce or eliminate the creation of pollutants through increased efficiency in the use of raw materials, energy, water, or other resources; or protection of natural resources by conservation.</p>	<p>Applicable to federal agencies that either own or operate a “facility” as that term is defined in section 329(4) of EPCRA if such facility meets the threshold requirements set forth in EPCRA. Hanford meets the definition and threshold requirements.</p>
<p>DOE 1999, Draft Hanford Remedial Action Environmental Impact Statement, DOE/EIS-0222D</p>	<p>The draft Hanford Remedial Action EIS defines land use for the next 50 years at the Hanford Site.</p>	<p>Land use and associated exposure scenarios are important in assessing risk and determining appropriate response actions.</p>

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
National Historic Preservation Act of 1966, 16 USC 470	Requires that historically significant properties be protected. The act requires that agencies undertaking projects must evaluate impacts to properties listed on or eligible for inclusion in the National Register of Historic Places. An eligibility determination provides a site with the same level of protection as a site listed on the National Register of Historic Places. The regulations implementing the act require that the lead agency for a project identify, evaluate, and determine the effects of the project on any cultural resource sites that may be within the area impacted by the project. The implementing regulations require that negative impacts be resolved.	This law is applicable to assessment or response actions that could impact any of the various buildings/ structures at the Hanford Site that are eligible for the National Register.
Archeological and Historic Preservation Act, 16 USC 469a	Requires that actions conducted at the site must not cause the loss of any archeological and historic data. This act mandates preservation of the data and does not require protection of the actual facility. Where a site is determined to be eligible for the National Register and mitigation is unavailable, artifacts and data will be recovered and preserved prior to commencement of the action.	Archeological and historic sites have been identified at the Hanford Site, and therefore these requirements are applicable to activities that might disturb these sites.
Endangered Species Act of 1973, 16 USC 1531, et seq.	This act prohibits federal agencies from jeopardizing threatened or endangered species or adversely modifying habitats essential to their survival. If waste site remediation is within sensitive habitat or buffer zones surrounding threatened or endangered species, mitigation measures must be taken to protect these resources.	The Endangered Species Act of 1973 would be considered applicable if threatened or endangered species are identified in areas covered by the assessment. Their presence could dictate the approach to assessment or response actions that may be necessary.

Regulatory Drivers

Table 5-1. Pertinent Federal Laws, Regulations, and DOE Orders. (11 Pages)

Citation	Requirement	Application
ACL	=	alternate concentration level
ALARA	=	as low as reasonably achievable
CAMU	=	corrective action management unit
CERCLA	=	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	=	Code of Federal Regulations
DCG	=	derived concentration guide
DOE	=	U.S. Department of Energy
EPA	=	U.S. Environmental Protection Agency
HCRL	=	Hanford Cultural Resources Laboratory
MCL	=	maximum contaminant level
MCLG	=	maximum contaminant level goal
NESHAP	=	National Emission Standards for Hazardous Air Pollutants
NCP	=	National Oil and Hazardous Substance Contingency Plan
NEPA	=	National Environmental Policy Act
NPDES	=	National Pollutant Discharge Elimination System
NRC	=	U.S. Nuclear Regulatory Commission
PCB	=	polychlorinated biphenyls
RCRA	=	<i>Resource Conservation and Recovery Act</i>
SDWA	=	Safe Drinking Water Act
TBC	=	to be considered
TSCA	=	Toxic Substance Control Act.

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
<p>Hazardous Waste Clean Up/Model Toxics Control Act, Ch. 70.105D RCW</p> <p>Model Toxics Control Act, WAC 173-340-700</p>	<p>Establishes a process and requirements for cleanup of contaminated sites in the state. MTCA regulations have been authorized for use in implementing RCRA corrective action in the state. Specifies that all cleanup actions be protective of human health; comply with all applicable state and federal regulations; and provide for compliance monitoring. Identifies the methods used to develop cleanup standards and their use in selection of a cleanup action. Specifies cleanup goals, which implement the strictest federal or state cleanup criteria. In addition to meeting requirements of other regulations, MTCA uses three basic methods for establishing cleanup levels. These methods may be used to identify cleanup standards for groundwater, surface water, soils, and protection of air quality. Cleanup levels for soils may be calculated using Method A – routine; Method B – standard method; and Method C – conditional standards. MCLs, MCLGs, and secondary drinking water standards are identified in the regulation as groundwater cleanup criteria.</p>	<p>Requirements of MTCA are relevant and appropriate for cleanup of Hanford waste sites. State requirements that are not authorized through a federal program, such as MTCA, are not directly applicable to federal facilities.</p>
<p>Hazardous Waste Management Act, 70.105 RCW</p> <p>Dangerous Waste Regulations, WAC 173-303</p>	<p>Establishes the design, operation, and monitoring requirements for managing dangerous waste.</p>	<p>Dangerous waste is present in Hanford Site waste units and might be generated during assessment or response actions. Sections of this chapter are applicable to dangerous waste management activities and may be relevant and appropriate in certain situations even when they are not Applicable. Key sections are discussed below.</p>

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
Designation of Waste, WAC 173-303-070 through 110	Establishes the methods and procedures to determine if solid waste requires management as dangerous waste.	The requirements of this section are applicable because dangerous waste might be generated.
Land Disposal Restrictions, WAC 173-303-140	Identifies dangerous wastes that are restricted from land disposal and describes requirements for state-only restricted wastes; defines the circumstances under which a prohibited waste may be disposed.	Applicable to the disposal of restricted wastes.
Spills and Discharges into the Environment, WAC 173-303-145	Sets forth the requirements that apply when any dangerous waste or hazardous substance is intentionally or accidentally spilled or discharged into the environment such that human health and the environment are threatened, regardless of the quantity of dangerous waste or hazardous substance.	Applicable should dangerous waste or hazardous substances be spilled or discharged into the environment.
Requirements for Generators of Dangerous Waste, WAC 173-303-170 through 230	Requirements defined under this section include specific levels of training and emergency preparedness.	Applicable to actions performed at the site if dangerous waste is generated.
General Requirements for Dangerous Waste Management Facilities, WAC 173-303-280 through 395	General requirements include siting standards, training, emergency preparedness, security, inspections, contingency planning, waste analysis, and management of containers.	Applicable to actions that include treatment, storage, or disposal of designated dangerous waste.
Treatment, Storage, and Disposal Facility Requirements, WAC 173-303-600 through 695	Specifies closure and post-closure standards (which require compliance with MTCA cleanup levels), groundwater monitoring requirements, corrective action management unit/temporary unit requirements, air emission standards for process vents and equipment leaks, and specific unit requirements for containers, tanks, surface impoundments, land treatment units, waste piles, landfills, incinerators, drip pads, miscellaneous units, and containment buildings.	Applicable because permitted TSD units are present and/or assessment or remediation wastes may be managed in units that are TSDs.
Releases from regulated units, WAC 173-303-645	Establishes groundwater protection Standards for releases to groundwater from dangerous waste management units.	The standard is applicable because TSD units are present.

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
<p>Solid Waste Management, Recovery and Recycling Act, Ch. 70.95 RCW</p> <p>Minimum Functional Standards for Solid Waste Handling, WAC 173-304</p>	<p>These standards establish requirements to be met for the management of solid waste. Solid waste controlled by this Act includes garbage, industrial waste, construction waste, and ashes. Requirements for containerized storage, collection, transportation, treatment, and disposal of solid waste are included. These standards set groundwater MCLs at the same levels as the state drinking water standards.</p>	<p>These regulations are applicable when solid waste is generated during assessment or response actions, and may be relevant and appropriate to existing solid waste facilities at the Hanford Site.</p>
<p>Water Pollution Control/Water Resource Act of 1971, Ch. 90.48 RCW/Ch. 90.54 RCW</p> <p>Surface Water Quality Standards, WAC 173-201A</p>	<p>These standards set water quality standards at levels protective of aquatic life.</p>	<p>Groundwater from the Hanford Site discharges to the Columbia River; therefore, surface water quality criteria established under this chapter are applicable in assessing risk and response actions.</p>
<p>Protection of Upper Aquifer Zones, WAC 173-154</p>	<p>This regulation directs Ecology to provide for protection of upper aquifers and upper aquifer zones to avoid depletions, excessive water level declines, or reductions in water quality.</p>	<p>This regulation is not applicable because it establishes the policy and program for Ecology. However, the regulation is Relevant and appropriate because protection of the aquifer from adverse impacts caused by waste management units is a primary goal.</p>
<p>State Waste Discharge Program, WAC 173-216</p>	<p>The regulation establishes requirements for industrial and commercial operations that discharge to the groundwater, surface Waters, or municipal sewerage systems. Specific discharges prohibited under the Program are identified. The intent of the Regulation is to maintain the highest possible standards, and the law requires the use of all known available and reasonable methods to prevent and control the discharge of wastes into the waters of the state.</p>	<p>Requirements of this program are applicable to assessment or response actions that include discharges to the ground.</p>

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
<p>Department of Health Standards for Public Water Supplies, WAC 246-290</p>	<p>The rule established under WAC 246-290 defines the regulatory requirements necessary to protect consumers using public drinking water supplies. The rules are intended to conform with the federal SDWA, as amended. WAC 246-290-310 establishes MCLs that define the water quality requirements for public water supplies. WAC 246-290-310 establishes both primary and secondary MCLs and identifies that enforcement of the primary standards is the Department of Health's first priority.</p>	<p>The requirements of WAC 246-290-310 are relevant and appropriate because the groundwater at the Hanford Site is classified as a potential future source of drinking water, based on the State Classification strategy.</p>
<p>State Radiation Protection Requirements, Ch. 70.98 RCW Radiation Protection Standards, WAC 246-221</p>	<p>Establishes annual average concentration limits for radionuclides in gaseous and liquid effluents released to unrestricted areas from licensed nuclear facilities. Occupational dose to adults and minors are set in these requirements. Dose limits that individual members of the public may receive in unrestricted areas from external Sources are also set. The standard identifies the methods required to demonstrate compliance and provides derived air concentration and annual limit on uptake values that may be used to determine an individual's occupational dose.</p> <p>The standard specifies requirements for monitoring personnel exposure for both external and internal exposure.</p>	<p>This regulation is not strictly applicable because the Hanford Site does not have licensed nuclear facilities; however, it might be relevant and appropriate because it establishes standards for acceptable levels of exposure to radiation.</p>
<p>Radioactive Waste-Licensing Land Disposal, WAC 246-250</p>	<p>Establishes the procedures, criteria, and conditions for licensing of low-level radioactive waste land disposal facilities. This section presents specific levels of radiation protection and technical requirements for land disposal of radioactive waste.</p>	<p>This regulation is not strictly applicable because the Hanford Site does not have licensed disposal facilities; however, it might be relevant and appropriate to the assessment if response actions allow radioactive waste to remain on site.</p>

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
<p>Washington Clean Air Act, Ch. 70.94 RCW and Ch. 43.21A RCW</p> <p>General Regulations for Air Pollution, WAC 173-400</p>	<p>The regulation requires that all sources of air contaminants meet emission standards for visible, particulate, fugitive, odors, and hazardous air emissions. This section requires that all emission units use reasonably available control technology, which may be determined for some source categories to be more stringent than the emission limitations listed in this chapter. The regulation requires that source testing and monitoring be performed. A new source would include any process or source that may increase emissions or ambient air concentration of any contaminant for which federal or state ambient or emission standards have been established.</p>	<p>Requirements of this standard are applicable to assessment and response actions that could result in the emission of hazardous air pollutants.</p>
<p>Controls for New Sources of Air Pollution, WAC 173-460</p>	<p>This standard requires that new sources of air emissions provide emission estimates for toxic air contaminants listed in the regulation. The standard requires that emissions be quantified and used in risk modeling to evaluate ambient impacts and to establish acceptable source impact levels. The standard establishes three major requirements for new sources of air pollutants: use of best available control technology; quantification of toxic emissions; and demonstration that human health is protected.</p>	<p>The standard is applicable to assessment and response actions where contaminants identified as toxic air pollutants are present and air emissions might be generated.</p>
<p>Ambient Air Quality Standards for Particulate Matter, WAC 173-470</p>	<p>These requirements set maximum acceptable levels for particulate matter in the ambient air and the 24-hour ambient air concentration standard for particles less than 10 µm in diameter (PM10). The section defines standards for particle fallout in industrial, commercial, and residential areas. Alternate levels are set for areas where natural dust levels are high.</p>	<p>These requirements are applicable to assessment and response actions (e.g., drilling) that might emit particulate matter to the air.</p>

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
Ambient Air Quality Standards and Emission Limits for Radionuclides, WAC 173-480	These requirements establish that the most stringent federal or state ambient air quality standard for radionuclides are enforced. The requirements define the maximum allowable level for radionuclides in the ambient air, which shall not cause a maximum accumulated dose equivalent of 25 mrem/yr to the whole body or 75 mrem/yr to any critical organ. However, ambient air standards under 40 CFR 61 Subparts H and I are not to exceed amounts that result in an effective dose equivalent of 10 mrem/yr to any member of the public. Emission standards for new and modified emission units shall utilize best available radionuclide control technology.	Requirements of this standard are applicable to assessment and response actions that might emit radionuclides to the air.
Emission Standards and Controls for Sources Emitting Volatile Organic Compounds (VOC), WAC 173-490	This chapter establishes technically feasible and attainable standards for sources emitting volatile organic compounds.	This regulation is applicable if assessment or response actions will result in airborne emissions of volatile organic compound.
Radiation Protection - Air Emissions, WAC 246-247	This regulation promulgates air-emission limits for airborne radionuclide emissions as defined in WAC 173-480 and 40 CFR 61, Subparts H and I. The ambient air standards under WAC 173-480 require that the most stringent standard be enforced. Ambient air standards under 40 CFR 61, Subparts H and I, are not to exceed amounts that result in an effective dose equivalent of 10 mrem/yr to any member of the public. The ambient standard in WAC 173-480 specifies that emission of radionuclides to the air must not cause a dose equivalent of 25 mrem/yr to the whole body or 75 mrem/yr to any critical organ.	This regulation is applicable to any assessment or response actions that would result in airborne emissions of radionuclides.

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
Radiation Protection at Uranium and Thorium Milling Operations, WAC 246-252	Radium-226 concentrations are required to be less than 5 pCi/g, averaged over the Upper 15 cm, and not more than 15 pCi/g Averaged over any 15-cm interval deeper than 15 cm from the surface. Groundwater protection standards established for gross alpha excluding radon and uranium are set at 15 pCi/L, and for combined radium-226 and radium-228 not to exceed 5 pCi/L.	This regulation is not strictly applicable because the Hanford Site does not have Uranium or thorium milling operations; however, it is relevant and appropriate because it contains specific soil cleanup limits for radium-226 and radium-228 and Groundwater protection limits.
Department of Game Procedures, WAC 232-012	This standard defines the requirements that the Department of Game must take to protect endangered or threatened wildlife.	These requirements may be applicable if endangered or threatened wildlife are identified in areas affected by assessment or response actions. The requirements of this chapter should be evaluated on an activity-specific basis.
National Area Preserves, RCW 79.70 Washington Natural Heritage Program	The Washington State Natural Heritage Program is authorized under RCW 79.70, Natural Area Preserves, and serves as an advisory council to the Washington State Department of Natural Resources, Fish and Wildlife, the Parks and Recreation Commission, and other state agencies Managing state-owned land or natural Resources. The list of state endangered, Threatened, and sensitive plants developed by the program, along with program-recommended levels of protection, are to be used to assist resource managers in determining which species of concern occur in their areas and recommend protection. The designations provided to plants by the Washington State Natural Heritage program are advisory and do not specify a regulatory level of protection.	The requirements of the Natural Heritage Program provide guidance that could affect assessment or response actions in areas where threatened or endangered plant species have been identified.

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
<p>Water Well Construction, Ch. 18.104 RCW</p> <p>Minimum Standards for Construction and Maintenance of Water Wells, WAC 173-160</p>	<p>These requirements establish minimum standards for design, construction, capping, and sealing of all wells. The requirements set additional requirements, including disinfection of equipment, decommissioning of wells, and quality of drilling water.</p>	<p>These requirements are applicable because assessment or response actions could include construction of wells for groundwater extraction, monitoring, injection of treated groundwater, or resource protection, or geotechnical borings.</p>
<p>Rules and Regulations Governing the Licensing of Well Contractors and Operators, WAC 173-162</p>	<p>This regulation establishes training standards for well contractors and operators.</p>	<p>This regulation is relevant and appropriate because assessment or response actions could involve groundwater well installation or construction of geotechnical borings.</p>
<p>State Environmental Policy Act, Chapter 43.21C RCW</p> <p>SEPA Rules, WAC 197-11</p>	<p>These requirements establish the process for evaluating environmental impacts associated with activities that require a state permit.</p>	<p>These requirements are applicable for any new actions that require a permit.</p>
<p>Water Quality Standards for Ground Waters of the State of Washington; WAC 173-200</p>	<p>Establishes groundwater quality standards to provide for protection of the environment and human health, as well as an antidegradation policy to protect existing and future beneficial uses of ground water.</p>	<p>WAC 173-200 standards do not apply to cleanup actions undertaken pursuant to the Model Toxics Control Act (MTCA) or the Comprehensive Environmental Response, Compensation, and Liability Act. Instead, MTCA establishes groundwater cleanup standards at such sites.</p>
<p>Sediment Management Standards; WAC 173-204-340, WAC 173-204 Part V</p>	<p>WAC 173-204-340 establishes freshwater sediment quality standards. Part V of WAC 173-204 establishes the process for establishing sediment cleanup standards and managing contaminated sediments.</p>	<p>WAC 173-204-340 is currently reserved and freshwater sediment standards are established on a case-by-case basis. Part V identifies specific sediment cleanup standards only for Puget Sound; cleanup standards for all other sites are established on a case-by-case basis.</p>

Regulatory Drivers

Table 5-2. Pertinent State of Washington Laws and Regulations. (9 Pages)

Citation	Requirement	Application
CERCLA	= Comprehensive Environmental Response, Compensation, and Liability Act	
CFR	= Code of Federal Regulations	
Ecology	= Washington Department of Ecology	
MCL	= maximum contaminant level	
MCLG	= maximum contaminant level goal	
MTCA	= Model Toxics Control Act	
NPDES	= National Pollutant Discharge Elimination System	
RCRA	= Resource Conservation and Recovery Act	
RCW	= Revised Code of Washington	
SEPA	= State Environmental Policy Act	
SDWA	= Safe Drinking Water Act	
TBC	= to be considered	
TSD	= treatment, storage, and disposal	
VOC	= Volatile Organic Compounds	
WAC	= Washington Administrative Code.	

6.0 SCOPING RESULTS

The numerical results of the screening studies are presented in Appendix F. The radionuclides and chemicals identified by the various scoping criteria are listed in Table 6-1. Together, these constituents comprise the recommendations for the initial SAC Study Set.

