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EXECUTIVE SUMMARY

This report provides the qualitative risk assessment (QRA) for the 100-KR-4 groundwater operable unit at the U.S. Department of Energy's (DOE) Hanford Site in southeastern Washington State. The extent of the groundwater beneath the 100 K Area is defined in the *Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit* (DOE-RL 1992a). The QRA is an evaluation of risk using a limited amount of data and a predefined set of human and environmental exposure scenarios and is not intended to replace or be a substitute for a baseline risk assessment.

BACKGROUND

The Washington Department of Ecology (Ecology), the U.S. Environmental Protection Agency (EPA), and DOE, signatories to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1990), developed the *Hanford Past-Practice Strategy* (DOE-RL 1991) to emphasize initiating and completing waste site cleanups with a bias for action. This strategy relies, in part, on the use of a QRA to assist in decisionmaking. The QRA was performed using the *Hanford Site Baseline Risk Assessment Methodology* (DOE-RL 1993) as guidance. The results will be used in the limited field investigation (LFI) report, along with other considerations, to make a recommendation regarding the need for interim remedial measures (IRM).

The QRA was streamlined to consider only two human health exposure scenarios (frequent and occasional use) with two pathways (groundwater ingestion and inhalation of volatile organics from groundwater use), and a limited ecological evaluation, based on agreements by the 100 Area Tri-Party Agreement unit managers (December 21, 1992 and February 8, 1993). For humans, reasonable maximum exposure (RME) estimates of risk are made under frequent- and occasional-use exposure scenarios. These scenarios are synonymous with the "residential" and "recreational" scenarios, respectively. The inhalation pathway was only evaluated in the frequent-use scenario because it was assumed that exposures to volatile organics would occur during domestic water use within the confines of a residence, which would not be expected to occur in an occasional-use setting. The ecological evaluation concentrated on the hypothetical effects of contaminants on selected aquatic organisms present in or near the Columbia River. The limited scope of the evaluation and the lack of environmental transport modeling make the analysis qualitative.

The data for the 100-KR-4 groundwater operable unit QRA were from four rounds of data collected during recent LFI sampling. The data were evaluated as recommended in the risk assessment methodology (DOE-RL 1993a). Maximum representative detected concentrations of inorganic analytes were screened by comparison with background levels for groundwater established in *Hanford Site Groundwater Background* (DOE-RL 1992b) consistent with agreements for other operable units made by 100 Area Tri-Party Agreement unit managers (February 8, 1993). No organic and radionuclide analytes, with the exception of the uranium isotopes, were screened by comparison to background because there were no background values agreed on. Human health risks were calculated for the maximum representative concentrations of the organic and radionuclide analytes using the appropriate methodology (e.g., hazard quotient [HQ], incremental cancer risk [ICR]). The ecological evaluation compared the maximum representative concentrations to risk-based benchmark concentrations (e.g., radiation dose limit, lowest observable effect level [LOEL]) to form an environmental hazard quotient [EHQ]. No evaluation of spatial or temporal distribution of the contaminants was performed.

RESULTS

The analysis of human health risks considered both carcinogenic and noncarcinogenic impacts. The carcinogenic impacts were further divided into those caused by exposure to radioactive and nonradioactive contaminants. The results of the human health risk estimations for carcinogenic contaminants were grouped into high ($ICR \geq 1 \times 10^{-2}$), medium ($1 \times 10^{-4} \leq ICR < 1 \times 10^{-2}$), low ($1 \times 10^{-6} \leq ICR < 1 \times 10^{-4}$), and very low ($ICR < 1 \times 10^{-6}$) categories to represent the qualitative nature of the assessment. EPA supports the concept of a risk range and defines the risk range of 1×10^{-6} to 1×10^{-4} as a "generally acceptable level", with 1×10^{-6} being a "point of departure for establishing remediation goals" (40 CFR 300.340(e)(2)). These categories were defined to be consistent with this concept. For noncarcinogenic contaminants, the HQ estimations were considered a significant risk if they exceeded 1.0 and the converse if they did not exceed 1.0.

The following were the primary human health evaluation findings:

- The estimated chemical-specific risks for 10 carcinogenic (radioactive and nonradioactive) contaminants for the frequent-use scenario were rated medium to very low. For the occasional-use scenario, the estimated risks were rated low to very low for the same contaminants.
- The cumulative risk for all carcinogenic contaminants was classified as medium for the frequent-use scenario and low for the occasional-use scenario.
- Two radioactive contaminants (tritium and carbon-14) and one nonradioactive contaminant (arsenic) had estimates in the medium carcinogenic risk category for the frequent-use scenario. Tritium and carbon-14 together accounted for almost 90% of the total risk for both the frequent- and occasional-use scenarios.
- Hanford Site background concentration information was available for arsenic and it corresponded to a medium risk level under the frequent-use scenario.
- Of the noncarcinogenic contaminants analyzed, three inorganic contaminants (chromium, arsenic, and nitrate/nitrite) produced an HQ > 1.0 for the frequent-use scenario and none exceeded 1.0 for the occasional-use scenario.
- The highest-risk organic contaminants (chloroform and trichloroethene) produced estimates in the low carcinogenic risk category for the frequent-use scenario and the very low risk category for the occasional-use scenario.

The ecological evaluation analyzed the likelihood of an adverse effect occurring to riparian and aquatic life. As the maximum conservative assumption, the concentrations of contaminants in groundwater were used as exposure concentrations for assessing the risk to generic aquatic organisms. The measurement points used for the assessment were the near-river wells. However, once contaminated groundwater entered the river, the effect of dilution was virtually immediate; well and spring contaminant concentrations were much higher than the corresponding river concentrations.

The major findings were:

- The ecological criterion used for radionuclides was a total internal dose of 1 rad/day (DOE Order 5400.5). Only the fish-eating duck exposed to carbon-14 was found to produce an internal dose greater than 1 rad/day and an EHQ greater than 1.0.
- Acute and chronic LOELs for fish were used as criteria for nonradioactive contaminants to produce acute and chronic EHQs. Chromium (hexavalent), zinc, silver, and lead concentrations in the near-river groundwater resulted in chronic EHQs exceeding 1.0. Acute EHQs exceeding 1.0 were associated with chromium, zinc, and iron.

UNCERTAINTIES

Uncertainties exist in the results of the human health and ecological evaluations because of uncertainty in the contaminant concentration data, in the assumptions of the exposure scenarios analyzed, and in the toxicity values for both human and ecological receptors. The identification of contaminants and concentrations were based on four rounds of LFI data which represented a limited "snapshot" and were not likely to fully characterize the groundwater under the 100 K Area.

The conservative assumptions of the scenarios and the risk evaluation itself also led to uncertainty in the risk results, although the evaluation was meant to be an RME estimate for the two risk-bounding scenarios. Conservatism was introduced by the use of maximum representative, rather than average, concentrations in the risk evaluation. No allowance was made for dilution effects, radioactive decay or bioavailability in the exposure calculations. The assumptions of exposure times for both humans and aquatic organisms as receptors were conservative. The two human health scenarios (frequent and occasional use) evaluated to provide estimates of hazard or risk do not currently occur in the 100 K Area. The assumption of contact duration with contaminant concentrations in the springs for fish does not account for the mobility of the fish.