**Table 6-1. Radionuclides and Chemicals Identified by the Various Scoping Criteria.
(2 Pages)**

Contaminant	Human Risk	Background	Ecological Benchmarks	Validation and Models	Existing Plumes
Radionuclides					
Americium 241	X	X			X
Carbon 14	X	X	X		
Cesium 137				X	X
Chlorine 36	X	X	X		
Iodine 129	X	X		X	X
Neptunium 237	X	X			
Plutonium 239/240/242	X	X		X	X
Radium 226	X	X			
Selenium 79	X	X	X		
Strontium 90	X	X		X	X
Technetium 99	X	X	X	X	X
Thorium 232	X	X			
Tritium (Hydrogen 3)	X	X		X	X
Uranium 234/235/236/238	X	X	X		X
Chemicals					
Ammonium Carbonate	X	X	X		
Ammonium Nitrate	X		X		
Carbon Tetrachloride	X	X	X	X	X
Chromium	X			X	X
Copper Sulfate			X		
Dibutyl Phosphate	X	X	X	X	
Ferrocyanide		X	X		X
Fluoride			X		X
Lead		X	X		
Mercury			X		
Nitrate		X		X	X
Nitrite	X	X	X	X	
Potassium Borate		X			

Scoping Results

**Table 6-1. Radionuclides and Chemicals Identified by the Various Scoping Criteria.
(2 Pages)**

Contaminant	Human Risk	Background	Ecological Benchmarks	Validation and Models	Existing Plumes
Sodium		X		X	
Sodium Dichromate	X	X	X	X	X
Sodium Hydroxide	X		X	X	
Sodium Oxalate		X			
Sodium Sulfamate		X	X		
Sulfamic Acid		X	X		
Sulfuric Acid	X				
Tetrachloroethylene					X
Trichloroethylene	X		X	X	X
Uranium	X	X	X		

6.1 HUMAN HEALTH

A scoping cutoff of 1 mrem/lifetime was used for human exposure to radionuclides. If uranium and plutonium are counted as single entries, the human criteria scoping identified 13 radionuclides. For toxic chemicals, a lifetime average hazard index greater than 1.0 was used as the scoping cutoff, and for carcinogenic chemicals, a lifetime risk level of greater than 10^{-6} was used. These cutoffs give 11 chemicals above the criteria cutoffs; however, uranium has also been identified as a radionuclide of concern.

6.2 ECOSYSTEM IMPACTS

For ecosystem impacts, the calculated concentrations in river water and near-river groundwater (as a surrogate for seep water in the riparian zone) were compared to the most limiting surface water criterion for each chemical. For radionuclides, the criterion was a biota dose rate in excess of 1 mrem/day, which is 1/1000 of the current limits. These limits identified only carbon-14, chlorine-36, technitium-99, and uranium as radionuclides with potential ecological impact. However, more chemicals were identified. If ammonium carbonate and ammonium nitrate are combined as ammonia; sodium sulfamate and sulfamic acid are combined as sulfamate, then a total of 14 chemicals exceed the scoping criteria. A number of these chemicals exceed the cutoff by only a small amount, but most of them are also indicated by other criteria, so little is gained by adjusting the criterion by up to an order of magnitude.

6.3 SOCIO-CULTURAL IMPACTS

For socio-cultural impact, the concepts of loss-of-use, loss of religious or spiritual value, and intangible mental stress are all related to the possible contamination of environmental materials.

Scoping Results

Because these are not directly connected to health or risk metrics, the ability to detect materials above background concentrations is considered as the benchmark; predicted environmental contaminant concentrations in groundwater, as prepared for the human health and ecological health calculations, are compared to background values. Because the concentrations are several orders-of-magnitude higher in the groundwater than the surface water, the comparisons are made for that medium.

Assuming uranium isotopes are combined, this criterion identifies the same 13 radionuclides as the human health criterion. The possible contaminants uniquely identified by only this criterion are potassium borate (a large inventory in the 100-D Area), and sodium oxalate. A total of 14 chemicals are identified using this criterion.

6.4 OTHER CONSIDERATIONS

The SAC requires certain types of information, not all of which are related to the health of the Hanford Site and the Columbia River.

6.4.1 SAC Transport Model Inputs

Predictions of contaminant release, migration and fate in the environment are dependent on the contaminant, the chemistry of the released waste, and the physical properties and chemistry of the environment. A number of factors, including release amounts, the radiological half-life, biogeochemical degradation, and geochemical interactions with Hanford soils, will govern whether or not radionuclides and chemicals have an adverse impact on the environment. Clearly, in addition to contaminants, chemical constituents in releases may influence the migration and fate of contaminants in the environment. Those of interest include forms of sodium (Na), iron (Fe), calcium (Ca), potassium (K), complexants (EDTA, HEDTA), nitrate (NO^3^-), nitrite (NO^2^-), aluminum (Al), and hydroxide (OH). Physicochemical properties of releases that may also influence their mobility in the environment include the pH, density, viscosity, ionic strength, temperature, and redox state of the release fluid. These constituents in and physicochemical properties of releases are of greater interest when they appear in relatively large concentrations. Thus, they will be of greater interest for leaks of tank wastes and discharges of tank wastes to ground in cribs, specific retention trenches, french drains, reverse wells, etc., than for dilute waste streams. For those waste streams that exhibit low concentrations of contaminants and associated chemicals, the plumes may be dilute and the complexities of associated chemicals and physicochemical properties should be less dominant in determining the future migration and fate of contaminants.

6.4.2 Validation and Groundwater Transport History Matching

The Hanford Site has maintained and improved a historical record of contaminants in the groundwater. This record has improved over time both in terms of the quality of measurements reported and the number of contaminants analyzed. A similar detection and reporting of contaminants in the vadose zone has not occurred. Inventories released to facilities, (e.g., cribs, ponds, specific retention trenches, tank leaks), and recorded in historical databases are often

Scoping Results

restricted to radionuclides of concern at the time of releases, (e.g., cesium, strontium, plutonium, americium, and uranium). Most of these contaminants are relatively highly sorbed on Hanford sediments and do not appear in the groundwater unless injected directly into the aquifer through reverse wells or carried to the aquifer through preferential pathways, many created by unsealed well-bore casings.

Thus, history matching of contaminant releases and their migration and fate in a large-scale model of the Hanford Site rely on those contaminants that have been detected and monitored in groundwater. For these contaminants, inventory source terms are a high priority if SAC is going to history match the simulation capability and build public and regulatory confidence in models that will be used to extrapolate the migration and fate of moderately to highly sorbed contaminants. History matching at the scale of a site-wide model tests the overall simulation of inventory, release, vadose zone, and groundwater. Thus, history matching will provide assurance that not only are we able to simulate the migration and fate of contamination in groundwater, but that we have appropriately estimated the inventory, its release to the environment, and its mobility in the vadose zone.

The annual report of groundwater contamination summarizes observations of several contaminants in the unconfined aquifer at Hanford Site (Hartman et al. 1999). Those with the longest record and representing the most widespread contamination include tritium, nitrate and iodine-129. Chromium contamination is widespread in several of the 100 Areas. Strontium-90 plumes in the 100 Areas exhibit very high activities in some cases but are of relatively smaller extent. Other extensive contaminant plumes include carbon tetrachloride, chloroform, and trichloroethylene in the 200 West Area, chromium in the 600 Area south of the 200 Areas, technetium-99 and uranium extending eastward from the 200 West Area, and technetium-99 with minor amounts of cyanide and cobalt-60 northeast of the 200 East Area. These contaminants offer the best opportunities to history match over the spectrum of inventory, release, vadose zone and groundwater.

Some data exist for vadose zone plumes of interest, however the multidimensional extent of contamination in this zone must be assumed based on few observations. Thus, specific disposal facilities and leak events may offer opportunities to history match the migration and fate of contaminants that remain the vadose zone. Examples include the 1973 leak from the 241-T-106 Tank and the PFP cribs and trenches. The 241-T-106 Tank leak lead to the detection of ruthenium-106, cesium-137, and cerium-144 in the vadose zone beneath the T tank farm. Discharges of plutonium waste streams from the PFP to cribs (216-Z-1A and -12 cribs) and trenches (216-Z-9 and -18 trenches) have lead to observations of cesium-137, protactinium-233, plutonium-239, and americium-241 in the vadose zone beneath specific disposal facilities. These contaminants, especially cesium-137 and plutonium-239 may offer the best opportunities to history match over the spectrum of inventory, release, and vadose zone migration for contaminants that do not routinely reach the unconfined aquifer.

6.4.3 Regulatory Influences

A large number of Federal and Washington State regulations and treaties have some impact on the SAC function; however, none of them directly influence the selection of the Study Set of

Scoping Results

radionuclides and chemicals for SAC analyses. As described above, the requirements set forth by the regulations have all been addressed in the selection of scoping models and metrics.

6.4.4 Public Interest

A cursory inspection of the radionuclides and chemicals identified through the scoping process reveals a number of materials that are commonly questioned in public discussions. Rather than attempt to tell the public what it wants, this draft anticipates comments and suggestions for additional constituents. The authors anticipate comments and suggestions.

6.5 SUMMARY

A total of 15 individual radionuclides (assuming uranium is combined into one category) have been identified. A larger number of chemicals, about 21 assuming several compounds that decompose into the same ions are aggregated, are also identified. These constituents should be addressed in the GW/VZ Integration Project SAC development.

7.0 RECOMMENDATIONS

In the efforts to compile the initial SAC database and perform the scoping analysis reported herein, a number of weaknesses and strengths of the Hanford Site information and processes were identified by the authors.

The WIDS contains the official summary of the history and status of Hanford waste sites. The authors found that most Hanford projects report data to the WIDS staff. However, the WIDS staff is small and the funding levels do not seem to be commensurate with the importance of the data. The WIDS database is undergoing a major revision; but because of this, data have not been entered from the Hanford Projects for some time. It seems important that the Integration Project ensure that continued funding for updates, improvements, and entry of existing data is provided for WIDS.

In the course of establishing the SAC initial database, all of the inventory estimates in the existing version of WIDS were hand verified by consulting with the original published records. A number of minor errors were found and, by agreement, reported to the WIDS staff. The corrections identified in the SAC database verification effort need to be implemented.

The TWINS/Best Basis Inventory effort is a major ongoing activity. It has much more funding on a regular basis than the SAC can afford to duplicate. This source of data needs to be followed closely by the SAC team in order to gain the benefit of the extensive activity. The TWINS staff themselves have suggested a number of possible improvements (e.g., Cammann et al. 1999):

- Input updated ORIGEN2 and DKPRO data files to improve radionuclide source terms
- Update waste transaction files for missing transactions (1944 - 1994)
- Update solubility factors, tank carryover factors, and plant split factors for better distribution of wastes among tanks
- Update analyte list with additional elements and chemical compounds to reflect data end-user needs (performance assessments, privatization, SAC, etc.)
- Update ORIGEN2 and DKPRO data files to reflect data end-user needs.

It is apparent that data collection and collation is a major effort with several Hanford Site contractors and Core Projects. The SAC is not the appropriate manager of these efforts, but it is obvious that the SAC needs to be intimately tied in with the various databases and to act to coordinate some of the efforts. The Integration Project needs to identify an appropriate mechanism for cooperation with the various groups involved in data collection, and then ensure that new data are forwarded to the SAC for incorporation in the databases that will be used for the SAC assessments.

Recommendations

This data collection effort has identified a number of weaknesses in Hanford inventory tracking. Research is required to improve information on many waste site categories. Little is really known about contents of the canyon buildings and tunnels, for instance. The Environmental Restoration Disposal Facility will never have a strong estimate of inventory, because of the way upper-bound estimates are made.

The screening performed in this study to select a proposed Study Set of contaminants for SAC, Rev. 0 indicates that the range of potential risks among individual constituents of the waste varies over many orders of magnitude. For example, potential screening doses from radionuclides in seeps from the 200 Areas are predicted, using the simple screening model, to range from about 11 (carbon-14) to 10^{-17} (lead-210). The total screening dose through this pathway omitted by selecting the radionuclides recommended is about 2×10^{-5} . This sort of example is true of the other sources as well (see Appendix F). It would appear that there is no necessity to add a “surrogate contaminant” to represent the all-other category.

Finally, the database developed for this scoping study is very large, and organizes much of the available Hanford Site inventory information. However, it should not be considered as a final product. Considerable effort went towards designing a system that could expand as more data become available. One of the CRCIA recommendations, which was strongly urged during the SAC criteria development process, is that a long-term “data-mining” operation be considered. In the sense that this is also the focus of inventory model development of the Integration Project’s Science and Technology program, that idea is supported by the authors of this report. An ongoing, public effort to provide information based on historical operations would be invaluable for the numerous waste sites that now have only a physical description and no information on radionuclide or chemical content. While the overwhelming preponderance of the Hanford global inventory is accounted for with the HDW model and Best Basis Inventory, there are still hundreds of smaller locations for which only minimal approximations can now be made.

As additional radionuclide and/or chemical inventories are identified in the future, the method used in this report is applicable to them to determine if they should be given further additional detailed consideration. The approach used in this report is independent of the results of the other contaminants – if any future combination of contaminant and quantity is identified, application of the scoping techniques developed here will indicate whether the materials exceed any of the scoping criteria, and thus indicate whether the material should be included in the SAC analyses.

8.0 REFERENCES

- ACGIH, 1987, *Threshold Limit Values and Biological Exposure Indices for 1987-1988*, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio.
- Andelman, J. B., 1990, *Total Exposure to Volatile Organic Chemicals in Potable Water*, N. M. Ram, R. F. Christman, and K. G. Cantor, eds, Lewis Publishers, Boca Raton, Florida.
- Anderson, J. D. and D. L. Hagel, 1996, *Summary of Radioactive Solid Waste Received in the 200 Areas During Calendar Year 1995*, WHC-EP-0125-8, Westinghouse Hanford Company, Richland, Washington.
- Baker, D. A. and J. K. Soldat, 1992, *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment*, PNL-8150, Pacific Northwest Laboratory, Richland, Washington.
- Bateman, H., 1910, "Solution of Differential Equations Occurring in the Theory of Radioactive Transformation," *Proc. Cambridge Phil. Soc.* 15:423-427.
- BCMOELP, 1994, *Approved and Working Criteria for Water Quality - 1994*, ISBN 0-7726-2061-X, Water Quality Branch, Environmental Protection Department. British Columbia Ministry of Environment Lands and Parks, Victoria, British Columbia.
- Burmester, D. E. and N. I. Maxwell, 1991, "Time and Loading-Dependence in the McKone Model for Dermal Uptake of Organic Chemicals from a Soil Matrix," *Risk Analysis*, 11:491-497.
- Cammann, J., B. Harmsen, M. Kupfer, B. Watrous, B. Higley, and S. Lambert, 1999, "HDW Model Limitations & Improvements," Presentation January 13, 1999, Lockheed Martin Hanford, Inc., Richland, Washington.
- CCREM, 1987, *Canadian Water Quality Guidelines*, Task Force on Water Quality Guidelines, Canadian Council of Resource and Environment Ministers, Ottawa, Canada. (This document includes updates to February 28, 1994).
- CEC, 1987, *European Community Environmental Legislation: 1967 - 1987*, XI/989/87, 229 pp., Directorate-General for Environment, Consumer Protection and Nuclear Safety, Commission of European Communities, Brussels, Belgium.
- CRITFC, 1994, *A Fish Consumption Survey of the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin*, CRITFC Technical Report 94-3, Columbia River Inter-Tribal Fish Commission, Portland, Oregon.

References

- Diediker, L. P., 1999, *Cumulative Decayed Inventories for Hanford Waste Disposal Sites*, HNF-1744, pre-print, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- Dirkes, R. L., R. W. Hanf, R. K. Woodruff, and R. E. Lundgren, 1994, *Hanford Site Environmental Report for Calendar Year 1993*, PNL-9823, Pacific Northwest Laboratory, Richland, Washington.
- Dirkes, R. L. and R. W. Hanf, 1995, *Hanford Site Environmental Report for Calendar Year 1994*, PNL-10574, Pacific Northwest Laboratory, Richland, Washington.
- Dirkes, R. L. and R. W. Hanf, 1996, *Hanford Site Environmental Report for Calendar Year 1995*, PNNL-11139, Pacific Northwest National Laboratory, Richland, Washington.
- Dirkes, R. L. and R. W. Hanf, 1997, *Hanford Site Environmental Report for Calendar Year 1996*, PNNL-11472, Pacific Northwest National Laboratory, Richland, Washington.
- Dirkes, R. L. and R. W. Hanf, 1998, *Hanford Site Environmental Report for Calendar Year 1997*, PNNL-11795, Pacific Northwest National Laboratory, Richland, Washington.
- DOE-RL, 1994, *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities*, DOE/RL-93-88, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE-RL, 1995, *Hanford Site Risk Assessment Methodology*, DOE/RL-91-45, Rev. 3, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE-RL, 1997, *Hanford Site Background: Part 3, Groundwater Background*, DOE/RL-96-61, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE-RL, 1998a, *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 1997*, DOE/RL-98-33, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE-RL, 1998b, *Screening Assessment and Requirements for a Comprehensive Assessment*, DOE/RL-96-16, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOH, 1999, Letter dated June 11, 1999, to S. Snyder from D. Thatcher of the State of Washington Department of Health, Olympia, Washington.
- DOI, 1942, *Report on the Source, Nature, and Extent of the Fishing, Hunting, and Miscellaneous Related Rights of Certain Indian Tribes in Washington and Oregon Together with Affidavits Showing Locations of a Number of Usual and Accustomed Fishing Grounds and Stations*, Department of the Interior, Los Angeles, California.

References

- EPA, 1984, *Health Effects Assessment for Lead*, EPA/540/1-86-055, U.S. Environmental Protection Agency, Cincinnati, Ohio.
- EPA, 1986, *Verified Reference Doses (RfDs) of the US EPA*, ECAO-CIN-475, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1988, *Limiting Values of Radionuclide Intake and Air Concentrations and Dose Conversion Factors for Inhalation, Submersion, and Ingestion: Federal Guidance Report No. 11*, EPA-520/1-88-020, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1989, *Exposure Factors Handbook*, EPA/600/8-89/043, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1990, *Quality Criteria for Water - 1989*, (Updated 1986 Water Quality Criteria Summary), Criteria and Standards Division, Office of Water, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1991a, *Standard Default Exposure Factors*, OSWER Directive 9285.6-03, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1992a, *Dermal Exposure Assessment: Principles and Applications*, EPA/600/8-91/011B, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1993, *External Exposure to Radionuclides in Air, Water, and Soil: Federal Guidance Report No. 12*, EPA-402/R-93-081, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, 1996, "IRIS – Integrated Risk Information System," *In TOMES Plus® - Toxicology, Occupational Medicine, and Environmental Series*, Vol. 31 (CD-ROM), Micromedex, Inc., U.S. Environmental Protection Agency, Denver, Colorado.
- EPA, 1997, *Health Effects Assessment Summary Tables (HEAST)*, FY-1997 Supplement, EPA-540-R-97-036, U.S. Environmental Protection Agency, Washington, D.C.
- Ford, B. H., 1993, *Groundwater Field Characterization Report for the 200 Aggregate Area Management Study*, WHC-SD-EN-TI-020, Westinghouse Hanford Company, Richland, Washington.
- Freshley, M. D. and M. J. Graham, 1988, *Estimation of Ground-water Travel Time at the Hanford Site: Description, Past Work, and Future Needs*, PNL-6328, Pacific Northwest Laboratory, Richland, Washington.
- Gydeson, S. P., 1993, *Fuel-Element Failures in Hanford Single-Pass Reactors 1944-1971*, PNWD-2161 HEDR, Pacific Northwest Laboratory, Richland, Washington.

References

- Haines, M. L., K. Brydges, M. J. MacDonald, S. L. Smith, and D. D. MacDonald, 1994, *A Review of Environmental Quality Criteria and Guidelines for Priority Substances in the Fraser River Basin*, supporting documentation, Environment Canada, North Vancouver, DOE FRAP 1994-31. Available at: http://INWEH1.uwaterloo.ca/447/waterguidelines/suppdoc_ToC.html
- Harmsen, D. P., et al., 1998, *Hanford Defined Waste Model Limitations and Improvements*, HNF-3273, Rev. 0, Lockheed Martin Hanford, Corp., Richland, Washington.
- Hartman, M. J., 1999, *Hanford Site Groundwater Monitoring for Fiscal Year 1998*, PNNL-12086, Pacific Northwest Laboratory, Richland, Washington.
- Heeb, C. M. and D. J. Bates, 1994, *Radionuclide Releases to the Columbia River from Hanford Operations, 1944-1971*, PNWD-2223 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- Heeb, C. M., 1994, *Radionuclide Releases to the Atmosphere from Hanford Operations, 1944-1972*, PNWD-2222 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- HPS, 1994, *STELLA II Software*, Windows Version, High Performance Systems, Hanover, New Hampshire.
- Hunn, H. S., 1990, *Nch'i-wana, "The Big River": Mid-Columbia Indians and their Land*, University of Washington Press, Seattle, Washington.
- Jaeger, R. G., E. P. Blizard, A. B. Chilton, M. Grotenhuis, A. Honig, T. A. Jaeger, and H. H. Eisenlohr, eds, 1968, *Engineering Compendium on Radiation Shielding, Vol. 1: Shielding Fundamentals and Methods*, Springer-Verlag, New York.
- Kennedy, W. E., Jr. and D. L. Strenge, 1992, *Residual Radioactive Contamination From Decommissioning*, NUREG/CR-5512, Vol. 1, U.S. Nuclear Regulatory Commission, Washington, D.C.
- Kupfer, M. J., et al., 1999, *Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes*, HNF-SD-WM-TI-740, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- MDEWPSH, 1988, "Manitoba Surface Water Quality Objectives," *Water Standards and Studies*, 47 pp., Manitoba Department of Environment and Workplace Safety and Health, Manitoba, Canada.
- MENVIQ, 1990, *Criteres de qualite de l'eau*, EMA88-09, Gouvernement du Quebec, Ministere de l'environnement du Quebec, Quebec City, Quebec.
- MENVIQ, 1993, *Criteres de qualite de l'eau*, (Modifications et nouveaux criteres), EMA88-09, Gouvernement du Quebec, Ministere de l'environnement du Quebec, Quebec City, Quebec.

References

- Miller, R. L. and J. M. Steffes, 1986, *Radionuclide Inventory and Source Terms for the Surplus Production Reactors at Hanford*, UNI-3714, UNC Nuclear Industries, Richland, Washington.
- Napier, B.A., 1991, *Selection of the Dominant Radionuclides for Phase I of the Hanford Environmental Dose Reconstruction Project*, PNL-7231 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- Napier, B.A., 1992, *Determination of Radionuclides and Pathways Contributing to Cumulative Dose*, BN-SA-3673 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- Napier, B. A., 1993, *Determination of the Key Radionuclides and Parameters Related to Dose from the Columbia River Pathway*, BN-SA-3768 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- NATO, 1998, *Cross-Border Environmental Problems Emanating From Defense-Related Installations and Activities, Phase II: 1995-1998*, Report No. 225, NATO/CCMS Pilot Study, North Atlantic Treaty Organization, Oslo, Norway.
- NIOSH, 1996, *Registry of Toxic Effects of Chemical Substances (RTECS)*, In TOMES Plus® - Toxicology, Occupational Medicine, and Environmental Series, Vol. 31 (CD-ROM), Micromedex, Inc., National Institute of Occupational Safety and Health, Denver, Colorado.
- McKone, T. E., 1990, "Dermal Uptake of Organic Chemicals from a Soil Matrix," *Risk Analysis*, 10(3):407-419.
- Morgan, K. Z. and J. E. Turner, 1973, *Principles of Radiation Protection: A Textbook of Health Physics*, Robert E. Krieger Publishing Company, Huntington, New York.
- OHM/TADS and EPA, 1996, "OHM-TADS: Oil and Hazardous Materials Technical Assistance Data System," In: TOMES Plus® - Toxicology, Occupational Medicine, and Environmental Series, Vol. 27 (CD-ROM), Micromedex, Inc., U.S. Environmental Protection Agency, Englewood, Colorado.
- OMEE, 1994, *Provincial Water Quality Objectives and Guidelines*, 3 pp., Ontario Ministry of Environment and Energy, Toronto, Ontario.
- Pommen, L. W., 1989, *Approved and Working Criteria for Water Quality*, 38 pp., Water Management Branch, British Columbia Ministry of Environment, Victoria, British Columbia.
- Skowronski, G. A., R. M. Turkall, A. R. M. Kadry, and M. S. Abdel-Raman, 1990, "Effects of Soil on the Dermal Bioavailability of m-Xylene in Male Rats," *Experimental Research*, 51: 182-193.

References

- Stortelder, P. B., M. A. van der Gaag, and L. A. van der Kooij, 1989, "Perspectives for Water Organisms," *An Ecotoxicological Basis for Quality Objectives for Water and Sediment, Part 1, Results and Calculations*, DBW/RIZA Memorandum N. 89.016a, (English version August 1991) Institute for Inland Water Management and Waste, Water Treatment, The Netherlands.
- UNEP, 1985, "Zinc, International Register of Potentially Toxic Chemicals (IRPTC)," *Scientific Reviews of Soviet Literature on Toxicity and Hazards of Chemicals #94*, 80 pp., United Nations Environment Program, Moscow, U.S.S.R.
- Wester, R. C., H. I. Maibach, L. Seik, J. Melendres, S. DiZio, I. Jamall, and M. Wade, 1991, "In Vivo Percutaneous Absorption of Cadmium from Water and Soil," *Toxicology*, 11:289.
- Woodruff, R. K., R. W. Hanf, and R. E. Lundgren, 1993, *Hanford Site Environmental Report for Calendar Year 1992*, PNL-8682, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

SCOPING MODEL FOR ENVIRONMENTAL TRANSPORT

APPENDIX A

SCOPING MODEL FOR ENVIRONMENTAL TRANSPORT

The following is the verbatim listing of the source code generated by the STELLA II computer program to implement the simple scoping transport model illustrated in Figure 3-2 of the main text. This particular example calculates Pu-239 (half-life 24,100 years) in the 200 Areas.

Groundwater(t) = Groundwater(t - dt) + (VZGW_transfer - decay_GW - GWRiver_transfer) * dt
INIT Groundwater = 0

VZGW_transfer = Vadose*Recharge/(Vadose_thickness*VWC1*(1+Kd*density/VWC1))
decay_GW = Groundwater*decay_constant
GWRiver_transfer = Groundwater/(GW_Travel_time*(1+Kd*density/VWC2))
Vadose(t) = Vadose(t - dt) + (Release - VZGW_transfer - decay_VZ) * dt
INIT Vadose = 0

Release = Waste*Recharge/(Waste_thickness*VWC1*(1+Kd*density/VWC1))
VZGW_transfer = Vadose*Recharge/(Vadose_thickness*VWC1*(1+Kd*density/VWC1))
decay_VZ = Vadose*decay_constant
Waste(t) = Waste(t - dt) + (- Release - decay_soil) * dt
INIT Waste = 1

Release = Waste*Recharge/(Waste_thickness*VWC1*(1+Kd*density/VWC1))
decay_soil = Waste*decay_constant
decay_constant = 0.693/950
density = 1500
GW_Concentration = Groundwater/((5*10000*100*1000)*(VWC2+Kd*(1-VWC2)))
GW_Travel_time = 20
Kd = 600
Recharge = .01
River_Concentration = Groundwater/(GW_Travel_time*(1+Kd*density/VWC2))/River_flow_rate
River_flow_rate = 1E14
Vadose_thickness = 50
VWC1 = 0.02
VWC2 = 0.35
Waste_thickness = 5



APPENDIX B

FUEL FAILURE RELEASES TO THE COLUMBIA RIVER

APPENDIX B

FUEL FAILURE RELEASES TO THE COLUMBIA RIVER

Table B-1 was used to estimate release to the Columbia River from fuel element cladding ruptures in the single-pass production reactors.

The calculations performed in this spreadsheet are based on distributions of fuel burnup provided by Heeb and Bates (1994), loss of metal from ruptured fuel elements summarized by Gydesen (1993), and ORIGEN2 estimates of radionuclide content in irradiated fuel (Napier 1991).

The spreadsheet is actually a stochastic implementation and many of the parameters have a distribution associated with them. Only the central values are listed here.

REFERENCES

- Heeb, C. M. and D. J. Bates, 1994, *Radionuclide Releases to the Columbia River from Hanford Operations, 1944-1971*, PNWD-2223 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- Gydesen, S. P., 1993, *Fuel-Element Failures in Hanford Single-Pass Reactors 1944-1971*, PNWD-2161 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- Napier, B. A., 1991, *Selection of Dominant Radionuclides for Phase I of the Hanford Environmental Dose Reconstruction Project*, PNL-7231 HEDR, Pacific Northwest Laboratory, Richland, Washington.

**Table B-1. Release of Material From Fuel Element Failures Based on PNWD-2161 HEDR (Gydesen 1993)
 and PNWD-2233 HEDR (Heeb and Bates 1994) and Napier 1991. (2 Pages)**

Grams From Rupture	Burnup MWd/t	Nuclide	Ci/ton "@ 500 MWd	Ci/g per MWd/t (assume linear) [except U, Ci/g]	Release per Rupture		Total Ci 1,963 Failures	Approx Ci Remaining
					Ci	t ½		
85	500	Hydrogen 3 (Tritium)	8.55	1.71E-08	0.0007268	12.33	1.43E+00	2.00E-01
		Actinium 227	7.40E-11	1.48E-19	6.29E-15	21.7	1.23E-11	4.04E-12
		Americium 241	0.016	3.2E-11	1.36E-06	433	2.67E-03	2.52E-03
		Americium 242m	1.50E-04	3E-13	1.275E-08	152	2.50E-05	2.13E-05
		Cadmium 113m	0.83	1.66E-09	7.055E-05	13.6	1.38E-01	2.33E-02
		Carbon 14	1.80E-06	3.6E-15	1.53E-10	5730	3.00E-07	2.99E-07
		Cesium 135	0.0035	7E-12	2.975E-07	2.30E+06	5.84E-04	5.84E-04
		Cesium 137	1592	0.000003184	0.13532	30.2	2.66E+02	1.19E+02
		Chlorine 36	0	0	0	3.07E+05	0.00E+00	0.00E+00
		Cobalt 60	3.20E+05	0.00064	27.2	5.26	5.34E+04	5.31E+02
		Curium 243	6.30E-06	1.26E-14	5.355E-10	32	1.05E-06	4.93E-07
		Curium 244	2.70E-04	5.4E-13	2.295E-08	18.1	4.51E-05	1.18E-05
		Europium 152	0.03	6E-11	2.55E-06	14	5.01E-03	8.85E-04
		Europium 154	10.6	2.12E-08	0.000901	7.8	1.77E+00	7.89E-02
		Iodine 129	4.30E-04	8.6E-13	3.655E-08	1.60E+07	7.17E-05	7.17E-05
		Krypton 85	175	0.00000035	0.014875	10.74	2.92E+01	3.05E+00
		Lead 210	0	0	0	22	0.00E+00	0.00E+00
		Neptunium 237	3.90E-03	7.8E-12	3.315E-07	2.14E+06	6.51E-04	6.51E-04
		Nickel 59	8.60E-04	1.72E-12	7.31E-08	8.00E+04	1.43E-04	1.43E-04
		Nickel 63	0.11	2.2E-10	9.35E-06	92	1.84E-02	1.41E-02
		Palladium 107	9.20E-04	1.84E-12	7.82E-08	7.00E+06	1.54E-04	1.54E-04
		Protactinium 231	3.60E-08	7.2E-17	3.06E-12	3.24E+04	6.01E-09	6.00E-09
		Plutonium 238	1.5	0.000000003	0.0001275	87.4	2.50E-01	1.90E-01
		Plutonium 239/240	64	0.000000128	0.00544	24390	1.07E+01	1.07E+01

Table B-1. Release of Material From Fuel Element Failures Based on PNWD-2161 HEDR (Gydesen 1993) and PNWD-2233 HEDR (Heeb and Bates 1994) and Napier 1991. (2 Pages)

Grams From Rupture	Burnup MWd/t	Nuclide	Ci/ton "@ 500 MWd	Ci/g per MWd/t (assume linear) [except U, Ci/g]	Release per Rupture		Total Ci 1,963 Failures	Approx Ci Remaining
					Ci	t ½		
		Plutonium 241	290	0.00000058	0.02465	14.3	4.84E+01	8.87E+00
		Plutonium 242	1.40E-04	2.8E-13	1.19E-08	3.87E+05	2.34E-05	2.34E-05
		Radium 226	1.70E-15	3.4E-24	1.445E-19	1602	2.84E-16	2.79E-16
		Radium 228	9.00E-17	1.8E-25	7.65E-21	5.75	1.50E-17	2.21E-19
		Samarium 151	28.8	5.76E-08	0.002448	93	4.81E+00	3.70E+00
		Selenium 79	6.80E-03	1.36E-11	5.78E-07	65000	1.13E-03	1.13E-03
		Strontium 90	1325	0.00000265	0.112625	28.9	2.21E+02	9.55E+01
		Technetium 99	0.21	4.2E-10	1.785E-05	213000	3.50E-02	3.50E-02
		Tellurium 123	1.40E-16	2.8E-25	1.19E-20	1.20E+13	2.34E-17	2.34E-17
		Thorium 229	6.20E-13	1.24E-21	5.27E-17	7340	1.03E-13	1.03E-13
		Thorium 230	8.60E-11	1.72E-19	7.31E-15	78000	1.43E-11	1.43E-11
		Thorium 232	1.90E-14	3.8E-23	1.615E-18	1.41E+10	3.17E-15	3.17E-15
		Tin 121M	2.10E-03	4.2E-12	1.785E-07	76	3.50E-04	2.55E-04
		Tin 126	0.013	2.6E-11	1.105E-06	1.00E+05	2.17E-03	2.17E-03
		Uranium 232	8.70E-07	1.74E-15	7.395E-11	72	1.45E-07	1.04E-07
		Uranium 234	1.40E-04	2.8E-13	1.19E-08	2.47E+05	2.34E-05	2.34E-05
		Uranium 235	1.30E-02	1.30E-08	1.11E-06	7.10E+08	2.17E-03	2.17E-03
		Uranium 236	5.50E-03	1.1E-11	4.675E-07	2.42E+07	9.18E-04	9.18E-04
		Uranium 238	0.3	0.0000003	0.0000255	4.51E+09	5.01E-02	5.01E-02
		Zirconium 93	0.03	6E-11	2.55E-06	9.50E+05	5.01E-03	5.01E-03

Appendix B – Fuel Failure Releases to the Columbia River

APPENDIX C
NECESSARY PARAMETERS

APPENDIX C

NECESSARY PARAMETERS

A hierarchy of data sources was established to select recommended values for transfer factors. The most recent and comprehensive references were given priority. The first reference chosen was the International Atomic Energy Agency's Technical Report Series No. 364, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments* (IAEA 1994). This document encompasses a wide variety of plant types and is the result of extensive background investigations. It is based on data compiled by the International Union of Radioecologists. The second reference given consideration was the NUREG/CR-5512, *Residual Radioactive Contamination From Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent* (Kennedy and Strenge 1992) because of its large set of data and traceable references. Other references used to fill in data were the National Council on Radiation Protection and Measurements (NCRP) Report No. 123 (1996), *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground*, the library from the GENII Version 1.485 system of computer codes (Napier et al. 1988), and the series of documents by Coughtrey et al., *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Vols. 1-6* (1983). The NCRP Report No. 123 was chosen because it is a generally accepted reference for a generic model. The GENII V.1.485 values have been in use for a decade to model the semi-arid environment at Hanford and are reasonably well documented. Although the methodology for the Coughtrey and Thorne values was somewhat different, resulting in high values for transfer factors, it was necessary to use their values to fill in data where no other information was available. When no referenceable documents were available, data were derived based on chemical groupings in the periodic table of the elements, as described below.

FOOD TYPES EVALUATED

For this compendium of data, foods were grouped into the following types: meat, milk, birds, fish, and vegetables. When more than one food was listed for a given food type (e.g., spinach, cabbage, and lettuce listed as leafy vegetable), the transfer factor for each food was weighted by the U.S. Department of Agriculture annual per capita consumption rate (USDA 1983), and a weighted average of transfer factors was reported for that food type.

Plant transfer factors from the International Atomic Energy Agency (IAEA) Handbook No. 364, NUREG/CR-5512, GENII, and Coughtrey et al. are based on dry weight data (pCi per kg dry crop edible product)/(pCi/kg dry soil in the upper 20 cm). When data were presented on a wet weight basis, they were converted to dry weight using conversion factors found in Table C-1. All plant transfer factors presented in this report are based on dry weight. Animal products are presented on a wet weight or volume (milk) basis.

Appendix C – Necessary Parameters

Table C-1. Dry-to-Wet-Weight Conversion Factors for Food Products.^a

Plant Type		Conversion Factor
Leafy vegetation		0.2
Other vegetables		0.25
Fruit		0.18
Grain		0.91
Beef	Forage	0.22
	Stored hay	0.22
	Stored grain	0.91
Poultry	Forage	0.22
	Stored hay	0.22
	Stored grain	0.91
Dairy	Forage	0.22
	Stored hay	0.22
	Stored grain	0.91
Eggs	Forage	0.22
	Stored hay	0.22
	Stored grain	0.91

^a From Kennedy and Strenge (1992).

Methods Used to Estimate Transfer Factors

Experimental data are not available for all elements for all food types. Therefore, several methods were employed to estimate transfer factors for elements and food types where experimental data were lacking. In some cases, parameters from one vegetable type were applied to remaining vegetable types for the same element. In these cases, no adjustments were made for the wet/dry ratios for specific food types, due to the relatively large uncertainty inherent in applying the transfer factor from one food type to another. In other cases, chemical similarities among elements were the basis for estimating the transfer factor. If two or more transfer factors were available for elements in a chemical group, the geometric mean was calculated from the chemical group for the given food type (Figure C-1). Where data were available for only one element in a chemical group, the transfer factor for that element was applied to other elements in the same chemical group. Specific cases are listed in the Estimated Transfer Factors section below. For the actinides, many of the values from americium were applied to other elements for which parameters were not available. Cerium was selected as the surrogate element for other lanthanides for which values were not known.