There are uncertainties in the toxicity information for both human health and ecological evaluations. The human toxicity values for many contaminants were based on limited acute animal studies with the effects extrapolated to the chronic dose levels of environmental contamination levels for human receptors. The same situation applies to ecological toxicity values which are usually developed based on acute levels in laboratory studies on specific species and then applied to other species at lower concentration levels in the environment.

In summary, it can be reasonably assumed that the actual human and ecological risks are less than the risks calculated as part of this QRA. These estimates of risk, with their associated uncertainties, are sufficient to support an initial decision for the 100-KR-4 operable unit.

ACRONYMS

ARAR	applicable or relevant and appropriate requirement
AWQC	ambient water quality criteria
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFWQC	chronic freshwater quality criteria
CLP	Contact Laboratory Program
COPC	contaminants of potential concern
DOE	U. S. Department of Energy
DOE-RL	U. S. Department of Energy, Richland Operations Office
Ecology	Washington Department of Ecology
EHQ	environmental hazard quotient
EPA	U. S. Environmental Protection Agency
ERA	expedited response action
HEAST	Health Effects Assessment Summary Tables
HFSUWG	Hanford Future Site Uses Working Group
HI	hazard index
HQ	hazard quotient
HWQHC	human water quality health criteria
HWQWC	human water quality welfare criteria
ICR	incremental cancer risk
IRIS	Integrated Risk Information System
IRM	interim remedial measure
LC ₅₀	lethal concentration, 50% mortality
LFI	limited field investigation
LOEL	lowest observable effect level
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MTCACR	Model Toxics Control Act Cleanup Regulations
NCRP	National Council on Radiation Protection
ND	not detected
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NTU	nephelometric turbidity unit
PCB	polychlorinated biphenyls
QA	quality assurance
QC	quality control
QRA	qualitative risk assessment
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RME	reasonable maximum exposure
SF	slope factor
UCL	upper confidence limit
WA	Washington (State of)
WAC	Washington Administrative Code
WHC	Westinghouse Hanford Company

CONTENTS

1.0	INTRODUCTION	1-1
1.1	SCOPE	1-1
1.2	OPERABLE UNIT BACKGROUND	1-2
1.2.1	Location	1-2
1.2.2	History of Operations	1-2
1.3	PROCESS OVERVIEW	1-3
2.0	100-KR-4 QRA DATA EVALUATION	2-1
2.1	DATA SOURCES	2-1
2.1.1	LFI Data for the 100-KR-4 Operable Unit	2-1
2.1.2	100 K Area Spring and River Data	2-2
2.1.3	Hanford Site Background Data	2-2
2.2	DATA EVALUATION SCREENING	2-3
2.2.1	Data Validation	2-3
2.2.2	Data Screening in the LFI	2-3
2.2.3	Risk-Based Screening	2-3
2.2.4	Screening Calculations	2-4
2.2.5	Results of the Risk-Based Screening	2-5
2.3	SUMMARY OF CONTAMINANTS OF POTENTIAL CONCERN	2-5
2.4	DATA UNCERTAINTY	2-5
3.0	100-KR-4 HUMAN HEALTH EVALUATION	3-1
3.1	EXPOSURE ASSESSMENT	3-1
3.1.1	Groundwater Use Scenarios and Parameters	3-1
3.1.2	Exposure Quantification	3-1
3.2	TOXICITY ASSESSMENT	3-2
3.3	RISK CHARACTERIZATION	3-3
3.3.1	Human Health Risk Calculations	3-3
3.3.2	Results of Risk Characterization	3-4
3.4	UNCERTAINTY IN EXPOSURE AND TOXICITY ASSESSMENT	3-4
4.0	100-KR-4 ECOLOGICAL EVALUATION	4-1
4.1	PROBLEM FORMULATION	4-1
4.1.1	Stressor Identification	4-1
4.1.2	Ecosystems Potentially at Risk	4-1
4.1.3	Potential Ecological Effects	4-2
4.2	ANALYSIS	4-2
4.3	RISK CHARACTERIZATION	4-3
4.4	UNCERTAINTY EVALUATION	4-4

CONTENTS (Cont.)

5.0	SUMMARY AND CONCLUSIONS	5-1
5.1	SUMMARY OF HUMAN HEALTH EVALUATION	5-1
5.1.1	Noncarcinogenic Hazard	5-1
5.1.2	Carcinogenic Risk	5-1
5.1.3	Risk From Background Levels of COPCs	5-2
5.2	RESULTS OF ECOLOGICAL EVALUATION	5-2
5.2.1	Radionuclide Hazard	5-3
5.2.2	Nonradionuclide Hazard	5-3
5.3	SUMMARY OF UNCERTAINTY	5-3
5.3.1	Uncertainty in Data	5-4
5.3.2	Uncertainty in Human Health Evaluation	5-4
5.3.3	Uncertainty in Ecological Evaluation	5-5
5.4	CONCLUSIONS	5-5
6.0	REFERENCES	6-1

APPENDIXES:

A	Toxicological Information	A-1
B	Ecological Evaluation Radiological Dose Calculations	B-1

FIGURES:

1-1	The Hanford Site	1-4
1-2	100 K-Area Operable Unit Boundaries	1-5
2-1	Identification of Groundwater Well Locations	2-7

TABLES:

2-1	Summary of Detected Analytes: All Groundwater Wells	2-8
2-2	Summary of Detected Analytes: Near-River Groundwater Wells	2-10
2-3	Summary of Detected Analytes: K Area Springs and Columbia River	2-12
2-4a	Human Health Risk-Based Screening Calculations for Ingestion of Organics	2-13
2-4b	Human Health Risk-Based Screening Calculations for Inhalation of Organics	2-13
2-4c	Human Health Risk-Based Screening Calculations for Ingestion of Inorganics	2-14
2-4d	Human Health Risk-Based Screening Calculations for Ingestion of Radionuclides	2-15
3-1a	Exposure Factors for the Occasional-Use Scenario	3-6
3-1b	Exposure Factors for the Frequent-Use Scenario	3-6

CONTENTS (Cont)

FIGURES (Cont):

3-2a	Human Health Risk Calculations for Noncarcinogenic Effects of Ingestion of Organics	3-7
3-2b	Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Organics	3-7
3-2c	Human Health Risk Calculations for Carcinogenic Effects of Inhalation of Organics	3-7
3-2d	Human Health Risk Calculations for Noncarcinogenic Effects of Ingestion of Inorganics	3-7
3-2e	Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Inorganics	3-8
3-2f	Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Radionuclides	3-8
4-1	Environmental Hazard Quotients for Radionuclides in the Near-River Groundwater Wells	4-6
4-2	Environmental Hazard Quotients for Non-Radionuclides in the Near-River Groundwater Wells	4-6
5-1	Human Heal Risk Summary - Noncarcinogenic Effects	5-6
5-2	Human Health Risk Summary - Carcinogenic Effects	5-7
5-3	Comparison of Concentrations for Contaminants of Potential Concern	5-8
5-4	Ecological Summary for Radionuclides Organism: Fish-Eating Duck	5-9
5-5	Ecological Summary for Nonradionuclides	5-9

1.0 INTRODUCTION

This report documents the qualitative risk assessment (QRA) performed for the 100-KR-4 groundwater operable unit. This unit is located in the 100 K Area of the Hanford Site (Figure 1-1). The 100 Area of the Hanford Site was included on the U.S. Environmental Protection Agency's (EPA's) National Priority List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The Washington Department of Ecology (Ecology), EPA, and the U.S. Department of Energy (DOE) are signatories to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1990). The signatories have developed a strategy to emphasize initiating and completing waste site cleanups in the *Hanford Past-Practice Strategy* (DOE-RL 1991). The strategy identified three paths to support this bias for action. The paths are expedited response actions (ERA), and interim remedial measures (IRM), with or without a limited field investigation (LFI).