Appendix C – Necessary Parameters

Vegetation: The soil-to-vegetation transfer factors for N, Hf, Ta, and Au were calculated as the geometric means of the transfer factors in their respective periodic table groups. All the lanthanide elements were assigned the value for Ce. Actinium (Ac), Pa, and Cf were assigned the vegetable transfer factor from Am.

Sorption Coefficients: The sorption coefficient K_d is the ratio of radionuclides in solid and liquid phases (the units are pCi/kg of soil per pCi/L of water = L/kg). One of the applications of K_d is in its use as a retardation factor. Because natural Hanford soils are basic, oxidizing, low in organic content, and low in complexants, they differ from most other soils in the world. Therefore, where available, Hanford-specific values for K_d were used. The Hanford values were taken as the “conservative” values reported in Table E.11 of Kincaid et al. (1998). The backup source of K_d values for radionuclides and non-radioactive inorganic materials was the IAEA Technical Report Series No. 364, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments* (IAEA 1994). This document is the result of extensive background investigations. It is based on data compiled by the International Union of Radioecologists. For this application, conservatively small values of K_d were selected representing sandy soil. Where K_d values were not available in these references, they were supplemented with Streng and Peterson (1989), a Hanford-developed compilation. Again, values representative of neutral, sandy, soil were used to provide small retardation and quick transport times. A few constituents were approximated using chemical similarity. For organic constituents, the Multimedia Environmental Database Editor collection of materials was consulted. The bulk of the organic constituents tend to have low K_d values and high transportability.

Appendix C – Necessary Parameters

Table C-2. Transfer Factors for Meat (pCi/kg Muscle per pCi/d Intake).

Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference	Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference
04 Be	1.0E-3	KS92	Ng68	52 Te	7.0E-3	IAEA94	Jo88
07 N	7.5E-2	KS92	Ng68	53 I	4.0E-2	IAEA94	Bi89
09 F	1.5E-1	KS92	Ng68	55 Cs	5.0E-2	IAEA94	Co90
11 Na	8.0E-2	IAEA94	Ng82a	56 Ba	2.0E-4	IAEA94	Jo88
12 Mg	2.0E-2	IAEA94	Ng82a	57 La	2.0E-3	NCRP96	NCRP96
14 Si	4.0E-5	KS92	Ng68	58 Ce	2.0E-5	IAEA94	CEC87
15 P	5.0E-2	IAEA94	Ng82a	59 Pr	2.0E-5	Based on Ce	CEC87
16 S	2.0E-1	Na88	IAEA87	60 Nd	2.0E-5	Based on Ce	CEC87
17 Cl	2.0E-2	IAEA94	Bi89	61 Pm	2.0E-5	Based on Ce	CEC87
19 K	2.0E-2	IAEA94	Ng82a	62 Sm	2.0E-5	Based on Ce	CEC87
20 Ca	2.0E-3	IAEA94	Ng82a	63 Eu	2.0E-5	Based on Ce	CEC87
21 Sc	1.5E-2	KS92	Ng68	64 Gd	2.0E-5	Based on Ce	CEC87
24 Cr	9.0E-3	IAEA94	Ng82a	65 Tb	2.0E-5	Based on Ce	CEC87
25 Mn	5.0E-4	IAEA94	Ng82a	66 Dy	2.0E-5	Based on Ce	CEC87
26 Fe	2.0E-2	IAEA94	Ng82a	67 Ho	2.0E-5	Based on Ce	CEC87
27 Co	1.0E-2	IAEA94	Ng82a	68 Er	2.0E-5	Based on Ce	CEC87
28 Ni	5.0E-3	IAEA94	Cr90	72 Hf	1.0E-3	KS92	Ng68
29 Cu	9.0E-3	IAEA94	Ng82a	73 Ta	3.0E-7	Based on Nb	Jo88
30 Zn	1.0E-1	IAEA94	Ng82a	74 W	4.0E-2	IAEA94	Ng82a
31 Ga	5.0E-4	KS92	Ba84	75 Re	8.0E-3	KS92	Ng68
33 As	2.0E-3	KS92	Ng68	76 Os	4.0E-1	KS92	Ng68
34 Se	1.5E-2	KS92	Ng68	77 Ir	1.5E-3	KS92	Ng68
35 Br	2.5E-2	KS92	Ng68	79 Au	5.0E-3	Na88	NCRP86
37 Rb	1.0E-2	IAEA94	Ng82a	80 Hg	2.5E-1	KS92	Ng68
38 Sr	8.0E-3	IAEA94	Co90	81 Tl	4.0E-2	KS92	Ng68
39 Y	1.0E-3	IAEA94	Ng82a	82 Pb	4.0E-4	IAEA94	Ng82a
40 Zr	1.0E-6	IAEA94	Jo88	83 Bi	4.0E-4	KS92	Ng68
41 Nb	3.0E-7	IAEA94	Jo88	84 Po	5.0E-3	IAEA94	Ng82a
42 Mo	1.0E-3	IAEA94	Jo88	88 Ra	9.0E-4	IAEA94	MB90
43 Tc	1.0E-4	IAEA94	Bi89	89 Ac	4.0E-4	Na88	LS85
44 Ru	5.0E-2	IAEA94	Co90	90 Th	4.0E-5	Based on Am	Co90
45 Rh	2.0E-3	KS92	Ng79	91 Pa	4.0E-5	Based on Am	Co90
46 Pd	4.0E-3	KS92	Ng68	92 U	3.0E-4	IAEA94	Cr90
47 Ag	3.0E-3	IAEA94	CEC87	93 Np	1.0E-3	IAEA94	Br79
48 Cd	4.0E-4	IAEA94	Ng82a	94 Pu	1.0E-5	IAEA94	Co90
49 In	8.0E-3	KS92	Ng68	95 Am	4.0E-5	IAEA94	Co90
50 Sn	8.0E-2	KS92	Ng68	96 Cm	4.0E-5	Based on Am	Co90
51 Sb	1.0E-3	Na88	IAEA87	98 Cf	4.0E-5	Based on Am	Co90

g.m. = geometric mean.

Appendix C – Necessary Parameters

Table C-3. Concentration Ratios for Fish (pCi/kg Muscle per pCi/L).

Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference	Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference
02 He	1.0E+0	IAEA94	IAEA94	51 Sb	1.0E+2	IAEA94	IAEA82
04 Be	1.0E+2	IAEA94	IAEA94	52 Te	4.0E+2	IAEA94	IAEA82
06 C	5.0E+4	IAEA94	IAEA94	53 I	4.0E+1	IAEA94	IAEA82
07 N	2.0E+5	IAEA94	IAEA94	55 Cs	2.0E+3	IAEA94	IAEA82
08 O	1.0E+0	IAEA94	IAEA94	56 Ba	4.0E+0	IAEA94	IAEA82
09 F	1.0E+1	KS92	St86	57 La	3.0E+1	IAEA94	IAEA82
11 Na	2.0E+1	IAEA94	IAEA82	58 Ce	3.0E+1	IAEA94	IAEA82
12 Mg	5.0E+1	NCRP96	NCRP96	59 Pr	3.0E+1	Based on Ce	IAEA82
14 Si	2.0E+1	NCRP96	NCRP96	60 Nd	3.0E+1	Based on Ce	IAEA82
15 P	5.0E+4	IAEA94	IAEA82	61 Pm	3.0E+1	Based on Ce	IAEA82
16 S	8.0E+2	IAEA94	IAEA82	62 Sm	3.0E+1	Based on Ce	IAEA82
17 Cl	5.0E+1	KS92	St86	63 Eu	3.0E+1	Based on Ce	IAEA82
19 K	1.0E+3	KS92	St86	64 Gd	3.0E+1	Based on Ce	IAEA82
20 Ca	4.0E+1	KS92	St86	65 Tb	3.0E+1	Based on Ce	IAEA82
21 Sc	1.0E+2	IAEA94	IAEA94	66 Dy	3.0E+1	Based on Ce	IAEA82
24 Cr	4.0E+0	Sn94	Th94	67 Ho	3.0E+1	Based on Ce	IAEA82
25 Mn	4.0E+2	IAEA94	IAEA82	68 Er	3.0E+1	Based on Ce	IAEA82
26 Fe	2.0E+2	IAEA94	IAEA82	72 Hf	3.0E+2	Based on Zr	IAEA82
27 Co	3.0E+2	IAEA94	IAEA82	73 Ta	3.0E+2	Based on Nb	IAEA94
28 Ni	1.0E+2	IAEA94	IAEA82	74 W	1.0E+1	Based on Mo	IAEA94
29 Cu	2.0E+2	IAEA94	IAEA94	75 Re	1.2E+2	KS92	St86
30 Zn	3.5E+2	Sn94	Th94	76 Os	1.0E+1	KS92	St86
31 Ga	4.0E+2	NCRP96	NCRP96	77 Ir	1.0E+1	KS92	St86
33 As	1.7E+3	Sn94	Th94	79 Au	3.3E+1	KS92	St86
34 Se	1.7E+2	KS92	St86	80 Hg	1.0E+3	KS92	St86
35 Br	4.0E+2	IAEA94	IAEA94	81 Tl	1.0E+4	NCRP96	NCRP96
37 Rb	2.0E+3	IAEA94	IAEA94	82 Pb	3.0E+2	IAEA94	IAEA82
38 Sr	6.0E+1	IAEA94	IAEA82	83 Bi	1.5E+1	KS92	St86
39 Y	3.0E+1	IAEA94	IAEA82	84 Po	5.0E+1	IAEA94	IAEA82
40 Zr	3.0E+2	IAEA94	IAEA82	88 Ra	5.0E+1	IAEA94	IAEA82
41 Nb	3.0E+2	IAEA94	IAEA82	89 Ac	2.5E+1	KS92	St86
42 Mo	1.0E+1	IAEA94	IAEA94	90 Th	1.0E+2	KS92	Na88
43 Tc	2.0E+1	IAEA94	IAEA82	91 Pa	1.0E+1	NCRP96	NCRP96
44 Ru	1.0E+2	KS92	Na88	92 U	1.0E+1	IAEA94	IAEA82
45 Rh	1.0E+1	IAEA94	IAEA94	93 Np	2.1E+1	Sn94	Th94
46 Pd	1.0E+1	KS92	St86	94 Pu	3.0E+1	IAEA94	IAEA82
47 Ag	5.0E+0	IAEA94	IAEA82	95 Am	3.0E+1	IAEA94	IAEA82
48 Cd	2.0E+2	KS92	St86	96 Cm	3.0E+1	IAEA94	IAEA82
49 In	1.0E+4	NCRP96	NCRP96	98 Cf	2.5E+1	KS92	St86
50 Sn	3.0E+3	KS92	St86				

g.m. = geometric mean.

Appendix C – Necessary Parameters

Table C-4. Transfer Factors for Vegetation (pCi/kg Leafy Vegetation per pCi/kg Soil).

Z and Element	Recommended Value (Dry Weight)	Compiled in	Primary Reference	Z and Element	Recommended Value (Dry Weight)	Compiled in	Primary Reference
04 Be	1.0E-2	KS92	Ba84	52 Te	2.5E-2	KS92	Ba84
06 C	7.0E-1	KS92		53 I	4.0E-2	Sn94	Sn94
07 N	5.5E-2	KS92	Ba84	55 Cs	4.6E-1	IAEA94	Fr82
09 F	6.0E-2	KS92	Ba84	56 Ba	1.5E-1	KS92	Ba84
11 Na	3.0E-1	IAEA94	Ng82b	57 La	5.2E-3	IAEA94	Fr89
12 Mg	1.0E+0	KS92	Ba84	58 Ce	2.0E-2	Ng82b	Ng82b
14 Si	3.5E-1	KS92	Ba84	59 Pr	2.0E-2	Based on Ce	Ng82b
15 P	3.5E+0	KS92	Ba84	60 Nd	2.0E-2	Based on Ce	Ng82b
16 S	1.5E+0	KS92	Ba84	61 Pm	2.0E-2	Based on Ce	Ng82b
17 Cl	7.0E+1	KS92	Ba84	62 Sm	2.0E-2	Based on Ce	Ng82b
19 K	1.0E+0	KS92	Ba84	63 Eu	2.0E-2	Based on Ce	Ng82b
20 Ca	3.5E+0	KS92	Ba84	64 Gd	2.0E-2	Based on Ce	Ng82b
21 Sc	6.0E-3	KS92	Ba84	65 Tb	2.0E-2	Based on Ce	Ng82b
24 Cr	7.5E-3	KS92	Ba84	66 Dy	2.0E-2	Based on Ce	Ng82b
25 Mn	7.0E-1	IAEA94	Fr89	67 Ho	2.0E-2	Based on Ce	Ng82b
26 Fe	5.0E-2	CT83	CT83	68 Er	2.0E-2	Based on Ce	Ng82b
27 Co	2.3E-1	IAEA94	Fr89	72 Hf	1.0E-3	Based on Zr	Ng82b
28 Ni	2.8E-1	KS92	IUR89	73 Ta	2.5E-2	Based on Nb	CT83
29 Cu	4.0E-1	KS92	Ba84	74 W	3.0E+0	Na88	NCRP86
30 Zn	1.3E+0	IAEA94	Fr89	75 Re	1.5E+0	KS92	Ba84
31 Ga	4.0E-3	Based on In	Ba84	76 Os	1.5E-2	KS92	Ba84
33 As	4.0E-2	KS92	Ba84	77 Ir	5.5E-2	KS92	Ba84
34 Se	2.5E-1	CT83	CT83	79 Au	1.0E-2	g.m.	g.m.
35 Br	1.5E+0	KS92	Fu78	80 Hg	8.5E-1	g.m.	g.m.
37 Rb	9.0E-1	IAEA94	Ng82b	81 Tl	4.0E-3	Based on In	Fu78
38 Sr	3.0E+0	IAEA94	Fr82	82 Pb	1.0E-2	IAEA94	Fr89
39 Y	1.0E-2	IAEA94	Ng82b	83 Bi	5.0E-1	IAEA94	IAEA82
40 Zr	1.0E-3	IAEA94	Ng82b	84 Po	1.2E-3	IAEA94	Ho91
41 Nb	2.5E-2	CT83	CT83	88 Ra	4.9E-2	IAEA94	Fr89
42 Mo	8.0E-1	IAEA94	Ng82b	89 Ac	4.7E-4	Based on Am	Fr82
43 Tc	2.1E+2	IAEA94	Fr89	90 Th	1.8E-3	IAEA94	Fr89
44 Ru	4.0E-2	IAEA94	Ng82b	91 Pa	4.7E-4	Based on Am	Fr82
45 Rh	1.5E-1	KS92	Ba84	92 U	8.3E-3	IAEA94	Fr89
46 Pd	1.5E-1	KS92	Ba84	93 Np	3.2E-2	IAEA94	Fr82
47 Ag	2.7E-4	IAEA94	Fr89	94 Pu	6.0E-5	IAEA94	Fr82
48 Cd	5.5E-1	KS92	Ba84	95 Am	4.7E-4	IAEA94	Fr82
49 In	4.0E-3	KS92	Fu78	96 Cm	7.7E-4	IAEA94	Fr82
50 Sn	3.0E-2	KS92	Fu78	98 Cf	4.7E-4	Based on Am	Fr82
51 Sb	1.3E-4	KS92	IUR89				

g.m. = geometric mean.

Appendix C – Necessary Parameters

Table C-5. Transfer Factors for Milk (pCi/L Milk per pCi/d Intake).

Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference	Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference
01 H	1.5E-2	IAEA94	Va83	52 Te	4.5E-4	IAEA94	Jo88
04 Be	9.0E-7	KS92	Ng77	53 I	9.0E-3	Sn94	Sn94
07 N	2.5E-2	KS92	Ng77	55 Cs	7.9E-3	IAEA94	Co90
09 F	1.0E-3	KS92	Ng77	56 Ba	4.8E-4	IAEA94	Jo88
11 Na	1.6E-2	IAEA94	IAEA94	57 La	2.0E-5	KS92	Ng77
12 Mg	3.9E-3	IAEA94	Ng82a	58 Ce	3.0E-5	IAEA94	CEC87
14 Si	2.0E-5	KS92	Ng77	59 Pr	3.0E-5	Based on Ce	CEC87
15 P	1.6E-2	IAEA94	Ng82a	60 Nd	3.0E-5	Based on Ce	CEC87
16 S	1.6E-2	IAEA94	Ng82a	61 Pm	3.0E-5	Based on Ce	CEC87
17 Cl	1.7E-2	IAEA94	Bi89	62 Sm	3.0E-5	Based on Ce	CEC87
19 K	7.2E-3	IAEA94	Ng82a	63 Eu	3.0E-5	Based on Ce	CEC87
20 Ca	3.0E-3	IAEA94	CT83	64 Gd	3.0E-5	Based on Ce	CEC87
21 Sc	5.0E-6	KS92	Ng77	65 Tb	3.0E-5	Based on Ce	CEC87
24 Cr	1.0E-5	IAEA94	Va84	66 Dy	3.0E-5	Based on Ce	CEC87
25 Mn	3.0E-5	IAEA94	Va84	67 Ho	3.0E-5	Based on Ce	CEC87
26 Fe	3.0E-5	IAEA94	Va84	68 Er	3.0E-5	Based on Ce	CEC87
27 Co	3.0E-4	IAEA94	Ba84	72 Hf	5.5E-7	Based on Zr	Jo88
28 Ni	1.6E-2	IAEA94	Cr90	73 Ta	4.1E-7	Based on Nb	Jo88
29 Cu	2.0E-3	Na88	IAEA87	74 W	3.0E-4	KS92	Ng77
30 Zn	1.0E-2	KS92	Ng77	75 Re	1.5E-3	KS92	Ng77
31 Ga	5.0E-5	KS92	Ng77	76 Os	5.0E-3	KS92	Ng77
33 As	6.0E-5	KS92	Ng77	77 Ir	2.0E-6	KS92	Ng77
34 Se	4.0E-3	KS92	Ng77	79 Au	5.5E-6	KS92	Ng77
35 Br	2.0E-2	KS92	Ng77	80 Hg	4.7E-4	IAEA94	Ng82a
37 Rb	1.2E-2	IAEA94	Ng82a	81 Tl	2.0E-3	Na88	Na88
38 Sr	2.8E-3	IAEA94	Co90	82 Pb	2.6E-4	KS92	Ng77
39 Y	2.0E-5	KS92	Ng77	83 Bi	5.0E-4	KS92	Ng77
40 Zr	5.5E-7	IAEA94	Jo88	84 Po	3.4E-4	IAEA94	Ng82a
41 Nb	4.1E-7	IAEA94	Jo88	88 Ra	1.3E-3	IAEA94	MB90
42 Mo	1.7E-3	IAEA94	Jo88	89 Ac	2.0E-5	KS92	Ng77
43 Tc	1.4E-4	IAEA94	Jo88	90 Th	5.0E-6	KS92	Ng77
44 Ru	3.3E-6	IAEA94	Co90	91 Pa	5.0E-6	KS92	Ng77
45 Rh	1.0E-2	KS92	Ng77	92 U	4.0E-4	IAEA94	MB90
46 Pd	1.0E-2	KS92	Ng77	93 Np	5.0E-6	IAEA94	Ng82a
47 Ag	5.0E-5	IAEA94	CEC87	94 Pu	1.1E-6	IAEA94	Co90
48 Cd	1.0E-3	KS92	Ng77	95 Am	1.5E-6	IAEA94	Co90
49 In	2.0E-4	Na88	NCRP86	96 Cm	2.0E-5	KS92	Ng77
50 Sn	1.0E-3	Na88	NCRP86	98 Cf	1.5E-6	Based on Am	Co90
51 Sb	2.5E-5	IAEA94	Va82				

g.m. = geometric mean.

Appendix C – Necessary Parameters

Table C-6. Transfer Factors for Birds (pCi/kg Muscle per pCi/d Intake).

Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference	Z and Element	Recommended Value (Wet Weight)	Compiled in	Primary Reference
04 Be	4.0E-1	KS92	Na88	52 Te	6.0E-1	IAEA94	En88a
07 N	9.8E-2	g.m.	g.m.	53 I	5.0E-2	Sn94	Sn94
09 F	1.4E-2	g.m.	g.m.	55 Cs	3.0E+0	Vo93	Vo93
11 Na	1.0E-2	KS92	Na88	56 Ba	9.0E-3	IAEA94	En88a
12 Mg	3.0E-2	KS92	KS92	57 La	1.0E-1	IAEA94	Ng82a
14 Si	8.0E-1	Based on As	Na88	58 Ce	2.0E-3	IAEA94	Ng82a
15 P	1.9E-1	KS92	Na88	59 Pr	2.0E-3	Based on Ce	Ng82a
16 S	2.3E+0	g.m.	g.m.	60 Nd	2.0E-3	Based on Ce	Ng82a
17 Cl	3.0E-2	KS92	Na88	61 Pm	2.0E-3	Based on Ce	Ng82a
19 K	4.0E-1	KS92	KS92	62 Sm	2.0E-3	Based on Ce	Ng82a
20 Ca	4.0E-2	IAEA94	Ng82a	63 Eu	2.0E-3	Based on Ce	Ng82a
21 Sc	4.0E-3	KS92	Na88	64 Gd	2.0E-3	Based on Ce	Ng82a
24 Cr	2.0E-1	KS92	KS92	65 Tb	2.0E-3	Based on Ce	Ng82a
25 Mn	5.0E-2	IAEA94	Ng82a	66 Dy	2.0E-3	Based on Ce	Ng82a
26 Fe	1.0E+0	IAEA94	Ng82a	67 Ho	2.0E-3	Based on Ce	Ng82a
27 Co	2.0E+0	IAEA94	Ng82a	68 Er	2.0E-3	Based on Ce	Ng82a
28 Ni	1.0E-3	KS92	Na88	72 Hf	6.0E-5	based on Zr	En88a
29 Cu	5.0E-1	IAEA94	Ng82a	73 Ta	3.0E-4	Based on Nb	En88a
30 Zn	7.0E+0	IAEA94	Ng82a	74 W	2.0E-1	Based on Mo	IAEA94
31 Ga	8.0E-1	Based on As	Na88	75 Re	4.0E-2	KS92	Ba84
33 As	8.3E-1	KS92	Na88	76 Os	8.4E-2	g.m.	g.m.
34 Se	9.0E+0	IAEA94	Ng82a	77 Ir	2.0E+0	Based on Co	Ng82a
35 Br	4.0E-3	KS92	Na88	79 Au	1.0E+0	g.m.	g.m.
37 Rb	2.0E+0	KS92	Na88	80 Hg	3.0E-2	IAEA94	Ng82a
38 Sr	8.0E-2	IAEA94	Co90	81 Tl	8.0E-1	Based on In	Na88
39 Y	1.0E-2	IAEA94	Ng82a	82 Pb	8.0E-1	Based on As	Na88
40 Zr	6.0E-5	IAEA94	En88a	83 Bi	9.8E-2	g.m.	g.m.
41 Nb	3.0E-4	IAEA94	En88a	84 Po	2.3E+0	g.m.	g.m.
42 Mo	1.8E-1	En88a	En88a	88 Ra	3.0E-2	KS92	KS92
43 Tc	3.0E-2	IAEA94	En88b	89 Ac	6.0E-3	Based on Am	Co90
44 Ru	7.0E-3	Na88	Ng82a	90 Th	6.0E-3	Based on Am	Co90
45 Rh	2.0E+0	Based on Co	Ng82a	91 Pa	6.0E-3	Based on Am	Co90
46 Pd	3.0E-4	KS92	Na88	92 U	1.0E+0	IAEA94	Ng82a
47 Ag	2.0E+0	IAEA94	CEC87	93 Np	6.0E-3	Based on Am	Co90
48 Cd	8.0E-1	IAEA94	Ng82a	94 Pu	3.0E-3	IAEA94	Co90
49 In	8.0E-1	Based on As	Na88	95 Am	6.0E-3	IAEA94	Co90
50 Sn	8.0E-1	Based on As	Na88	96 Cm	6.0E-3	Based on Am	Co90
51 Sb	6.0E-3	Na88	Na88	98 Cf	6.0E-3	Based on Am	Co90

g.m. = geometric mean.

Appendix C – Necessary Parameters

Table C-7. Sorption Coefficients, K_d (ml/g).

Z and Element	Recommended Value	Compiled in	Primary Reference	Z and Element	Recommended Value	Compiled in	Primary Reference
01 H (H ₂ O)	0	Ki98	see Ki98	52 Te	150	IAEA94	see IAEA94
04 Be	8000	IAEA94	see IAEA94	53 I	0	Ki98	see Ki98
06 C	0.5	Ki98	see Ki98	55 Cs	540	Ki98	see Ki98
07 N	0	St89	see St89	56 Ba			
09 F	0	St89	see St89	57 La	100	= cerium	
11 Na	0.2	St89	see St89	58 Ce	100	Ki98	see Ki98
12 Mg	1400	St89	see St89	59 Pr			
14 Si	33	IAEA94	see IAEA94	60 Nd			
15 P	9	IAEA94	see IAEA94	61 Pm			
16 S	0	St89	see St89.	62 Sm	240	IAEA94	see IAEA94
17 Cl	0	St89	see St89	63 Eu	100	Ki98	see Ki98
19 K	0.8	St89	see St89	64 Gd			
20 Ca	9	IAEA94	see IAEA94	65 Tb			
21 Sc				66 Dy			
24 Cr	360	St89	see St89	67 Ho			
25 Mn	49	IAEA94	see IAEA94	68 Er			
26 Fe	15	St89	see St89	72 Hf			
27 Co	1200	Ki98	see Ki98	73 Ta			
28 Ni	50	Ki98	see Ki98	74 W			
29 Cu	336	St89	see St89	75 Re			
30 Zn	200	IAEA94	see IAEA94	76 Os			
31 Ga				77 Ir			
33 As	20	St89	see St89	79 Au			
34 Se	0	Ki98	see Ki98	80 Hg	580	St89	see St89
35 Br				81 Tl			
37 Rb	55	IAEA94	see IAEA94	82 Pb	2000	Ki98	see Ki98
38 Sr	8	Ki98	see Ki98	83 Bi	2000	= Lead	
39 Y				84 Po	150	Ki98	see Ki98
40 Zr	40	Ki98	see Ki98	88 Ra	8	Ki98	see Ki98
41 Nb		Ki98	see Ki98	89 Ac	100	Ki98	see Ki98
42 Mo	7.4	IAEA94	see IAEA94	90 Th	40	Ki98	see Ki98
43 Tc	0	St89	see St89	91 Pa	10	Ki98	see Ki98
44 Ru	10	Ki98	see Ki98	92 U	0.6	Ki98	see Ki98
45 Rh				93 Np	10	Ki98	see Ki98
46 Pd	55	IAEA94	see IAEA94	94 Pu	80	Ki98	see Ki98
47 Ag	90	IAEA94	see IAEA94	95 Am	100	Ki98	see Ki98
48 Cd	74	IAEA94	see IAEA94	96 Cm	100	Ki98	see Ki98
49 In				98 Cf			
50 Sn	50	Ki98	see Ki98				
51 Sb	45	IAEA94	see IAEA94				

g.m. = geometric mean.

Appendix C – Necessary Parameters

REFERENCES

- Coughtrey, P. C. and M. C. Thorne, 1983, "Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems," *A Critical Review of Data*, Vols. 1-6, A.A. Balkema, Rotterdam.
- IAEA, 1994, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*, Tech. Rep. Series No. 364, International Union of Radioecologists, International Atomic Energy Agency, Vienna, Austria.
- Kennedy, W. E., Jr., and D. L. Strenge, 1992, *Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*, NUREG/CR-5512, Pacific Northwest Laboratory, Richland, Washington.
- Kincaid, C. T., et al., 1998, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site*, PNNL-11800, Pacific Northwest Laboratory, Richland, Washington.
- Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell, 1988, *GENII - The Hanford Environmental Radiation Dosimetry Software System*, PNL-6584, Pacific Northwest Laboratory, Richland, Washington.
- NCRP, 1996, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water and Ground*, NCRP Report No. 123, Vol. I., National Council on Ionizing Radiation and Protection, Bethesda, Maryland.
- Strenge, D.L. and S.R. Peterson, 1989, *Chemical Data Bases for the Multimedia Environmental Pollutant Assessment System (MEPAS): Version 1*, PNL-7145, Pacific Northwest Laboratory, Richland, Washington.
- USDA, 1983, *Food Consumption: Households in the United States, Seasons and Years 1977-1978*, National Food Consumption Survey 1977-1978, Report No. H-6, Human Nutrition Information Service, Consumer Nutrition Division. U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D.C.

Appendix C – Necessary Parameters

BIBLIOGRAPHY

- Baes, C. F., R. D. Sharp, A. L. Sjoreen, and R. W. Shor, 1984, *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*, ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Bilo, M., 1991, Untersuchungen zum Transfer des durch den Reaktorunfall von Tschernobyl abgelagerten Radiocasiums vom Boden in die Pflanze, Thesis, Personal Communication w/ Zezina, N. Tubingen.
- Bishop, G. P., C. J. Beetham, and Y. S. Cuff, 1989, *Review of Literature for Chlorine Technetium, Iodine and Neptunium*, Nirex Radioactive Waste Disposal Safety Studies, NSS/R193, UK Nirex Ltd., Harwell, England.
- Bruland, W., et al., 1979, "Transfer of Organically Bound Radionuclides through Food Chains to Man, Model--Example with Radiocobalt and Vitamin B12," In *Biological Implications of Radionuclides Released from Nuclear Industries I*, Vol. 2, Proceedings of a Symposium, IAEA, Vienna.
- CEC, 1987, *Radionuclide Transfer Factors of Animal Feedingstuffs and Animal Products*, CEC Doc. 7682/87, Commission of the European Communities, Luxembourg.
- Coughtrey, P. J., 1990, *Radioactivity Transfer to Animal Products*, EUR 12608 EN, Commission on European Communities, Luxembourg.
- Cramp, T. J., Y. S. Cuff, A. Davis, and J. E. Morgan, 1990, *Review of Data for Uranium, Nickel, and Cobalt*, 2150-RI, Associated Nuclear Services, Ltd., Epsom, England.
- Ennis, M. E. Jr., J. E. Johnson, G. M. Ward, and G. M. Voigt, 1988, "A Specific Activity Effect in the Metabolism of Tc," *Health Physics*, 54:157-160.
- Ennis, M. E., Jr., G. M. Ward, J. E. Johnson, and K. N. Boamah, 1988, "Transfer Coefficients of Selected Radionuclides to Animal Products II. Hen Eggs and Meat," *Health Physics*, 54:167-170.
- Frissel, M. J., 1992, "An Update of the Recommended Soil-to-Plant Transfer Factors," *Eighth Report of the IUR Working Group on Soil-to-Plant Transfer Factors*, IUR, Balen, Belgium.
- Frissel, M. J. and K. E. van Bergeijk, 1989, "Mean Transfer Values Derived by Simple Statistical Regression Analysis," *Sixth Report of IUR Working Group on Soil-to-Plant Transfer Factors*, RIVM, Bilthoven, Netherlands.
- Furr, A. K., T. F. Parkinson, C. L. Heffron, J. T. Reid, W. M. Haschek, W. H. Gutenmann, C. A. Backe, L. E. St. John, Jr., and D. J. Lisk, 1979, "Elemental Content of Tissues and Excreta of Lambs, Goats and Kids Fed White Sweet Clover Growing on Fly Ash," *Journal of Agric, Food Chem.*, 26(4):847-851.

Appendix C – Necessary Parameters

- Holzer, F., and K. Wichterey, 1991, *Ermittlung von Transferfaktoren für den Übergang natürlicher Radionuklide vom Boden in die Pflanzen im Uranerzbergbauegebiet*, Jahresbericht des Bundesamtes für Strahlenschutz, 146.
- IAEA, 1982, *Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases, Exposures of Critical Groups*, Safety Series No. 57, International Atomic Energy Agency, Vienna, Austria.
- IAEA, 1987, *Draft Working Document: Handbook of Parameter Values for the Prediction of Radionuclide Transfer in the Terrestrial and Freshwater Environments*, International Atomic Energy Agency, Vienna, Austria.
- International Union of Radioecologists, 1989, *Sixth Report of the Working Group on Soil-to-Plant Transfer Factors*, RIVM, Bilthoven, The Netherlands.
- Johnson, J. E., G. M. Ward, M. E. Ennis, Jr., and K. N. Boamah, 1988, “Transfer Coefficients of Selected Radionuclides to Animal Products, 1. Comparison of Milk and Meat from Dairy Cows and Goats,” *Health Physics*, 54:161-166.
- Lawson, G. and G. M. Smith, 1985, *BIOS: A Model to Predict Radionuclide Transfer and Doses to Man Following Releases for Geological Repositories for Radioactive Wastes*, National Radiation Protection Board, NRPB-R169, Chilton, England.
- Morgan, J. E. and C. J. Beetham, 1990, *Review of Literature for Radium, Protactinium, Tin and Carbon*, Nirex Radioactive Waste Disposal Safety Studies, UK Nirex LT Harwell, England.
- NCRP, 1986, *Screening Techniques for Determining Compliance with Environmental Standards, Releases of Radionuclides to the Atmosphere*, NCRP Commentary No. 3, National Council on Radiation Protection and Measurements, Bethesda, Maryland.
- Ng, Y. C., C. A. Burton, S. E. Thompson, R. K. Tandy, H. K. Kretner, and M. W. Pratt, 1968, “Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices,” *In Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere*, UCRL-50163, Lawrence Radiation Laboratory, Pt. IV, Livermore, California.
- Ng, Y. C., C. S. Colsher, D. J. Quinn, and S. E. Thompson, 1977, *Transfer Coefficients for the Prediction of the Dose to Man via the Forage-Cow-Milk Pathway from Radionuclides Released to the Biosphere*, UCRL-51939, Lawrence Livermore National Lab, California.
- Ng, Y. C., C. S. Colsher, and S. E. Thompson, 1979, “Transfer Coefficients for Assessing the Terrestrial Food Chains—Their Derivation and Limitations,” *In Radioaktivität und Umwelt*, H. J. Kellermann, ed., Vol. I, pp. 455-481, Proceedings of the 12th Annual Conference of the Fachverband für Strahlenschutz, Norderney, West Germany, 2-6 October, 1978.

Appendix C – Necessary Parameters

- Ng, Y. C., C. S. Colsher and S. E. Thompson, 1982a, *Transfer Coefficients for Assessing the Dose from Radionuclides in Meat and Eggs*, USNRC, NUREG/CR-2976, UCID-19464, Lawrence Livermore National Laboratory, California.
- Ng, Y. C., C. S. Colsher, and S. E. Thompson, 1982b, *Soil-to-Plant Concentration Factors for Radiological Assessments*, NUREG/CR-2975 UCID19463, Lawrence Livermore National Laboratory, California.
- Ng, Y. C., 1982c, “A Review of Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products,” *Nuclear Safety*, 23:57-71.
- Snyder, S. F., W. T. Farris, B. A. Napier, T. A. Ikenberry, and R. O. Gilbert, 1994, *Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC)*, PNWD-2033 HEDR, Rev. 1, Pacific Northwest Laboratory, Richland, Washington.
- Streng, D. L., R. A. Peloquin, and G. Whelan, 1986, *LADTAP II - Technical Reference and User Guide*, NUREG/CR-4013 (PNL-5270), U.S. Nuclear Regulatory Commission, Washington, D.C.
- Thiede, M. E., D. J. Bates, E. I. Mart, and R. W. Hanf, 1994, *A Guide to Environmental Monitoring Data, 1945-1972*, PNWD-2226 HEDR, Pacific Northwest Laboratory, Richland, Washington.
- Van Bruwaene, R., G. B. Gerber, R. Kirchmann, and J. Colard, 1982, “Metabolism of Antimony-124 in Lactating Dairy Cows” *Health Physics*, 43:733-738.
- Van Bruwaene, R., G. B. Gerber, R. Kirchmann, J. Colard, and J. Van Kerkom, 1984, “Metabolism of ⁵¹Cr, ⁵⁴Mn, ⁵⁹Fe, and ⁶⁰Co in Lactating Dairy Cows,” *Health Physics*, 46:1069-1082.
- Van Den Hoek, J., M. H. J. Ten Have, and G. B. Gerber, 1983, “The Metabolism of Tritium and Water in the Lactating Dairy Cow” *Health Physics*, 44:127-133.
- Voight, G., H. Muller, H. G. Paretzke, T. Bauer, and G. Rohrmoser, 1993, “Cs-137 Transfer after Chernobyl from Fodder into Chicken Meat and Eggs,” *Health Physics*, 65:141-146.

APPENDIX D

**NATIVE AMERICAN SCENARIO RADIONUCLIDE
AND CHEMICAL SPREADSHEETS**

APPENDIX D

NATIVE AMERICAN SCENARIO RADIONUCLIDE AND CHEMICAL SPREADSHEETS

Sample pages for one radionuclide and one chemical are shown. Each radionuclide and each chemical in the Candidate Set has its own page.