The QRA provides information, along with other considerations in the LFI report, to justify conducting or not conducting an IRM, although it may be used to support the other paths when agreed on by the Tri-Party Agreement signatories. An IRM, as defined in the past-practice strategy, is an onsite response conducted pursuant to CERCLA 40 CFR 300.430 involving interim remedial actions that are conducted at a CERCLA past-practice operable unit at any time prior to initiation of final remedial action. IRM can include Resource Conservation and Recovery Act (RCRA) interim measures as deemed appropriate by the parties.

This report documents the QRA performed for the 100-KR-4 groundwater operable unit. The application of the past-practice strategy at the 100-KR-4 operable unit is discussed in detail in the *Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit, Hanford Site, Richland, Washington* (DOE-RL 1992a).

1.1 SCOPE

The scope of the QRA for the 100-KR-4 groundwater operable unit focuses on a limited set of human health and ecological exposure scenarios to provide sufficient information to assist the Tri-Party Agreement signatories in making defensible decisions on the necessity of IRMs. The "frequent-use" scenario is analogous to the "residential" scenario in the HSB RAM, as is "occasional" analogous to "recreational". The terms "frequent" and "occasional" are used to stress the qualitative aspect of the QRA as opposed to the more rigorous baseline risk assessment to be done in the future wherein the terms "residential" and "recreational" will be used. The frequent-use scenario considers the potential future uses of this site. Ecological scenarios are evaluated using biological endpoints appropriate for the size and the nature of the operable unit. These use scenarios are consistent with the recommendations of the Hanford Future Site Uses Working Group (HFSUWG). The HFSUWG identified several cleanup scenarios for the 100 Area. One of three cleanup scenarios for the 100 Area is to support unrestricted land use. To the HFSUWG, unrestricted means that contamination does not preclude any human uses. Residential is the most conservative use scenario in HSB RAM, so evaluation of this use scenario supports all the uses encompassed by the HFSUWG under the unrestricted cleanup scenario.

This QRA for the 100-KR-4 groundwater operable unit is based primarily on the nature and extent of contaminated groundwater and the risk posed by discharge of this groundwater to the Columbia River. The QRA is conducted using the *Hanford Site Baseline Risk Assessment Methodology* (DOE-RL 1993) as guidance. The QRA provides estimates of risk that might occur under frequent-use or occasional-use scenarios.

1.2 OPERABLE UNIT BACKGROUND

The 100 K Area at the Hanford Site was used by the U.S. Government to produce plutonium for nuclear weapons. These operations resulted in the release of chemical and radioactive wastes into the soil, air, and water. For cleanup purposes, the 100 K Area has been divided into four operable units, three of which are source operable units (100-KR-1, 100-KR-2, and 100-KR-3), while the fourth (100-KR-4) is the groundwater operable unit.

1.2.1 Location

The Hanford Site is a 1,434-km² (560-mi²) tract of land located in Benton, Franklin, and Grant counties in the south-central portion of the state of Washington. The 100 K Area is situated in the north-central part of the Hanford Site along the southern shoreline of the Columbia River, approximately 45 km (28 mi) northwest of the city of Richland, Washington, as shown in Figure 1-1. The 100 K Area is located just downstream of the 100 B/C Area, and encompasses approximately 3.1 km² (1.2 mi²). It lies within Sections 5 and 6 of Township 13N, Range 26E and Sections 31 and 32 of Township 14N, Range 26E. The 100 K Area lies between the north/south Hanford Plant coordinates N36700 and N73500, and the east/west coordinates W71700 and W63700. This area contains the facilities associated with operation of the K-East (KE) and K-West (KW) plutonium production reactors.

The 100-KR-4 operable unit includes the groundwater below the 100 K Area source operable units plus the adjacent groundwater, saturated soils, surface water, and aquatic biota impacted by 100 K Area operations. The 100 K Area source operable units are being addressed in separate QRAs. This QRA only addresses the 100-KR-4 groundwater operable unit. Figure 1-2 shows the approximate boundaries of the 100-KR-4 operable unit.

1.2.2 History of Operations

The KW and the KE reactors and support facilities were constructed between 1952 and 1954. The KW reactor operated from 1955 through 1970, when it was retired from service. The KE reactor operated from 1955 through 1971 and was then retired from service. Although a few ancillary structures were shared by the reactor facilities, in general the major support operations were duplicated. Two noteworthy exceptions are the 116-K-1 crib and 116-K-2 trench (Figure 1-2), which were used in the operation of both reactors when fuel cladding failures occurred. The 116-K-1 crib operated during 1955 and was replaced by the 116-K-2 trench in that same year; however recent aerial photographs show liquid in the 116-K-1 crib, which is thought to have leaked through a valve in the 116-K-2 trench and then into the 116-K-1 crib via the lines connecting the two (DOE-RL 1992a).

Currently, there are several active facilities within the 100 K Area. They include the KE and KW reactor fuel storage basins (located inside the 105-KE and 105 KW reactor buildings, respectively) used to store spent fuel from the N reactor; the alum tanks adjacent to building 183.1-KE; the 1706-KE building used for research and development (experimental fish-rearing activities); buildings used for site management; one pumphouse; one water treatment facility; and septic tanks and leach fields used for disposal of sanitary waste.

1.3 PROCESS OVERVIEW

This QRA is performed in accordance with guidance provided in the *Hanford Site Baseline Risk Assessment Methodology* (DOE-RL 1993). The QRA process is composed of four elements: data evaluation, human health evaluation, ecological evaluation, and a discussion of uncertainty in the evaluations.

A list of detected analytes is obtained from review of data generated from LFI sampling activities. These data are subjected to several validation procedures to determine the list of contaminants to be included in the human health and ecological evaluations. The maximum representative concentration for the retained constituents is provided to the risk assessors.

The human health evaluation consists of exposure assessment, toxicity assessment, and characterization of risk for the two exposure scenarios agreed on for the Site. The ecological evaluation is conducted in three phases: problem formulation, analysis, and risk characterization.

Uncertainty in the QRA is introduced at all stages of the process. The human health risks presented in the QRA are based on multiple assumptions about exposures, toxicity, and other variables. The ecological evaluation includes assumptions about populations and uptake of contaminants that incorporate many variables. Both the human health and ecological evaluations are based on data values that have a measure of uncertainty associated with them.