Table D-1. Native American Subsistence Lifestyle Scenario – Radionuclides. (3 Pages)

Medium	Route	Intake Rate	Units	EF Frequency (d/yr)	ED Duration (yr)	Parameter Name
Scenario Parameters						
Soil	Ingestion	2.00E-04	kg/d	180	70	IR_soil
	External	2.40E+01	hr/d	180	70	ET_soil
	Dermal	1.00E+00	mg/cm2-d	180	70	AF_soil
	Inhalation	3.00E+01	m3/d	180	70	IR air
Air	Inhalation	3.00E+01	m3/d	180	70	IR air
Seep/spring	Ingestion	3.00E+00	L/d	180	70	IR_river
	Inhalation	1.50E+01	m3/d	180	70	
	Sweat Lodge	1.00E+00	hr/d	365	70	ET_seep inh.
	Dermal	1.00E+00	hr/d	180	70	ET_seep dermal
Surface water	Ingestion	3.00E+00	L/d	365	70	IR_river
	Inhalation	1.50E+01	m3/d	70	70	
	Sweat Lodge	1.00E+00	hr/d	365	70	ET_river inh.
	Dermal	2.60E+00	hr/d	70	70	ET_river dermal
Biota	Fish	5.40E-01	kg/d	365	70	IR_fish
	Fruit/Veg.	6.60E-01	kg/d	365	70	IR_leafy + IR_root
	Meat	2.04E-01	kg/d	365	70	IR_meat
	Milk	6.00E-01	L/d	365	70	IR_milk
	Birds	1.80E-02	kg/d	365	70	IR_birds
	Waterfowl	7.00E-02	kg/d	365	70	IR_ducks
Sediment	Ingestion	2.00E-04	kg/d	270	70	IR_sed
	Dermal	1.00E+00	mg/cm2-d	270	70	AF_sed
	External	1.20E+01	hr/d	270	70	ET_sed
Others	pots	3.00E+00	hr/d	365	70	ET_items
	wooden items	1.00E+00	hr/d	365	70	ET_other

Appendix D – Native American Scenario Radionuclide and Chemical Spreadsheets

Table D-1. Native American Subsistence Lifestyle Scenario – Radionuclides. (3 Pages)

Parameter	Value	Units
Some Assumed and Derived Parameters for Testing		
C_river	0	pCi/L
C_seep	1	pCi/L
C_fish	0	pCi/g
C_sediment	0	pCi/g
C_soil	0	pCi/g
C_leafys	0	pCi/g
C_roots	0	pCi/g
C_meat	0	pCi/g
C_milk	0	pCi/g
C_bird	0	pCi/g
C_eggs	0	pCi/g
C_items	0	(pots made of clay from by the river = C_soil)
C_other	0	(wooden objects grown by river = vegetation)
Other Necessary Values Which are Specific for each Contaminant (Example Shown for Ac227)		
Kd	0.45	L/g - Note: includes 1000 ml/L
Bioaccumulation	25	pCi/kg per pCi/L
Con.Ratio	0.0005	pCi/kg plant per pCi/kg soil
CR_meat	0.0004	d/kg
CR_milk	0.00002	d/L
CR_bird	0.006	d/kg
CR_eggs	0.004	d/kg
DF1 - soil	5.512E-10	rem/hr per pCi/g
DF2 - swim	1.584E-13	rem/hr per pCi/L
DF3 - boat	7.92E-14	assumed 1/2 of A48
DF4 - items	5.51E-12	assumed 1% of infinite plane
DF5 - inhalation	6.70E-03	rem/pCi
DF6 - ingestion	0.000014	rem/pCi
ML	5.00E-05	g/m3
VF	0.1	L/m3
RF_soil	8.00E-01	soil shielding factor
CF_Other	0.0005	g/m3

Appendix D – Native American Scenario Radionuclide and Chemical Spreadsheets

Table D-1. Native American Subsistence Lifestyle Scenario – Radionuclides. (3 Pages)

External Exposure to Radionuclides	
$\text{Dose}_{\text{ext}} = ((C_{\text{soil}} \times \text{ET}_{\text{soil}} \times \text{RF}_{\text{soil}} \times \text{EF}_{\text{soil}} + C_{\text{sed}} \times \text{ET}_{\text{sed}} \times \text{EF}_{\text{sed}}) \times \text{DF1} + C_{\text{river}} \times \text{ET}_{\text{swim}} \times \text{EF}_{\text{swim}} \times \text{DF2} + C_{\text{river}} \times \text{ET}_{\text{boat}} \times \text{EF}_{\text{boat}} \times \text{DF3} + C_{\text{items}} \times \text{ET}_{\text{items}} \times \text{EF}_{\text{items}} \times \text{DF4}) \times \text{ED}$	
Dose_ext =	0.00E+00 rem/lifetime
dirt =	0. rem/lifetime
water=	0. rem/lifetime
items=	0.00E+00 rem/lifetime
Inhalation of Radionuclides	
$\text{Dose}_{\text{inh}} = (C_{\text{soil}} \times \text{ML} \times \text{ET}_{\text{soil}} \times \text{EF}_{\text{soil}} + C_{\text{seep}} \times \text{VF} \times \text{ET}_{\text{seep}} \times \text{EF}_{\text{seep}} + C_{\text{river}} \times \text{VF} \times \text{ET}_{\text{river}} \times \text{EF}_{\text{river}} + C_{\text{other}} \times \text{CF}_{\text{other}} \times \text{ET}_{\text{other}} \times \text{EF}_{\text{other}}) \times \text{ED} \times \text{IR} \times \text{DF5} / \text{HRD}$	
Dose_inh=	2.14E+01 rem/lifetime
soil=	0.00E+00
seep=	2.14E+01
river=	0.00E+00
other=	0.00E+00
Ingestion of Radionuclides	
$\text{Dose}_{\text{ing}} = (C_{\text{soil}} \times \text{IR}_{\text{soil}} + C_{\text{sed}} \times \text{IR}_{\text{sed}} + C_{\text{river}} \times \text{IR}_{\text{river}} + C_{\text{seep}} \times \text{IR}_{\text{seep}} + C_{\text{fish}} \times \text{IR}_{\text{fish}} + C_{\text{leafy}} \times \text{IR}_{\text{leafy}} + C_{\text{root}} \times \text{IR}_{\text{root}} + C_{\text{meat}} \times \text{IR}_{\text{meat}} + C_{\text{milk}} \times \text{IR}_{\text{milk}} + C_{\text{eggs}} \times \text{IR}_{\text{eggs}} + C_{\text{bird}} \times \text{IR}_{\text{bird}}) \times \text{EF} \times \text{ED} \times \text{CF} \times \text{DF6}$	
Dose_ing =	1.07E+00 rem/lifetime
soil =	0.
sediment =	0.
river=	0.
seep=	1.0731
fish=	0.
veg. =	0.
meat=	0.
milk=	0.
eggs=	0.00E+00
birds=	0.00E+00
Total Dose	
	2.25E+01 rem/lifetime

Appendix D – Native American Scenario Radionuclide and Chemical Spreadsheets

Table D-2. Native American Subsistence Lifestyle Scenario – Chemicals. (3 Pages)

Medium	Route	Intake Rate	Units	EF Frequency (d/yr)	ED Duration (yr)	Related Parameters	Value	Units
Scenario Parameters								
Soil	Ingestion	0.0002	kg/d	180	70	SA_soil	5000	cm2
	External	24	hr/d	180	70			
	Dermal	1	mg/cm2-d	180	70			
	Inhalation	30	m3/d	180	70			
Air	Inhalation	30	m3/d	180	70			
Seep/spring	Ingestion	3	L/d	180	70	SA_seep	20000	cm2
	Inhalation	15	m3/d	180	70			
	Sweat Lodge	1	hr/d	365	70			
	Dermal	1	hr/d	180	70			
Surface water	Ingestion	3	L/d	365	70	SA_river	20000	cm2
	Inhalation	15	m3/d	70	70			
	Sweat Lodge	1	hr/d	365	70			
	Dermal	2.6	hr/d	70	70			
Biota	Fish	0.54	kg/d	365	70			
	Fruit/Veg.	0.66	kg/d	365	70			
	Meat	0.204	kg/d	365	70			
	Milk	0.6	L/d	365	70			
	Birds	0.018	kg/d	365	70			
	Waterfowl	0.07	kg/d	365	70			
Sediment	Ingestion	0.0002	kg/d	270	70	SA_sed	5000	cm2
	Dermal	1	mg/cm2-d	270	70			
	External	12	hr/d	270	70			
Others	pots	3	hr/d	365	70	SA_other	1000	cm2
	wooden items	1	hr/d	365	70			

Appendix D – Native American Scenario Radionuclide and Chemical Spreadsheets

Table D-2. Native American Subsistence Lifestyle Scenario – Chemicals. (3 Pages)

Parameter	Value	Units
Some Assumed and Derived Parameters for Testing		
C_river	1	mg/L
C_seep	0	mg/L
C_fish	10	mg/kg
C_sediment	35.3	mg/kg
C_soil	35.3	mg/kg
C_leafys	0.1412	mg/kg
C_roots	0.1412	mg/kg
C_meat	0.002118	mg/kg
C_milk	0.0002824	mg/kg
C_bird	0	mg/kg
C_eggs	0	mg/kg
C_items	35.3	(pots made of clay from by the river = C_soil)
C_other	0.1412	(wooden objects grown by river = vegetation)
Other Necessary Values Which are Specific for each Contaminant (Example Shown for Aluminum)		
Kd	35.3	L/kg
Bioaccumulation	10	mg/kg per mg/L
Con.Ratio	0.004	mg/kg plant per mg/kg soil
CR_meat	0.0015	d/kg
CR_milk	2.00E-04	d/L
CR_bird	0	d/kg
CR_eggs	0	d/kg
ABS	0.001	
Kp	0.001	cm/hr
RfD Inh		
RfD Ingestion	0.004	
CFP Inhalation		
CPF Ingestion		
Other Necessary Values		
BW	70	kg
AF_soil	0.2	mg/cm2-d
AF_sed	0.2	mg/cm2-d
AF_other	0.1	mg/cm2/d
AT	25550	days
ML	5.00E-05	g/m3
VF	0.1	L/m3
CF_Other	0.0005	g/m3

Appendix D – Native American Scenario Radionuclide and Chemical Spreadsheets

Table D-2. Native American Subsistence Lifestyle Scenario – Chemicals. (3 Pages)

Dermal Exposure to Chemicals		
$\text{DAD} = (C_{\text{soil}} \times \text{AF}_{\text{soil}} \times \text{ABS} \times \text{SA}_{\text{soil}} \times \text{EF}_{\text{soil}} \times \text{CF1} + C_{\text{sed}} \times \text{AF}_{\text{sed}} \times \text{ABS} \times \text{SA}_{\text{sed}} \times \text{EF}_{\text{sed}} \times \text{CF1} + C_{\text{other}} \times \text{AF}_{\text{other}} \times \text{ABS} \times \text{SA}_{\text{other}} \times \text{ET}_{\text{other}} \times \text{EF}_{\text{other}} \times \text{CF2} + C_{\text{seep}} \times \text{Kp} \times \text{SA}_{\text{seep}} \times \text{ET}_{\text{seep}} \times \text{EF}_{\text{seep}} \times \text{CF3} + C_{\text{river}} \times \text{Kp} \times \text{SA}_{\text{river}} \times \text{ET}_{\text{river}} \times \text{EF}_{\text{river}} \times \text{CF3}) \times \text{ED} / (\text{BW} \times \text{AT})$		
DAD =	0.00014281	mg/kg -day
dirt =	2.49E-07	mg/kg -day
sediment	9.67E-08	mg/kg -day
other	8.4E-12	mg/kg -day
seeps	0	mg/kg -day
river	0.000142	mg/kg -day
Inhalation of Chemicals		
$\text{INH} = (C_{\text{soil}} \times \text{ML} \times \text{ET}_{\text{soil}} \times \text{EF}_{\text{soil}} + C_{\text{seep}} \times \text{VF} \times \text{ET}_{\text{seep}} \times \text{EF}_{\text{seep}} + C_{\text{river}} \times \text{VF} \times \text{ET}_{\text{river}} \times \text{EF}_{\text{river}} + C_{\text{other}} \times \text{CF}_{\text{other}} \times \text{ET}_{\text{other}} \times \text{EF}_{\text{other}}) \times \text{ED} / (\text{BW} \times \text{AT} \times \text{HRD})$		
INH =	0.00216001	mg/kg-d
soil=	0.000373	mg/kg-d
seep=	0	mg/kg-d
river=	0.001786	mg/kg-d
other=	1.26E-06	mg/kg-d
Ingestion of Chemicals		
$\text{ING} = (C_{\text{soil}} \times \text{IR}_{\text{soil}} + C_{\text{sed}} \times \text{IR}_{\text{sed}} + C_{\text{seep}} \times \text{IR}_{\text{seep}} + C_{\text{fish}} \times \text{IR}_{\text{fish}} + C_{\text{leafy}} \times \text{IR}_{\text{leafy}} + C_{\text{root}} \times \text{IR}_{\text{root}} + C_{\text{meat}} \times \text{IR}_{\text{meat}} + C_{\text{milk}} \times \text{IR}_{\text{milk}} + C_{\text{eggs}} \times \text{IR}_{\text{eggs}} + C_{\text{bird}} \times \text{IR}_{\text{bird}}) \times \text{EF} \times \text{ED} / (\text{AT} \times \text{BW})$		
ING =	0.09971727	
soil =	4.97E-05	
sediment =	4.97E-05	
river=	0.021135	
seep=	0	
fish=	0.077143	
veg. =	0.001331	
meat=	6.17E-06	
milk=	2.42E-06	
eggs=		
birds=	0	
Total Intake		
Intake	0.10202	mg/kg-d
Total H.I.	25.50502	
Total Risk	0	

APPENDIX E

RADIOLOGICAL AND CHEMICAL PARAMETERS

Table E-1. Radionuclide Parameters. (2 Pages)

Radionuclides	Kd L/g	BCF Fish	Soil/Plant	TF Meat	TF Milk	TF Chicken	TF Egg	DF1 - Soil	DF2 - Swim	DF3 - Boat	DF4 - Items	DF5 - Inhalation	DF6 - Ingestion	GW Background (fCi/L)
Actinium 227	0.1	25	0.0005	0.0004	0.00002	0.006	0.004	5.51E-10	1.584E-13	7.92E-14	5.512E-12	0.0067	0.000014	27
Americium 241	0.1	30	0.0005	0.00004	1.5E-06	0.006	0.004	7.77E-08	2.563E-11	1.28E-11	7.774E-10	0.00052	0.0000045	1.91
Americium 242m	0.1	30	0.0005	0.00004	1.5E-06	0.006	0.004	7.2E-09	6.413E-13	3.21E-13	7.202E-11	0.00051	0.0000042	81
Cadmium 113m	0.074	200	0.55	0.0004	0.001	0.8	0.1	0	0	0	0	0.000000065	0.000000015	81
Carbon 14	0	50000	0.7	1	1	1	1	0	0	0	0	2.4E-11	2.1E-09	81
Cesium 135	0.54	2000	0.5	0.05	0.0079	3	0.4	0	0	0	0	4.5E-09	7.1E-09	81
Cesium 137	0.54	2000	0.5	0.05	0.0079	3	0.4	1.59E-06	7.238E-10	3.62E-10	1.589E-08	0.000000032	0.00000005	8.43
Chlorine 36	0	50	70	0.02	0.017	0.03	2.7	0	0	0	0	0.00000002	0.000000003	81
Cobalt 60	1.2	300	0.23	0.01	0.0003	2	0.1	5.9E-06	3.102E-09	1.55E-09	5.902E-08	0.00000015	0.000000026	3.41
Curium 243	0.1	30	0.0008	0.00004	0.00002	0.006	0.004	3.8E-07	1.573E-10	7.87E-11	3.796E-09	0.00035	0.0000029	27
Curium 244	0.1	30	0.0008	0.00004	0.00002	0.006	0.004	2.16E-09	1.177E-13	5.89E-14	2.155E-11	0.00027	0.0000023	27
Europium 152	0.1	30	0.02	0.00002	0.00003	0.002	0.00004	2.89E-06	1.408E-09	7.04E-10	2.886E-08	7.6E-10	1.9E-09	21.8
Europium 154	0.1	30	0.02	0.00002	0.00003	0.002	0.00004	3.15E-06	1.551E-09	7.76E-10	3.146E-08	0.00000026	9.1E-09	13.6
Iodine 129	0.0003	40	0.04	0.04	0.009	0.05	4.4	5.72E-08	0	0	5.72E-10	0.00000018	0.00000028	0.0939
Krypton 85	0	0	0	0	0	0	0	5.98E-09	2.673E-12	1.34E-12	5.98E-11	0	0	81
Lead 210	2	300	0.01	0.0004	0.00026	0.8	1	7.8E-09	1.848E-12	9.24E-13	7.8E-11	0.000013	0.0000051	27
Neptunium 237	0.01	21	0.03	0.001	0.000005	0.006	0.004	8.42E-08	6.105E-11	3.05E-11	8.424E-10	0.00049	0.0000039	27
Nickel 59	0.05	100	0.28	0.005	0.016	0.001	0.1	1.08E-09	5.324E-14	2.66E-14	1.082E-11	1.3E-09	2E-10	81
Nickel 63	0.05	100	0.28	0.005	0.016	0.001	0.1	0	0	0	0	0.000000003	5.4E-10	81
Palladium 107	0.055	10	0.15	0.004	0.01	0.0003	0.004	0	0	0	0	0.000000013	1.4E-10	81
Protactinium 231	0.01	10	0.0005	0.00004	0.000005	0.006	0.004	9.31E-08	3.674E-11	1.84E-11	9.308E-10	0.0013	0.000011	27
Plutonium 238	0.08	30	0.00006	0.00001	1.1E-06	0.003	0.0005	2.23E-09	1.232E-13	6.16E-14	2.231E-11	0.00046	0.0000038	0.221
Plutonium 239/240	0.08	30	0.00006	0.00001	1.1E-06	0.003	0.0005	1.04E-09	4.4E-14	2.2E-14	1.04E-11	0.00051	0.0000043	0.949
Plutonium 241	0.08	30	0.00006	0.00001	1.1E-06	0.003	0.0005	0	0	0	0	0.00001	0.000000086	27
Plutonium 242	0.08	30	0.00006	0.00001	1.1E-06	0.003	0.0005	1.47E-08	1.025E-13	5.13E-14	1.474E-10	0.00048	0.0000041	27
Radium 226	0.008	50	0.05	0.0009	0.0013	0.03	0.31	1.98E-08	8.404E-12	4.2E-12	1.976E-10	0.0000079	0.0000011	33.2
Radium 228	0.008	50	0.05	0.0009	0.0013	0.03	0.31	0	0	0	0	0.0000042	0.0000012	64.9
Samarium 151	0.24	30	0.02	0.00002	0.00003	0.002	0.00004	0	0	0	0	0.000000029	3.4E-10	81
Selenium 79	0	170	0.25	0.015	0.004	9	9	0	0	0	0	8.9E-09	8.3E-09	81
Strontium 90	0.008	60	3	0.008	0.0028	0.08	0.2	0	0	0	0	0.00000023	0.00000013	14.6

Table E-1. Radionuclide Parameters. (2 Pages)