Figure 1-1. The Hanford Site.

Figure 1-2. 100 K Area Operable Unit Boundaries.

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2.0 100-KR-4 QRA DATA EVALUATION

This chapter describes the process of selecting the data to be used in the human health and ecological evaluations. The raw data sources are identified and the screening procedures used to refine the data are presented. A summary of the results of the data evaluation is provided and the uncertainty in the data is discussed.

2.1 DATA SOURCES

An overview of the general sources of information consulted to prepare the QRA is discussed in this section. Four data sets were developed for the QRA, and a set of background data was used in the screening process. The data sets used come from the LFI data, 100 K Area spring data, and Columbia River data. A more comprehensive discussion of data sources is provided in the LFI report for this operable unit.

2.1.1 LFI Data for the 100-KR-4 Operable Unit

An LFI was completed in accordance with the work plan (DOE-RL 1992a) and the *Description of Work for the 100-KR-4 Groundwater Operable Unit* (Roberts 1992a) to provide additional information and characterization needed to support selection, design and implementation of IRMs. Monitoring wells were installed during the LFI to define groundwater quality in areas of potential exposure (e.g., near seeps and springs along the Columbia River shoreline that are downgradient of contamination sources), to define groundwater quality immediately downgradient of 100 K Area waste sites, and to identify potential sources of groundwater contamination. A survey and inspection of existing wells were conducted to evaluate their "fitness-for-use" for environmental monitoring (Ledgerwood 1991).

Figure 2-1 is a map showing the locations of the monitoring wells within the 100-K Area. Seventeen wells included in the LFI were used in evaluating the 100-KR-4 groundwater operable unit. They are: K-11, K-13, K-18, K-19, K-20, K-21, K-22, K-23, K-27, K-30, K-31, K-32A, K-33, K-34, K-35, K-36, and K-37. All of these wells were used in developing the data set (Table 2-1) containing the overall site representative maximum values used in the human health evaluation, but not all wells were sampled in all rounds. Well K-19 was not sampled in rounds 1 and 2, and wells K-23 and K-33 were not sampled in round 2. In addition, there were instances where samples were broken or certain analyses were not provided. The number of detects presented in Tables 2-1 and 2-2 includes only the first three rounds of data; however, the maximum representative concentrations given in the tables are from all four rounds.

Some LFI wells were not used in the QRA. Well K-32B was completed in the confined aquifer and concentrations found in this well were not considered representative of the concentrations in the 100 Area unconfined aquifer wells. Several 600 Area wells (70-68, 78-62, and 73-61) were not included because they were outside the 100-KR-4 boundary and were sampled for use in characterizing groundwater flow in the area.

A second data set was constructed from the LFI data for use in the ecological evaluation (Table 2-2). This data set is composed of the maximum representative concentration observed in the set of groundwater wells determined to be "near-river". These are wells that are sufficiently close to the river to experience the influence of the river water. It was assumed that contaminants in these

wells could be discharged to the Columbia River system, where they would be available to the aquatic foodweb. The dividing line for determining the set of near-river wells was arbitrarily defined to be the 116-K-2 trench. A line was drawn through the trench and extended through the 100 K site. All wells on the river side of this line, a total of 11, were classified as near-river. They are: K-13, K-18, K-19, K-20, K-21, K-22, K-31, K-32A, K-33, K-34 and K-37.

The data from the first four sampling rounds of the LFI were used in the QRA. The maximum representative contaminant concentrations were derived from the data validation reports for the 100-KR-4 operable unit (Roberts 1992b, Biggerstaff 1993a,b,c).

Unfiltered samples were used in reporting all maximum representative concentrations for the QRA, though sample results for the inorganic data include both filtered and unfiltered data. The data progression over the four sampling rounds was examined to determine whether the wells constructed for the LFI (numbers K-32A and higher) have reached equilibrium. If the unfiltered sample results for inorganic constituents declined by an order of magnitude in successive rounds, the higher data values from the well were not used in the QRA. Also, well equilibrium is judged by comparison of the filtered and unfiltered sample results.

2.1.2 K Area Spring and River Data

Spring and river samples were collected in the fall of 1991 from the south and west banks of the Columbia River during a low-flow period of the river. The most upstream sample location was the intake structure at the 100 B/C reactor, and the most downstream sample location was in the Hanford Township below the 100 Area boundary. The spring and river samples were analyzed for chemical and radiological parameters (DOE-RL 1992b). Three of the springs sampled in this investigation are located at the 100 K Area. River samples were taken at the same approximate locations as the springs were found. The locations of the spring and river samples are those labeled with Sample Area "100K" in the Sampling and Analysis of 100 Area Springs (DOE/RL-92-12). There are three such samples and they occur at approximate Hanford River Mile markers 6, 7.5, and 8.33. The HRM 6 location is up gradient of the K Area, and the other two locations are down gradient.

Filtered and unfiltered samples were analyzed for the K Area springs and river, but only unfiltered samples were used in the QRA. These data are presented in Table 2-3 and are used for comparison purposes only, since these data are insufficient to choose representative concentrations for use in the human health and ecological evaluations.

2.1.3 Hanford Site Background Data

Naturally occurring inorganic material in groundwater at the Hanford Site was recently characterized (DOE-RL 1992c). The characterization effort identified the types of inorganic analytes that exist naturally in the groundwater within the unconfined aquifer, and provided a reference concentration for each analyte. The term "background" is defined according to the EPA definition as the ambient concentration of chemicals in the environment unimpacted by human activities. Provisional threshold levels for 40 inorganic analytes were developed to represent groundwater background concentrations at the Hanford Site. These site-wide data are used in this evaluation to represent background for the 100-KR-4 operable unit, consistent with agreements made by Tri-Party Agreement unit managers (February 8, 1993).

There are no site-wide background concentrations that have been agreed on for organic analytes or for most radionuclide analytes. Detected levels of organic and radionuclide analytes in LFI data are assumed to be site-related contaminants and are not compared to background.

2.2 DATA EVALUATION SCREENING

The representative values detected in the groundwater well sampling were subjected to several screening procedures in accordance with the Contaminant Identification Process: Phase 1 presented in the risk assessment methodology (DOE-RL 1993, Figure 2-1A). The methodology directs the use of screening procedures as recommended in the *Risk Assessment Guidance for Superfund Human Health Evaluation Manual* (EPA 1989). These data screening procedures include data validation, consistency checks, comparison to blank concentrations, comparison to background concentrations, elimination of nontoxic substances, and elimination of infrequently occurring analytes and risk-based screening. The following is a summary of the results of these procedures.

2.2.1 Data Validation

Samples from the LFI for the 100-KR-4 groundwater operable unit were analyzed for volatile, semivolatile, pesticide/polychlorinated biphenyls (PCBs), inorganic, radionuclide, and wet chemistry parameters according to the description of work (Roberts 1992a) for the 100-KR-4 operable unit and the work plan (DOE-RL 1992a). Laboratories performing the analysis were Weston Laboratory of Lionville, Pennsylvania, and TMA-Norcal Laboratory of Richmond, California.

The LFI data collected were analyzed using methods specified in Quality Criteria for Water 1986 (EPA 1986b) with contract laboratory program (CLP) deliverables. Based on the validation activities, data results were assigned qualifiers in accordance with criteria specified in the *Data Validation Procedures for Chemical Analyses* (Bechtold 1992). Data that are termed "usable" (detected compounds or estimated "J" values) can be used in the risk assessment. Examples of data that are not considered usable are data that were rejected (qualified with an "R") by the data validator. However, if on review of the rejected data, the reason for rejection was due to administrative concerns (e.g., missing data sheets) and not because of other quality assurance/quality control (QA/QC) issues (e.g., technical concerns), the rejected data were used in the QRA.

2.2.2 Data Screening in the LFI

Several screening processes were applied to the data in the LFI evaluation. The results of these processes are presented in Appendix A of the LFI. These screening processes are:

- Elimination of inconsistent data
- Elimination of infrequently-occurring analytes
- Comparison to blank concentrations.

In addition, two more screens are applied in the LFI whose results are shown in Tables 2-1 and 2-2. These screens are:

- Comparison to background concentrations
- Elimination of nontoxic substances.

All LFI screening processes are described in Section 2.5.1 of the LFI.

2.2.3 Risk-Based Screening

Risk-based screening of constituents eliminates from the evaluation those analytes below with target risk levels (DOE-RL 1993, Figure 2-1B). The objective of the risk-based screen is to use target risk and toxicity information to evaluate which constituents are most likely to contribute significantly to risk. The target values used are a 1×10^{-7} incremental cancer risk for carcinogenic contaminants, and a 0.1 HQ for noncarcinogenic contaminants. For screening purposes, the target criteria were set at one order of magnitude more conservative than the 1×10^{-6} incremental cancer risk for carcinogens and the HQ of 1.0 for noncarcinogens. The exposure parameters for the frequent-use scenario are used for the risk-based screen. For carcinogens (adult is RME), 2 L/d is consumed 365 d/yr for 30 yrs. For noncarcinogens (child is RME), 1 L/d is consumed 365 d/yr for 6 yrs.

The analytes are then compared to contaminant-specific potential applicable or relevant and appropriate requirements (ARAR) (federal and state ambient water criteria). If the contaminant-specific maximum concentration exceeds any potential ARAR value, the analyte is considered a contaminant of potential concern and is retained for further evaluation. Any analytes that are eliminated in the risk-based screen may be retained for the ecological risk assessment based on professional judgement.

2.2.4 Screening Calculations

For carcinogenic nonradioactive contaminants, the general equation to calculate ingestion or inhalation risk-based screening concentrations is:

$$C = \frac{TR \times BW \times AT \times CF}{SF \times IR \times EF \times ED} \quad 3-3$$

where:

C	=	risk-based benchmark concentration (mg/L for water, mg/m ³ for air)
TR	=	target risk (1E-07)
BW	=	body weight (kg)
AT	=	averaging time (365 d/yr x 70 yr)
SF	=	contaminant-specific slope factor (mg/kg-d) ⁻¹
IR	=	intake rate (L/d for water, m ³ /d for air)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
CF	=	conversion factor (as appropriate)

For noncarcinogenic effects, the general equation to calculate a risk-based screening concentration is:

$$C = \frac{THQ \times RfD \times BW \times AT \times CF}{IR \times EF \times ED}$$

3-4

where:

C	=	risk-based benchmark concentration (mg/L for water, mg/m ³ for air)
THQ	=	target hazard quotient (0.1)
RfD	=	contaminant-specific chronic reference dose (mg/kg-d)
BW	=	body weight (kg)
AT	=	averaging time (365 d/yr x ED in yr)
IR	=	intake rate (L/d or m ³ /d for ingestion or volatile inhalation, respectively)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
CF	=	conversion factor (as appropriate)

For radioactive contaminants, the general equation to calculate a risk-based screening concentration is:

$$C = \frac{TR \times CF}{SF \times IR \times EF \times ED}$$

2-3

where:

C	=	risk-based benchmark concentration (pCi/L for water, pCi/m ³ for air)
TR	=	target risk (1E-07)
SF	=	radionuclide-specific slope factor (pCi) ⁻¹
IR	=	intake rate (L/d or m ³ /d for ingestion or inhalation, respectively)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
CF	=	conversion factor (as appropriate)

2.2.5 Results of the Risk-Based Screen

Four tables are used to present the risk-based screening calculations done for the 100-KR-4 QRA. Table 2-4a presents the results for drinking water ingestion of organics, Table 2-4b presents the results for inhalation due to groundwater use for volatile organics, Table 2-4c presents the results for groundwater ingestion of inorganics, and Table 2-4d presents the results for groundwater ingestion of radionuclides. The tables also include the potential ARAR values used in the screen.

Any constituent whose risk-based concentration levels or potential ARAR values are exceeded by its representative measured concentration is shaded in the tables. These constituents are designated contaminants of potential concern and are carried through the risk assessment. Constituents that are eliminated through the risk-based screen are cobalt, nickel, silver, chloride, sulfate, and total dissolved solids.

2.3 SUMMARY OF CONTAMINANTS OF POTENTIAL CONCERN

The four data sets described are presented in Tables 2-1 through 2-3. These tables present the maximum representative concentrations detected in each target media, and note the results of data screening procedures. Table 2-1 summarizes the analytes detected in the set of all groundwater wells, including an indication of whether the analyte was retained for the human health evaluation or eliminated through one of the screening procedures. Table 2-2 is a summary of the analytes detected in the set of near-river groundwater wells, including an indication of whether the analyte was retained for the ecological evaluation. Table 2-3 presents the K Area springs and Columbia River data.

The COPC as identified in Table 3-1 of the LFI vary slightly from these tables. Table 3-1 of the LFI contains only the analytes that were retained at the end of the QRA process. This includes all analytes that were retained for the ecological evaluation. It includes analytes that were retained for the human health evaluation, except those that were eliminated in the risk-based screen. Both cobalt and sulfate were eliminated from the human health evaluation in the risk-based screen. For the ecological evaluation, cobalt was not detected in the near-river wells, and sulfate was eliminated from the near-river wells in the background screen.

2.4 DATA UNCERTAINTY

The major issues in data uncertainty for the QRA are confidence in the concentrations chosen for inclusion in the QRA, and confidence in contaminant identification. The data available to conduct the QRA are LFI data from four rounds of sampling. The confidence in the groundwater concentrations is given a high rating, since four sampling rounds of data were used. A low confidence rating was given to the spring and river data, as only one round of sampling was performed.

The effect of the river on the groundwater in the K Area is not known. The determination of the near-river well concentrations depends on a somewhat arbitrary partition of the wells into near-river and not near-river groups.

The distribution of contaminants in the groundwater varies with location within the 100-KR-4 operable unit. The maximum representative concentrations of the contaminants of potential concern (COPC) occur in several different wells. The QRA assumes that the maximum representative concentrations of COPC are associated with DOE activities at the operable unit, but makes no attempt to associate specific sources of contamination with each of the COPC. In addition, there is also uncertainty pertaining to the effects of upgradient sources on the 100-KR-4 groundwater.