Radionuclides	Kd L/g	BCF Fish	Soil/Plant	TF Meat	TF Milk	TF Chicken	TF Egg	DF1 - Soil	DF2 - Swim	DF3 - Boat	DF4 - Items	DF5 - Inhalation	DF6 - Ingestion	GW Background (fCi/L)
Technetium 99	0	20	210	0.0001	0.00014	0.03	3	0	0	0	0	7.5E-09	1.3E-09	81
Tellurium 123	0.15	400	0.025	0.007	0.00045	0.6	5	1.85E-08	4.301E-12	2.15E-12	1.849E-10	0.000000011	4.1E-09	81
Thorium 229	0.04	100	0.002	0.00004	0.000005	0.006	0.004	2.73E-07	1.092E-10	5.46E-11	2.73E-09	0.002	0.0000035	27
Thorium 230	0.04	100	0.002	0.00004	0.000005	0.006	0.004	2.36E-09	5.104E-13	2.55E-13	2.358E-11	0.00032	0.0000053	27
Thorium 232	0.04	100	0.002	0.00004	0.000005	0.006	0.004	1.73E-09	2.486E-13	1.24E-13	1.732E-11	0.0016	0.0000028	27
Tin 121m	0.05	3000	0.03	0.08	0.001	0.8	1	0	0	0	0	8.9E-09	1.3E-09	81
Tin 126	0.05	3000	0.03	0.08	0.001	0.8	1	1.61E-07	6.325E-11	3.16E-11	1.607E-09	4.7E-10	8.9E-10	81
Tritium (hydrogen 3)	0	1	1	1	0.015	1	1	0	0	0	0	6.3E-11	9.5E-11	14.5
Uranium 232	0.0006	10	0.008	0.0003	0.0004	1	1	2.68E-09	3.52E-13	1.76E-13	2.678E-11	0.00067	0.0000013	27
Uranium 234	0.0006	10	0.008	0.0003	0.0004	1	1	1.3E-09	2.046E-13	1.02E-13	1.3E-11	0.00013	0.00000026	27
Uranium 235	0.0006	10	0.008	0.0003	0.0004	1	1	4.45E-07	1.892E-10	9.46E-11	4.446E-09	0.00012	0.00000025	108
Uranium 236	0.0006	10	0.008	0.0003	0.0004	1	1	1.91E-09	1.65E-13	8.25E-14	1.906E-11	0.00012	0.00000025	27
Uranium 238	0.0006	10	0.008	0.0003	0.0004	1	1	1.68E-09	1.419E-13	7.1E-14	1.68E-11	0.00012	0.00000023	1630
Zirconium 93	0.04	300	0.001	0.000001	5.5E-07	0.00006	0.0002	0	0	0	0	0.00000032	1.6E-09	81

Table E-2. Chemical Parameters. (2 Pages)

Chemicals	Kd L/g	BCF Fish	Soil/Plant	TF Meat	TF Milk	TF Chicken	TF Egg	ABS	Kp	RfD Inhalation	RfD Ingestion	CFP Inhalation	CPF Ingestion	Eco Benchmark (µg/L)	GW Background (µg/L)
Aluminum	35.3	10	0.004	0.0015	0.0002	0	0	0.001	0.001		0.004			50	7.11
Ammonia/Ammonium	1.79E-05	0.04	0	0	0	0	0	0.001	0.001	0.029	0.029			5	113
Ammonium Carbonate	1.79E-05	0.036	0	0	0	0	0	0.01	0.001	0.029	0.04			5	113
Ammonium Nitrate	1.79E-05	0.04	0	0	0	0	0	0.01	0.001	0.029	0.09			5	26871
Benzene	0.001145	24	0.58	0	0	0	0	0.01	0.11			0.029	0.029	1.2	27
BENZO[A]PYRENE	75.9	24000	0.003	0	0	0	0	0.01	0.1			7.3	7.3	0.0028	27
Beryllium	1.4	2	0.00047	0.001	9E-07	0.4	0.02	0.001	0.001	0.005	0.005	8.4	8.4	5.3	2.29
Bismuth	0.27	15	0.0008	0.0004	0.0005	0.098	0.26	0.001	0.001	0.2	0.2			5	0.4
Cadmium	0.074	200	0.55	0.0004	0.001	0.8	0.1	0.001	0.001	0.0002	0.0002	6.3	6.3	0.01	0.916
Carbon Tetrachloride	0	150	0.3	0	0	0	0	0.01	0.1	0.007	0.007	0.13	0.13	13	27
Cerium	0.1	30	0.02	0.00002	0.00003	0.002	0.00004	0.001	0.001	0.001	0.001			0.3	135
Chloroform	0.000428	18	0.7	0	0	0	0	0.01	0.1	0.1	0.1	0.081	0.081	2	27
Chromium	0.000067	200	0.0075	0.009	0.00001	0.2	0.9	0.001	0.001	0.005	0.005	41	41	2	2.4
Chrysene	2.76	11000	0.0055	0	0	0	0	0.01	0.1			0.0255	0.0255	0.003	27
Copper Sulfate	0.092	50	0.4	0.009	0.002	0.5	0.55	0.001	0.001	0.01	0.012			0.04	0.81
Copper	0.092	50	0.4	0.009	0.002	0.5	0.5	0.001	0.001	0.01	0.04			0.04	0.81
Cyanide	7.73E-06	0.38	13.5	0	0	0	0	0.001	0.001	0.02	0.04			5	8.41
Dibutyl Butyl Phosponate	0	0	0	0	0	0	0	0.01	0.1	0.002	0.002			40	27
Dibutyl Phosphate	0	20	0.5	0	0	0	0	0.01	0.1	0.06	0.06			40	27
Dichloroethylene, 1,2-	0.000814	1.4	5.1	0	0	0	0	0.01	0.1	0.009	0.009			200	27
Diesel Fuel	0.0621	510	0.057	0	0	0	0	0.01	0.1	0.36	0.36			40	27
Ferrocyanide	0	0.4	13.5	0	0	0	0	0.001	0.001	0.02	0.15			5	8.41
Ferrous Sulfamate	0	0	0	0	0	0	0	0.001	0.001	0.2	0.2			240	27
Fluoride	0.0003	10	0.02	0.15	0.001	0.014	2.7	0.001	0.001	0.06	0.06			200	1047
Iron	0.015	2000	0.004	0.02	0.00003	1	1	0.001	0.001	1.3	1.3			300	570
Kerosene	0.0621	510	0.057	0	0	0	0	0.01	0.1	0.7	0.7			40	27
Lanthanum	0.1	30	0.005	0.002	0.00002	0.1	0.009	0.001	0.001	0.001	0.001			0.3	80
Lead	0.27	100	0.068	0.0004	0.00026	0.8	1	0.001	0.000004	0.00043	0.0014			1	0.917
Manganese	0.049	400	0.13	0.0005	0.00003	0.05	0.06	0.001	0.001	0.14	0.14			0.8	38.5
Mercury	0.58	1000	0.38	0.25	0.00047	0.03	0.5	0.001	0.001	0.000086	0.0003			0.006	0.003
Methyl Isobutyl Ketone (Hexone)	0.01	2.5	1.7	0	0	0	0	0.01	0.1	0.08	0.08			120000	27
Nph (Normal Parafin Hydrocarbon	0.062	510	0.057	0	0	0	0	0.01	0.1	0.7	0.7			120000	27

Table E-2. Chemical Parameters. (2 Pages)

Chemicals	Kd L/g	BCF Fish	Soil/Plant	TF Meat	TF Milk	TF Chicken	TF Egg	ABS	Kp	RfD Inhalation	RfD Ingestion	CFP Inhalation	CPF Ingestion	Eco Benchmark (µg/L)	GW Background (µg/L)
Nickel	0.05	100	0.06	0.005	0.016	0.001	0.1	0.001	0.00003	0.02	0.02			9.3	1.56
Nitrate	0.0003	150000	30	0	0	0	0	0.001	0.001	1.6	1.6			40000	26871
Nitrite	0	150000	30	0	0	0	0	0.001	0.001	0.1	0.1			10	93.7
Oxalate	0	0	0	0	0	0	0	0.01	0.1	0.3	0.3			2000	287
Pcbs (Arochlor)	3.864	14000	0.0045	1	1	1	1	0.01	0.1	0.00002	0.00002	7.7	7.7	0.00008	27
Phosphate	0.05	70000	50	0	0	0	0	0.001	0.001	0.007	0.46			10	162
Potassium	0.0002	1000	0.37	0.02	0.0072	0.4	1	0.001	0.001	510	510			10000	9122
Potassium Borate	0.0002	0.22	1	0.02	0.0072	0.4	1	0.001	0.001	0.09	0.09			10000	36
Silicon	0.033	2.5	0.35	0.00004	0.00002	0	0	0.001	0.001	0.2	0.2			25000	33949
Silver (I)	0.09	2.3	0.15	0.003	0.00005	2	0.5	0.001	0.001	0.005	0.005			0.4	5.28
Silver Chloride	0.09	2.3	0.15	0.003	0.00005	2	0.5	0.001	0.001	0.005	0.005			0.4	5.28
Sodium	0.0002	100	0.05	0.08	0.016	0.01	6	0.001	0.001	300	300			200000	26998
Sodium Aluminate	35.3	10	0	0.00002	0.0002	0	0	0.001	0.001	0.043	0.043			50	7.11
Sodium Dichromate	0	200	0	0.009	0.00001	0.2	0.9	0.001	0.001	0.005	0.005			2	2.4
Sodium Hydroxide	0	1.5	0	0	0	0	0	0.001	0.001	0.014	0.014			1000	147127
Sodium Nitrate	0.0003	150000	30	0	0	0	0	0.001	0.001	1.6	1.6			40000	26871
Sodium Oxylate	0	0	0	0	0	0	0	0.01	0.1	0.06	0.06			2000	287
Sodium Silicate	0	2.5	0.35	0.00004	0.00002	0	0	0.001	0.001	5	5			25000	33949
Sodium Sulfamate	0	0	0	0	0	0	0	0.001	0.001	0.2	0.2			240	27
Strontium	0.008	50	0.2	0.008	0.0028	0.08	0.2	0.001	0.001	0.6	0.6			7	323
Sulfamic Acid	0	0	0	0	0	0	0	0.001	0.001	0.2	0.2			240	27
Sulfate (Sulfur)	0.0003	750	1.5	0	0	0	0	0.001	0.001	71	71			100000	47014
Sulfuric Acid	0.0003	0.25	1.5	0	0	0	0	0.001	0.001	0.007	0.007			100000	47014
Tetrachloroethane 1,1,1,2-	0.010171	50	0.25	0	0	0	0	0.01	0.1	0.03	0.03	0.026	0.026	7	27
Tetrachloroethylene	0.004968	56	0.3	0	0	0	0	0.01	0.1	0.05	0.05	0.051	0.051	50	27
Tributyl Phosphate (Tbp)	0.083214	600	0.05	0	0	0	0	0.01	0.1	0.0175	0.0175			40	27
Tributyl Phosphonate	2.4E-05	500	0.05	0	0	0	0	0.01	0.1	0.12	0.12			40	27
Trichloroethylene	0.001794	38	0.41	0	0	0	0	0.01	0.1			0.011	0.011	1	27
Uranium	0.0006	10	0.008	0.0003	0.0004	1	1	0.001	0.001	0.001	0.001			300	9.85
Xylene	0.003312	180	0.13	0	0	0	0	0.001	0.08	2	0.2			40	27
Zinc	0.2	2500	0.4	0.1	0.01	7	3	0.001	0.0006	0.3	0.3			10	21.8
Zirconium	0.04	200	0.001	0.000001	5.5E-07	0.00006	0.0002	0.001	0.001	0.035	0.035			300	25

Appendix E – Radiological and Chemical Parameters

APPENDIX F

NUMERICAL RESULTS OF SCOPING STUDIES

Table F-1. Human Health Screening Results. (4 Pages)

Name of Analyte	Screening Results - 100 Area Wastes						Screening Results - 200 Area Wastes					
	Seep			River			Seep			River		
	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk
Radionuclides												
Actinium 227	0.00E+00			0.00E+00			4.06E-12			1.94E-20		
Americium 241	4.39E-03			6.43E-12			1.28E-07			9.39E-16		
Americium 242m	0.00E+00			0.00E+00			2.30E-14			1.66E-22		
Cadmium 113m	0.00E+00			0.00E+00			3.20E-14			4.74E-21		
Carbon 14	2.89E+03			4.50E+01			1.13E+01			8.96E-01		
Cesium 135	2.25E-06			6.98E-13			8.27E-13			1.32E-17		
Cesium 137	9.27E-09			3.73E-15			3.91E-12			7.78E-18		
Chlorine 36	8.16E+00			1.13E-04			1.07E-02			7.55E-07		
Cobalt 60	5.55E-14			6.08E-20			1.06E-16			5.93E-22		
Curium 243	0.00E+00			0.00E+00			1.17E-13			8.67E-22		
Curium 244	1.50E-08			2.20E-17			7.06E-13			5.19E-21		
Europium 152	1.25E-12			8.89E-19			2.42E-16			8.60E-22		
Europium 154	3.06E-10			2.34E-17			5.61E-14			2.10E-20		
Iodine 129	3.91E+00			6.74E-08			7.39E-02			6.32E-08		
Krypton 85	0.00E+00			0.00E+00			0.00E+00			0.00E+00		
Lead 210	0.00E+00			0.00E+00			2.36E-17			4.78E-24		
Neptunium 237	1.21E+02			1.58E-07			1.07E-01			6.68E-09		
Nickel 59	9.63E-07			1.43E-14			2.88E-09			2.19E-15		
Nickel 63	1.07E-09			1.57E-17			1.29E-11			8.95E-19		
Palladium 107	0.00E+00			0.00E+00			3.71E-10			2.48E-17		
Protactinium 231	0.00E+00			0.00E+00			1.02E-05			5.02E-13		
Plutonium 238				1.26E-13			7.74E-09			5.43E-17		
Plutonium 239/240	1.46E+01			2.12E-08			4.23E-04			3.23E-12		
Plutonium 241	3.15E-06			4.67E-15			7.67E-12			5.67E-20		
Plutonium 242	4.27E-01			6.25E-10			3.73E-04			2.73E-12		
Radium 226	3.52E-18			2.31E-26			3.96E-03			1.31E-10		
Radium 228	0.00E+00			0.00E+00			5.73E-12			2.03E-19		

Table F-1. Human Health Screening Results. (4 Pages)

Name of Analyte	Screening Results - 100 Area Wastes						Screening Results - 200 Area Wastes					
	Seep			River			Seep			River		
	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk
Samarium 151	0.00E+00			0.00E+00			5.92E-13			5.50E-21		
Selenium 79	3.77E+02			2.01E-02			3.53E+00			9.38E-04		
Strontium 90	5.19E-03			6.68E-11			3.03E-06			1.99E-13		
Technetium 99	2.65E+02			1.78E-03			2.63E+01			8.99E-04		
Tellurium 123				0.00E+00			0.00E+00			0.00E+00		
Thorium 229	0.00E+00			0.00E+00			3.12E-08			2.03E-16		
Thorium 230	0.00E+00			0.00E+00			5.52E-07			3.68E-15		
Thorium 232	0.00E+00			0.00E+00			6.65E+00			4.37E-08		
Tin 121m	0.00E+00			0.00E+00			2.81E-16			4.58E-22		
Tin 126	7.39E-05			3.30E-11			1.15E-06			2.64E-13		
Tritium (hydrogen 3)	3.73E+02			7.67E-04			3.12E-01			3.14E-05		
Uranium 232	0.00E+00			0.00E+00			1.12E-05			8.67E-14		
Uranium 234	5.25E+03			8.16E-06			8.06E+00			6.30E-08		
Uranium 235	2.71E+02			4.42E-07			1.41E+00			1.08E-08		
Uranium 236	1.02E+03			1.66E-06			1.08E+00			8.69E-09		
Uranium 238	5.57E+03			9.03E-06			3.45E+01			2.64E-07		
Zirconium 93	2.62E-02			1.40E-10			1.31E-04			3.53E-12		
Chemicals												
Aluminum		3.11E-09	0.00E+00		1.01E-17	0.00E+00		2.93E-09	0.00E+00		4.93E-17	0.00E+00
Ammonia/ammonium		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Ammonium carbonate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		2.34E+00	0.00E+00		2.05E-05	0.00E+00
Ammonium nitrate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		5.72E+00	0.00E+00		5.10E-05	0.00E+00
Benzene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Benzo[a]pyrene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Beryllium		1.48E-06	6.21E-08		1.24E-15	5.18E-17		3.32E-10	1.40E-11		2.47E-18	1.04E-19
Bismuth		0.00E+00	0.00E+00		0.00E+00	0.00E+00		6.51E-06	0.00E+00		1.31E-13	0.00E+00
Cadmium		8.83E-03	1.11E-05		4.52E-10	5.69E-13		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Carbon tetrachloride		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.02E+01	9.25E-03		2.89E-03	2.62E-06
Cerium		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00

Table F-1. Human Health Screening Results. (4 Pages)

Name of Analyte	Screening Results - 100 Area Wastes						Screening Results - 200 Area Wastes					
	Seep			River			Seep			River		
	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk
Chloroform		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Chromium		2.27E-04	4.66E-05		1.18E-11	2.42E-12		5.97E-03	1.23E-03		1.62E-09	3.33E-10
Chrysene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Copper sulfate		1.25E-04	0.00E+00		1.66E-12	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Copper		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Cyanide		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Dibutyl butyl phosponate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		2.05E+00	0.00E+00		1.81E-05	0.00E+00
Dibutyl phosphate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.00E+00	0.00E+00		4.56E-05	0.00E+00
Dichloroethylene, 1,2-		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Diesel fuel		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Ferrocyanide		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.02E-01	0.00E+00		1.02E-06	0.00E+00
Ferrous sulfamate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Fluoride		0.00E+00	0.00E+00		0.00E+00	0.00E+00		3.13E-01	0.00E+00		1.45E-08	0.00E+00
Iron		1.26E-05	0.00E+00		6.59E-12	0.00E+00		4.42E-04	0.00E+00		1.14E-09	0.00E+00
Kerosene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Lanthanum		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.06E-03	0.00E+00		5.20E-11	0.00E+00
Lead		4.06E-01	0.00E+00		9.35E-09	0.00E+00		1.25E-04	0.00E+00		1.92E-11	0.00E+00
Manganese		2.38E-06	0.00E+00		2.40E-13	0.00E+00		9.49E-05	0.00E+00		4.26E-11	0.00E+00
Mercury		6.23E-04	0.00E+00		1.40E-10	0.00E+00		1.39E-06	0.00E+00		1.87E-12	0.00E+00
Methyl isobutyl ketone (hexone)		0.00E+00	0.00E+00		0.00E+00	0.00E+00		7.50E-03	0.00E+00		4.41E-11	0.00E+00
Nph (normal parafin hydrocarbon)		0.00E+00	0.00E+00		0.00E+00	0.00E+00		4.71E-05	0.00E+00		2.27E-11	0.00E+00
Nickel		7.94E-05	0.00E+00		2.14E-12	0.00E+00		7.96E-04	0.00E+00		6.87E-11	0.00E+00
Nitrate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		4.77E-01	0.00E+00		2.54E-04	0.00E+00
Nitrite		0.00E+00	0.00E+00		0.00E+00	0.00E+00		2.53E+01	0.00E+00		1.11E+01	0.00E+00
Oxalate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		7.25E-02	0.00E+00		6.37E-07	0.00E+00
Pcbs (arochlor)		1.67E-04	2.57E-08		2.43E-10	3.74E-14		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Phosphate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.96E-03	0.00E+00		1.15E-07	0.00E+00
Potassium		0.00E+00	0.00E+00		0.00E+00	0.00E+00		2.86E-05	0.00E+00		1.35E-10	0.00E+00
Potassium borate		1.23E-02	0.00E+00		3.71E-11	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00