The uncertainty in the identification of contaminants present in the groundwater is low. The LFI data available to identify contaminants in the groundwater are of known quality, are analyzed using EPA methods, and are validated prior to use, although the degree of result acceptance is less rigorous than for a regular baseline risk assessment. For instance, all J (estimated values) are used, and R (rejected values) are used when they are rejected because of missing calibration sheets.

Existing radioactive constituents will decay with time, but the sources in the 100 K Area will continue to contribute to the constituent concentrations.

There is uncertainty associated with the identification of arsenic as a contaminant of potential concern. There were only two samples that showed arsenic in excess of background (equal to the contract required detection limit), therefore, the identification of arsenic as a Hanford-related contaminant is doubtful.

Figure 2-1. Identification of Groundwater Well Locations.

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Table 2-1. Summary of Detected Analytes: All Groundwater Wells (Page 1 of 2)

Analyte	Maximum Representative Concentration		# of Detects ¹	Data Range	Back-ground ²	Analyte Status
Volatile Organics (All concentrations in ug/L)						
Chloroform	17		34/46	1-17	NA	Retained
Trichloroethene	19		16/46	1-19	NA	Retained
Inorganics (All concentrations in ug/L)						
Aluminum	844	J*	40/47	15.1-844	<200	Eliminated: Non-toxic
Arsenic	10.4		24/47	2.2-10.4	10	Retained
Barium	61.8	B	46/46	12.8-61.8	68.5	Eliminated: Background
Cadmium	2.2	B	8/47	1.2-2.2	<10	Retained
Calcium	94600		47/47	31900-94600	63600	Eliminated: Non-toxic
Chromium	1950		41/47	3-1950	<30	Retained
Cobalt	3.9		8/47	2-3.9	no data	Retained
Iron	5430	J*	44/47	13.2-5430	291	Eliminated: Non-toxic
Lead	7.6		41/47	1.1-7.6	<5	Retained
Magnesium	17300		47/47	4600-17300	16480	Eliminated: Non-toxic
Manganese	69.6		37/47	1.1-69.6	24.5	Retained
Nickel	18.7		25/47	3.4-18.7	<30	Retained
Potassium	8510		47/47	1820-8510	7975	Eliminated: Non-toxic
Silver	7.1	B	8/47	2.7-7.1	<10	Retained
Sodium	31100		47/47	3720-31100	33500	Eliminated: Background
Vanadium	23.8	B	38/47	2.9-23.8	15	Retained
Zinc	461	E	37/47	2.3-461	<50	Retained

Table 2-1. Summary of Detected Analytes: All Groundwater Wells (Page 2 of 2)

Analyte	Maximum Representative Concentration		# of Detects ¹	Data Range	Back-ground ²	Analyte Status
Radionuclides (All concentrations in pCi/L)						
Carbon-14	23000	J	31/47	51-23000	NA	Retained
Strontium-90	36		20/47	1.3-36	NA	Retained
Technetium-99	46	J	13/47	1-46	NA	Retained
Tritium	1.9E+6		45/47	210-1.9E+6	NA	Retained
Uranium-233/234	3.3		46/47	0.2-3.3	3.43	Retained
Uranium-235	0.29		12/47	0.11-0.29		Retained
Uranium-238	2.6		46/47	0.15-2.6		Retained
Wet Chemistry and Anions (All concentrations in mg/L except as noted)						
Alkalinity	177		47/47	46-177	210	Eliminated: Background
Chloride	21.6		47/47	3.0-21.6	8.69	Retained
Fluoride	0.5		38/47	0.2-0.5	0.775	Eliminated: Background
Nitrate/Nitrite	26.0		45/45	0.71-26.0	12.4	Retained
pH (Std. Units)	7.3-8.7		47/47	7.7-8.7	7.3-8.3	Eliminated: Background
Sulfate	109	J	47/47	17-109	90.5	Retained
Total Dissolved Solids	452	J	47/47	132-452	no data	Retained

¹ = Number of detects based on three rounds of data² = < number indicates that the analyte was undetected at the given detection level

E/J = Estimated value

* = Duplicate analysis not within control limits

B = Value below the contract required detection limit

Table 2-2. Summary of Detected Analytes: Near-River Groundwater Wells (Page 1 of 2)

Analyte	Maximum Representative Concentration		# of Detects ¹	Data Range	Back-ground ²	Analyte Status
Volatile Organics (All concentrations in ug/L)						
Chloroform	17		20/29	1-17	NA	Retained
Trichloroethene	19		8/29	1-19	NA	Retained
Inorganics (All concentrations in ug/L)						
Aluminum	72.1	B	24/30	15.1-72.1	< 200	Retained
Arsenic	6.6	B	12/30	2.2-6.6	10	Eliminated: Background
Barium	61.8	B	30/30	12.8-61.8	68.5	Eliminated: Background
Cadmium	2.2	B	5/30	1.2-2.2	< 10	Retained
Calcium	94600		30/30	33300-94600	63600	Eliminated: Nutrient
Chromium	261		29/30	12.5-261	< 30	Retained
Iron	1230		28/30	13.2-1230	291	Retained
Lead	5.8	WJ	26/30	1.1-5.8	< 5	Retained
Magnesium	12100		30/30	4600-12100	16480	Eliminated: Background
Manganese	69.6		21/30	1.1-69.6	24.5	Retained
Nickel	9.9		15/30	3.4-9.9	< 30	Retained
Potassium	6400		30/30	1820-6400	7975	Eliminated: Background
Silver	5.2	B	4/30	2.7-5.2	< 10	Retained
Sodium	20300		30/30	3720-20300	33500	Eliminated: Background
Vanadium	19.1	B	21/30	2.9-19.1	15	Retained
Zinc	461	E	24/30	2.3-461	< 50	Retained

Table 2-2. Summary of Detected Analytes: Near-River Groundwater Wells (Page 2 of 2)

Analyte	Maximum Representative Concentration		# of Detects ¹	Data Range	Back-ground ²	Analyte Status
Radionuclides (All concentrations in pCi/L)						
Carbon-14	16,000	J	16/31	57-16000	NA	Retained
Strontium-90	36		20/31	1.3-36	NA	Retained
Technetium-99	11	R	8/31	1-11	NA	Retained
Tritium	35,000		30/31	210-35000	NA	Retained
Uranium-233/234	2.3		29/30	0.2-2.3	3.43	Retained
Uranium-235	0.16	J	4/31	0.046-0.16		Retained
Uranium-238	1.9		29/31	0.15-1.9		Retained
Wet Chemistry and Anions (All concentrations in mg/L, except as noted)						
Alkalinity	170	J	30/30	46-170	210	Eliminated: Background
Chloride	21.6		30/30	3-21.6	8.69	Retained
Fluoride	0.4		22/30	0.2-0.4	0.775	Eliminated: Background
Nitrate/Nitrite	26		29/29	0.71-26	12.4	Retained
pH (Std. Units)	7.3-8.7		30/30	7.8-8.7	7.3-8.3	Eliminated: Background
Sulfate	85.2		30/30	20-85.2	90.5	Eliminated: Background
Total Dissolved Solids	452		30/30	132-452	no data	Retained

¹ = Number of detects based on three rounds of data² = < number indicates that the analyte was not detected at the given detection level

B = Value below the contract required detection limit

E/J = Estimated value

R = Rejected for administrative reasons

W = Out of control limits

Table 2-3. Summary of Detected Analytes: K Area Springs and Columbia River. (DOE-RL 1992d)

Analyte	Maximum Springs Concentration	Maximum River Concentration
Volatile Organics (All concentrations in $\mu\text{g/L}$)		
Chloroform	NA	NA
Trichloroethene	NA	NA
Inorganics (All concentrations in $\mu\text{g/L}$)		
Aluminum	255	ND
Cadmium	ND	ND
Chromium	68.7	ND
Iron	243	171
Lead	NA	NA
Manganese	8.7 B	19.6
Nickel	ND	ND
Silver	ND	ND
Vanadium	10.7 B	ND
Zinc	ND	6.4 B
Radionuclides (All concentrations in pCi/L)		
Carbon-14	NA	NA
Total Uranium	1.1	0.49
Strontium-90	8.8	0.7
Technetium-99	5.2	2
Tritium	8900	ND
Total Uranium	1.1	0.49
Wet Chemistry (All concentrations in mg/L)		
Chloride	6.01	0.86
Nitrate/Nitrite	1.47	0.5
Total Dissolved Solids	221	89
Total Organic Carbon	0.75	1.5

ND - Not detected

NA - No data available

B - Value below the contract required detection limit.

Table 2-4a. Human Health Risk-Based Screening Calculations for Ingestion of Organics.

Analyte	Maximum Concentration (mg/L)	Oral	Conc. at	Oral	Conc	Drinking Water Standards		WA State	EPA Water Quality Criteria	
		RfD (mg/kg-d)	HQ = 0.1 (mg/L)	SF 1/(mg/kg-d)	at R = e-7 (mg/L)	MCL (mg/L)	MCLG (mg/L)	CFWQC (mg/L)	HWQHC (mg/L)	HWQWC (mg/L)
Chloroform	1.70E-02	1.00E-02	1.60E-02	6.10E-03	1.34E-03	1.00E-01	NA	1.24E+00	1.90E-04	NA
Trichloroethene	1.90E-02	6.00E-03	9.60E-03	1.10E-02	7.42E-04	5.00E-03	0.00E+00	2.20E+01	NA	NA

NA - No Data Available

Table 2-4b. Human Health Risk-Based Screening Calculations for Inhalation of Organics.

Analyte	Maximum Concentration (mg/L)	Inhalation RfD (mg/kg-d)	Conc. at HQ=0.1 (mg/L)	Inhalation SF 1/(mg/kg-d)	Conc at R=e-7 (mg/L)
Chloroform	1.70E-02	NA	—	8.10E-02	2.69E-05
Trichloroethene	1.90E-02	NA	—	6.00E-03	3.63E-04

NA - No Data Available

Table 2-4c. Human Health Risk-Based Screening Calculations for Ingestion of Inorganics.

Analyte	Maximum Concentration (mg/L)	Oral		Conc. at HQ=0.1 (mg/L)	Oral SF 1/(mg/kg-d)	Conc at R=e-7 (mg/L)	Drinking Water Standards			EPA Water Quality Criteria		
		RfD (mg/kg-d)					MCL (mg/L)	MCLG (mg/L)	CFWQC (mg/L)	HWQHC (mg/L)	HWQWC (mg/L)	
Arsenic	1.04E-02	3.00E-04	4.80E-04	1.70E+00	4.80E-06		5.00E-02	NA	4.80E-02	NA	NA	
Cadmium	2.20E-03	1.00E-03	1.80E-03	NA	--		5.00E-03	5.00E-03	7.00E-04	1.00E-02	NA	
Chromium	1.95E+00	5.00E-03	8.00E-03	NA	--		1.00E-01	1.00E-01	1.10E-02	5.00E-02	NA	
Cobalt	3.90E-03	6.00E-02	9.60E-02	NA	--		NA	NA	NA	NA	NA	
Lead	7.80E-03	NA	--	NA	--		1.50E-02	0.00E+00	1.20E-03	5.00E-02	NA	
Manganese	6.96E-02	5.00E-03	8.00E-03	NA	--		5.00E-02	NA	NA	1.00E-01	5.00E-02	
Nickel	1.87E-02	2.00E-02	3.20E-02	NA	--		1.00E-01	1.00E-01	1.00E-01	NA	NA	
Silver	7.10E-03	5.00E-03	8.00E-03	NA	--		1.00E-01	NA	NA	5.00E-02	NA	
Vanadium	2.38E-02	7.00E-03	1.12E-02	NA	--		NA	NA	NA	NA	NA	
Zinc	4.61E-01	3.00E-01	4.80E-01	NA	--		5.00E+00	NA	6.30E-02	NA	5.00E+00	
Chloride	2.16E+01	NA	--	NA	--		2.50E+02	NA	2.30E+02	NA	NA	
Sulfate	1.09E+02	NA	--	NA	--		2.50E+02	NA	NA	NA	NA	
Total Dissolved Solids	4.52E+02	NA	--	NA	--		5.00E+02	NA	NA	NA	NA	
Nitrate/Nitrite	2.80E+01	1.60E+00	2.56E+00	NA	--		1.00E+01	1.00E+01	NA	1.00E+01	NA	

NA - No Data Available

NA - No Data Available

Table 2-4d. Human Health Risk-Based Screening Calculations for Ingestion of Radionuclides.

Analyte	Maximum Concentration (pCi/L)	Oral SF 1/pCi	Conc at risk 1.0e-7	40 CFR 141 MCL (pCi/L)	10 CFR 20 NRC (pCi/L)
Carbon-14	2.30E+04	9.00E-13	5.07E+00	2.00E+03	8.00E+05
Strontium-90	3.60E+01	3.60E-11	1.27E-01	8.00E+00	3.00E+02
Technetium-99	4.60E+01	1.30E-12	3.51E+00	9.00E+02	3.00E+05
Tritium	1.90E+06	5.40E-14	8.46E+01	2.00E+04	3.00E+06
Uranium-233/234	3.30E+00	1.60E-11	2.85E-01	NA	3.00E+04
Uranium-235	2.90E-01	1.60E-11	2.85E-01	NA	3.00E+04
Uranium-238	2.60E+00	2.80E-11	1.63E-01	NA	4.00E+04

NA - No Data Available

3.0 100-KR-4 HUMAN HEALTH EVALUATION

The human health evaluation for the 100-KR-4 groundwater operable unit is presented. The human health evaluation consists of calculating exposure, presenting toxicity data, and characterizing risk.

3.1 EXPOSURE ASSESSMENT

The exposure assessment methodology is presented in Section 2.2 and in the risk assessment methodology (DOE-RL 1993, Appendices A and C). The exposure assessment includes the determination of exposure scenarios, exposure pathways, exposure parameters, exposure point concentrations, and the quantification of exposures.