Table F-1. Human Health Screening Results. (4 Pages)

Name of Analyte	Screening Results - 100 Area Wastes						Screening Results - 200 Area Wastes					
	Seep			River			Seep			River		
	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk	Rad (rem)	HI (ratio)	Risk
Silicon		1.13E-05	0.00E+00		1.60E-14	0.00E+00		7.42E-04	0.00E+00		5.86E-12	0.00E+00
Silver		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.01E-05	0.00E+00		7.19E-14	0.00E+00
Silver chloride		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Sodium		3.20E-06	0.00E+00		3.10E-13	0.00E+00		2.19E-03	0.00E+00		1.06E-09	0.00E+00
Sodium aluminate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		2.15E-11	0.00E+00		3.12E-19	0.00E+00
Sodium dichromate		5.28E+02	0.00E+00		6.20E-02	0.00E+00		3.76E-01	0.00E+00		2.24E-04	0.00E+00
Sodium hydroxide		6.11E+01	0.00E+00		1.58E-04	0.00E+00		2.90E+02	0.00E+00		3.81E-03	0.00E+00
Sodium nitrate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Sodium oxalate		1.87E+00	0.00E+00		3.25E-06	0.00E+00		4.34E-01	0.00E+00		3.82E-06	0.00E+00
Sodium silicate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		9.45E-03	0.00E+00		1.53E-07	0.00E+00
Sodium sulfamate		5.62E-01	0.00E+00		9.72E-07	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Strontium		8.06E-06	0.00E+00		1.12E-13	0.00E+00		5.51E-05	0.00E+00		3.97E-12	0.00E+00
Sulfamic acid		9.79E-01	0.00E+00		1.69E-06	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Sulfate (sulfur)		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Sulfuric acid		9.68E+00	0.00E+00		2.25E-08	0.00E+00		2.21E-02	0.00E+00		2.55E-10	0.00E+00
Tetrachloroethane 1,1,1,2-		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Tetrachloroethylene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Tributyl phosphate (tbp)		0.00E+00	0.00E+00		0.00E+00	0.00E+00		4.41E-04	0.00E+00		2.77E-10	0.00E+00
Tributyl phosphonate		0.00E+00	0.00E+00		0.00E+00	0.00E+00		3.19E-02	0.00E+00		2.95E-05	0.00E+00
Trichloroethylene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	9.77E-06		0.00E+00	4.14E-13
Uranium		4.85E+02	0.00E+00		3.16E-06	0.00E+00		5.09E+00	0.00E+00		1.56E-07	0.00E+00
Xylene		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Zinc		0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.38E-07	0.00E+00		4.06E-13	0.00E+00
Zirconium		2.87E-02	0.00E+00		1.48E-09	0.00E+00		1.55E-03	0.00E+00		4.20E-10	0.00E+00

Appendix F – Numerical Results of Scoping Studies

Table F-2. Ecological Screening Results. (4 Pages)

Name of Analyte	100 Areas - Fish Dose		200 Areas - Fish Dose	
	River (Rad/d)	Seep (Rad/d)	River (Rad/d)	Seep (Rad/d)
Radionuclides				
Actinium 227	0.00E+00	0.00E+00	5.72E-28	1.46E-19
Americium 241	1.40E-17	1.84E-08	2.04E-21	5.39E-13
Americium 242m	0.00E+00	0.00E+00	3.58E-28	9.41E-20
Cadmium 113m	0.00E+00	0.00E+00	4.56E-26	1.20E-17
Carbon 14	3.97E-03	2.30E+03	7.91E-05	9.02E+00
Cesium 135	1.75E-17	2.39E-08	3.32E-22	8.79E-15
Cesium 137	4.98E-20	6.52E-11	1.04E-22	2.75E-14
Chlorine 36	3.19E-08	1.85E-02	2.13E-10	2.42E-05
Cobalt 60	6.30E-26	8.29E-17	6.14E-28	1.58E-19
Curium 243	0.00E+00	0.00E+00	3.00E-27	7.76E-19
Curium 244	9.75E-23	1.28E-13	2.30E-26	6.05E-18
Europium 152	3.29E-24	4.29E-15	3.18E-27	8.30E-19
Europium 154	7.29E-23	9.55E-14	6.55E-26	1.75E-17
Iodine 129	4.92E-14	2.29E-05	4.61E-14	4.34E-07
Krypton 85	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead 210	0.00E+00	0.00E+00	1.16E-29	3.11E-21
Neptunium 237	2.76E-13	3.42E-04	1.17E-14	3.02E-07
Nickel 59	1.50E-18	1.95E-09	2.29E-19	5.83E-12
Nickel 63	1.53E-21	1.94E-12	8.74E-23	2.32E-14
Palladium 107	0.00E+00	0.00E+00	1.36E-21	3.64E-14
Protactinium 231	0.00E+00	0.00E+00	2.01E-19	5.32E-12
Plutonium 238	3.19E-19	4.31E-10	1.37E-22	3.72E-14
Plutonium 239/240	4.54E-14	5.93E-05	6.89E-18	1.72E-09
Plutonium 241	5.18E-22	6.72E-13	6.27E-27	1.64E-18
Plutonium 242	1.32E-15	1.74E-06	5.78E-18	1.52E-09
Radium 226	3.23E-31	3.93E-22	1.83E-15	4.42E-07
Radium 228	0.00E+00	0.00E+00	6.61E-25	1.68E-16
Samarium 151	0.00E+00	0.00E+00	8.80E-25	2.29E-16
Selenium 79	4.34E-07	2.47E-01	2.03E-08	2.31E-03
Strontium 90	1.34E-15	1.70E-06	4.01E-18	9.93E-10
Technetium 99	3.18E-07	1.84E-01	1.60E-07	1.83E-02
Tellurium 123	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Thorium 229	0.00E+00	0.00E+00	4.34E-22	1.15E-13
Thorium 230	0.00E+00	0.00E+00	4.82E-20	1.23E-11

Appendix F – Numerical Results of Scoping Studies

Table F-2. Ecological Screening Results. (4 Pages)

Name of Analyte	100 Areas - Fish Dose		200 Areas - Fish Dose	
	River (Rad/d)	Seep (Rad/d)	River (Rad/d)	Seep (Rad/d)
Thorium 232	0.00E+00	0.00E+00	9.73E-14	2.56E-05
Tin 121m	0.00E+00	0.00E+00	1.56E-25	4.05E-17
Tin 126	7.48E-14	9.78E-05	5.99E-16	1.52E-06
Tritium (hydrogen 3)	2.59E-08	1.48E-02	1.06E-09	1.24E-05
Uranium 232	0.00E+00	0.00E+00	1.01E-19	1.41E-11
Uranium 234	4.35E-11	3.03E-02	3.36E-13	4.65E-05
Uranium 235	2.38E-12	1.59E-03	5.85E-14	8.25E-06
Uranium 236	8.78E-12	5.85E-03	4.58E-14	6.20E-06
Uranium 238	4.59E-11	3.06E-02	1.34E-12	1.89E-04
Zirconium 93	5.27E-15	6.71E-06	1.32E-16	3.36E-08
Chemicals				
Aluminum	7.92E-18	1.08E-08	9.67E-14	9.67E-09
Ammonia/Ammonium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium Carbonate	0.00E+00	0.00E+00	4.76E-04	5.41E+01
Ammonium Nitrate	0.00E+00	0.00E+00	2.74E-03	3.11E+02
Benzene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo[a]pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beryllium	3.02E-14	6.04E-05	1.21E-13	1.36E-08
Bismuth	0.00E+00	0.00E+00	1.01E-07	1.13E-01
Cadmium	5.76E-09	7.68E+00	3.20E-07	3.20E-02
Carbon Tetrachloride	0.00E+00	0.00E+00	8.80E-05	1.00E+01
Cerium	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chloroform	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chromium	1.89E-11	2.47E-02	6.57E-06	6.57E+00
Chrysene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper Sulfate	1.21E-09	1.63E+00	0.00E+00	0.00E+00
Copper	0.00E+00	0.00E+00	3.25E-05	3.25E+01
Cyanide	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibutyl Butyl Phosponate	0.00E+00	0.00E+00	1.65E-06	1.88E-01
Dibutyl Phosphate	0.00E+00	0.00E+00	2.42E-05	2.75E+00
Dichloroethylene, 1,2-	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Diesel Fuel	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ferrocyanide	0.00E+00	0.00E+00	7.91E-05	8.99E+00
Ferrous Sulfamate	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fluoride	0.00E+00	0.00E+00	3.59E-05	4.10E+00

Appendix F – Numerical Results of Scoping Studies

Table F-2. Ecological Screening Results. (4 Pages)

Name of Analyte	100 Areas - Fish Dose		200 Areas - Fish Dose	
	River (Rad/d)	Seep (Rad/d)	River (Rad/d)	Seep (Rad/d)
Iron	1.85E-12	2.38E-03	6.94E-07	7.86E-02
Kerosene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lanthanum	0.00E+00	0.00E+00	3.40E-08	3.40E-03
Lead	1.65E-08	2.47E+01	7.16E-08	8.06E-03
Manganese	1.35E-11	1.80E-02	7.19E-06	9.59E-01
Mercury	9.00E-10	1.35E+00	3.01E-08	3.01E-02
Methyl Isobutyl Ketone (Hexone)	0.00E+00	0.00E+00	1.14E-09	1.30E-04
Nph (Normal Parafin Hydrocarbon	0.00E+00	0.00E+00	7.42E-11	7.42E-06
Nickel	5.81E-12	7.42E-03	6.27E-09	6.27E-04
Nitrate	0.00E+00	0.00E+00	7.24E-06	8.28E-01
Nitrite	0.00E+00	0.00E+00	6.51E-03	7.39E+02
Oxalate	0.00E+00	0.00E+00	1.74E-07	1.98E-02
Pcbs (Arochlor)	5.63E-10	1.13E+00	0.00E+00	0.00E+00
Phosphate	0.00E+00	0.00E+00	2.93E-05	3.91E+00
Potassium	0.00E+00	0.00E+00	5.47E-07	6.32E-01
Potassium Borate	1.35E-11	4.80E-03	0.00E+00	0.00E+00
Silicon	3.02E-15	3.92E-06	2.21E-09	2.58E-04
Silver	0.00E+00	0.00E+00	5.50E-08	5.50E-02
Silver Chloride	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium	5.85E-13	2.08E-04	1.23E-06	1.42E+00
Sodium Aluminate	0.00E+00	0.00E+00	5.60E-14	5.60E-09
Sodium Dichromate	9.90E-02	5.72E+04	2.42E-05	2.76E+00
Sodium Hydroxide	6.40E-05	3.70E+01	1.04E-04	1.19E+01
Sodium Nitrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium Oxalate	2.62E-06	1.52E+00	2.09E-07	2.38E-02
Sodium Silicate	0.00E+00	0.00E+00	8.22E-08	9.35E-03
Sodium Sulfamate	3.52E-05	2.04E+01	0.00E+00	0.00E+00
Strontium	2.36E-11	3.00E-02	1.09E-06	1.22E-01
Sulfamic Acid	6.13E-05	3.55E+01	0.00E+00	0.00E+00
Sulfate (Sulfur)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulfuric Acid	6.30E-11	2.94E-02	5.88E-10	6.72E-05
Tetrachloroethane 1,1,1,2-	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tetrachloroethylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tributyl Phosphate (Tbp)	0.00E+00	0.00E+00	1.04E-07	1.04E-02
Tributyl Phosphonate	0.00E+00	0.00E+00	1.54E-06	1.75E-01

Appendix F – Numerical Results of Scoping Studies

Table F-2. Ecological Screening Results. (4 Pages)

Name of Analyte	100 Areas - Fish Dose		200 Areas - Fish Dose	
	River (Rad/d)	Seep (Rad/d)	River (Rad/d)	Seep (Rad/d)
Trichloroethylene	0.00E+00	0.00E+00	2.00E-04	2.40E+01
Uranium	1.05E-07	7.00E+01	2.00E-07	2.33E-02
Xylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc	0.00E+00	0.00E+00	1.80E-09	1.80E-03
Zirconium	1.10E-10	1.45E-01	1.41E-10	1.57E-05

Appendix F – Numerical Results of Scoping Studies

Table F-3. Screening with Background Benchmarking. (3 Pages)

Name of Analyte	Detectability (P/Bkdg)	
	100 Areas	200 Areas
Radionuclides		
Actinium 227	0.00E+00	6.69E-12
Americium 241	1.14E+00	3.34E-05
Americium 242m	0.00E+00	1.46E-13
Cadmium 113m	0.00E+00	2.90E-10
Carbon 14	2.22E+08	8.70E+05
Cesium 135	4.98E-02	1.83E-08
Cesium 137	2.80E-04	1.18E-07
Chlorine 36	3.43E+05	4.49E+02
Cobalt 60	6.59E-09	1.26E-11
Curium 243	0.00E+00	3.23E-12
Curium 244	5.33E-07	2.51E-11
Europium 152	3.88E-07	7.51E-11
Europium 154	1.47E-05	2.70E-09
Iodine 129	1.89E+06	3.58E+04
Krypton 85	0.00E+00	0.00E+00
Lead 210	0.00E+00	2.03E-15
Neptunium 237	2.41E+03	2.12E+00
Nickel 59	6.09E-01	1.83E-03
Nickel 63	2.59E-04	3.11E-06
Palladium 107	0.00E+00	8.77E-05
Protactinium 231	0.00E+00	7.55E-05
Plutonium 238	2.31E-01	1.99E-05
Plutonium 239/240	7.83E+03	2.27E-01
Plutonium 241	3.03E-03	7.38E-09
Plutonium 242	8.56E+00	7.47E-03
Radium 226	9.63E-16	1.08E+00
Radium 228	0.00E+00	8.40E-10
Samarium 151	0.00E+00	6.14E-08
Selenium 79	7.01E+06	6.56E+04
Strontium 90	3.32E+01	1.94E-02
Technetium 99	2.64E+07	2.62E+06
Tellurium 123	0.00E+00	0.00E+00
Thorium 229	0.00E+00	1.73E-07
Thorium 230	0.00E+00	1.93E-05
Thorium 232	0.00E+00	4.63E+01
Tin 121m	0.00E+00	2.71E-11
Tin 126	1.31E+01	2.04E-01

Appendix F – Numerical Results of Scoping Studies

Table F-3. Screening with Background Benchmarking. (3 Pages)

Name of Analyte	Detectability (P/Bkdg)	
	100 Areas	200 Areas
Tritium (Hydrogen 3)	3.44E+09	2.88E+06
Uranium 232	0.00E+00	1.85E-04
Uranium 234	4.47E+05	6.86E+02
Uranium 235	6.24E+03	3.24E+01
Uranium 236	9.41E+04	9.97E+01
Uranium 238	8.53E+03	5.27E+01
Zirconium 93	2.84E+02	1.42E+00
Chemicals		
Aluminum	7.59E-08	7.14E-08
Ammonia/Ammonium	0.00E+00	0.00E+00
Ammonium Carbonate	0.00E+00	3.54E+01
Ammonium Nitrate	0.00E+00	8.32E-01
Benzene	0.00E+00	0.00E+00
Benzo[a]pyrene	0.00E+00	0.00E+00
Beryllium	1.40E-04	3.14E-08
Bismuth	0.00E+00	1.42E-01
Cadmium	8.38E-02	0.00E+00
Carbon Tetrachloride	0.00E+00	7.13E+01
Cerium	0.00E+00	0.00E+00
Chloroform	0.00E+00	0.00E+00
Chromium	2.05E-02	5.40E-01
Chrysene	0.00E+00	0.00E+00
Copper Sulfate	8.02E-02	0.00E+00
Copper	0.00E+00	0.00E+00
Cyanide	0.00E+00	0.00E+00
Dibutyl Butyl Phosponate	0.00E+00	4.11E+00
Dibutyl Phosphate	0.00E+00	6.03E+01
Dichloroethylene, 1,2-	0.00E+00	0.00E+00
Diesel Fuel	0.00E+00	0.00E+00
Ferrocyanide	0.00E+00	7.91E+01
Ferrous Sulfamate	0.00E+00	0.00E+00
Fluoride	0.00E+00	7.79E-01
Iron	1.25E-03	4.38E-02
Kerosene	0.00E+00	0.00E+00
Lanthanum	0.00E+00	5.74E-04
Lead	2.70E+01	8.29E-03
Manganese	3.74E-04	1.49E-02
Mercury	2.70E+00	6.03E-03

Appendix F – Numerical Results of Scoping Studies

Table F-3. Screening with Background Benchmarking. (3 Pages)

Name of Analyte	Detectability (P/Bkdg)	
	100 Areas	200 Areas
Methyl Isobutyl Ketone (Hexone)	0.00E+00	6.00E-01
Nph (Normal Parafin Hydrocarbon)	0.00E+00	3.30E-02
Nickel	4.42E-02	4.44E-01
Nitrate	0.00E+00	1.23E+00
Nitrite	0.00E+00	1.17E+03
Oxalate	0.00E+00	2.04E+00
Pcbs (Arochlor)	3.33E-06	0.00E+00
Phosphate	0.00E+00	2.41E-01
Potassium	0.00E+00	6.93E-02
Potassium Borate	1.33E+00	0.00E+00
Silicon	2.89E-06	1.90E-04
Silver (1)	0.00E+00	4.17E-04
Silver Chloride	0.00E+00	0.00E+00
Sodium	1.54E-03	1.05E+00
Sodium Aluminate	0.00E+00	5.65E-09
Sodium Dichromate	4.77E+04	3.40E+01
Sodium Hydroxide	2.51E-01	1.19E+00
Sodium Nitrate	0.00E+00	0.00E+00
Sodium Oxalate	1.06E+01	2.45E+00
Sodium Silicate	0.00E+00	6.04E-02
Sodium Sulfamate	1.81E+02	0.00E+00
Strontium	6.50E-04	4.44E-03
Sulfamic Acid	3.15E+02	0.00E+00
Sulfate (Sulfur)	0.00E+00	0.00E+00
Sulfuric Acid	6.25E-02	1.43E-04
Tetrachloroethane 1,1,1,2-	0.00E+00	0.00E+00
Tetrachloroethylene	0.00E+00	0.00E+00
Tributyl Phosphate (Tbp)	0.00E+00	7.70E-03
Tributyl Phosphonate	0.00E+00	3.84E+00
Trichloroethylene	0.00E+00	8.89E-01
Uranium	2.13E+03	2.24E+01
Xylene	0.00E+00	0.00E+00
Zinc	0.00E+00	8.26E-05
Zirconium	1.74E+00	9.40E-02