3.1.1 Groundwater Use Scenarios and Parameters

The pathways and scenarios used in the 100-KR-4 groundwater operable unit QRA are those discussed and selected by the 100 Area Tri-Party Agreement unit managers (February 8, 1993). The exposure pathways selected for analysis are ingestion of groundwater and inhalation of volatile contaminants during groundwater use.

Two scenarios were selected to provide a bounding estimate of potential risk. These scenarios are a frequent-use scenario and an occasional-use scenario. There are no frequent or occasional users of groundwater at the 100-KR-4 operable unit, so the risks presented in the QRA are not actual risks but estimates of potential risks under frequent and occasional groundwater usage. The occasional-use scenario may approximate a trespasser scenario, the only scenario under which current groundwater use could occur. There is no industrial use of groundwater in the 100 K Area.

The exposure parameters include the intake rate of contaminated groundwater, frequency and duration of exposure, body weight, and averaging time. A summary of the parameters used for the 100-KR-4 QRA are presented in Tables 3-1a (occasional-use) and 3-1b (frequent-use). The exposure point concentrations used for the 100-KR-4 QRA are the maximum representative concentrations for all groundwater wells for those contaminants retained in the initial data evaluation.

3.1.2 Exposure Quantification

The quantification of exposures involves estimating the intake of contaminants using the parameters for the scenarios and pathways described above. The basic equation for calculating intakes of nonradioactive contaminants via groundwater ingestion or inhalation of volatile organic compounds from groundwater use is:

$$\text{Intake} = \frac{C \times IR \times CF \times EF \times ED}{BW \times AT}$$

3-1

where:

Intake	=	chronic daily intake of the contaminant (mg/kg-d)
C	=	contaminant concentration (mg/L)
IR	=	intake rate (L/d for water or m ³ /d for air)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
CF	=	conversion factor (L/m ³ for inhalation exposures)
BW	=	body weight (kg)
AT	=	averaging time (yr x 365 d/yr)

The quantification of exposures to radioactive contaminants requires a separate treatment, as the units used to express environmental concentrations of radioactive and nonradioactive contaminants are different. In addition, intake estimates for radionuclides should not be divided by body weight or averaging time. Instead, the calculated intakes for radioactive contaminants represent radionuclide activities that are inhaled or ingested over a lifetime.

The basic equation for calculating intakes of radioactive contaminants via groundwater ingestion or inhalation of volatile organic compounds from groundwater use is:

$$\text{Intake} = C \times IR \times EF \times ED \quad 3-2$$

where:

Intake	=	radionuclide-specific lifetime intake (pCi)
C	=	radionuclide concentration (pCi/L for water, pCi/m ³ for air)

3.2 TOXICITY ASSESSMENT

The general procedures for toxicity assessment are presented by DOE (DOE-RL 1993, Section 2.3). The toxicity assessment for the QRA identifies contaminant-specific toxicity factors and briefly discusses the key toxicities associated with contaminants identified in the data evaluation process. The intent is to include sufficient toxicity information to assist project managers in reaching decisions on IRMs, but not to evaluate all potential toxicities.

The toxicity information for carcinogenic contaminants is the slope factor (SF), an estimate of chemical-specific risk per unit dose. The toxicity information for the noncarcinogenic contaminants is the reference dose (RfD), chemical-specific provisional reference doses for toxicity from chronic inhalation and oral exposure. A limited number of contaminants have sufficient data to have established toxicity values. There are uncertainties associated with the toxicity values as outlined in the risk assessment methodology (DOE-RL 1993).

The toxicity values and supporting information for both noncarcinogenic and carcinogenic substances carried through the risk assessment are included in the risk-based screening calculation tables. A brief discussion of the primary toxic effects for each contaminant of potential concern is provided in Appendix A.

3.3 RISK CHARACTERIZATION

The risk characterization for the human health evaluation is conducted as presented by DOE (DOE-RL 1993, Section 2.4) based on the information from the data evaluation, the exposure assessment, and the toxicity assessment. It forms the basis for characterizing risks and human health hazards from potential exposures to COPC detected at the 100-KR-4 groundwater operable unit. Risk characterization is a key element in the process for identifying the contaminants of concern at the 100-KR-4 groundwater operable unit.

The risk characterization process is divided into discussion of carcinogenic and noncarcinogenic calculations. The distinction is made because the methodology differs for these two modes of chemical toxicity. In both modes, the calculated intakes and the toxicity information are combined to quantify the potential for human health effects.

For a carcinogenic contaminant, the projected intake is multiplied by the contaminant-specific SF to estimate the incremental probability of an individual developing cancer over a lifetime above the background cancer rate in the general population as a result of exposure to that carcinogen. This risk is called the lifetime incremental cancer risk (ICR). Calculated ICRs are compared to an ICR of $1E-06$. For noncarcinogenic contaminants, potential human health hazards are estimated through a contaminant-specific quantity known as the hazard quotient (HQ), which is the intake divided by the contaminant-specific chronic reference dose (RfD). Calculated HQs are compared to a HQ of unity.

3.3.1 Human Health Risk Calculations

Human health risk is quantified for noncarcinogens by the HQ. The basic equation for determining the HQ for the ingestion and inhalation exposure pathways is:

$$HQ = I/RfD \quad 3-6$$

where:

HQ	=	hazard quotient (unitless)
I	=	intake (mg/kg-d)
RfD	=	contaminant-specific chronic reference dose (mg/kg-d).

The basic equation for determining the ICR for the ingestion and inhalation pathways is:

$$ICR = I \times SF \quad 3-7$$

where:

ICR	=	lifetime incremental cancer risk (unitless)
I	=	intake (mg/kg-d or pCi for nonradioactive and radioactive constituents, respectively)
SF	=	chemical-specific slope factor $[(mg/kg-d)^{-1}$ or $(pCi)^{-1}$ for nonradioactive and radioactive constituents, respectively].

3.3.2 Results of Risk Characterization

The calculations done for the risk characterization were separated into contaminant class, carcinogenic and noncarcinogenic contaminants, and ingestion and inhalation (for organic only) pathways. Six tables are needed to present the results. The risk calculations are shown in Tables 3-2a through 3-2f. For the noncarcinogens, the HQs are summed to produce a total hazard index (HI) for each contaminant class and exposure pathway combination. For carcinogens the ICRs are summed to produce a total ICR for radionuclides and nonradionuclides separately for each exposure pathway. All ICRs exceeding $1\text{E-}06$ and all HQs or HIs exceeding unity are highlighted in the tables.

Calculations for the organic contaminants are presented in three tables. As presented in Table 3-2a, there are no adverse noncarcinogenic effects for ingestion of organics at the maximum representative concentrations. All observed HQs are well below unity. There is significant carcinogenic risk associated with both ingestion and inhalation of organics at the maximum representative concentrations. Tables 3-2b and 3-2c indicate that under the frequent-use scenario, the risk estimates for both chloroform and trichloroethene exceed $1\text{E-}06$. Inhalation is not an exposure pathway for the occasional-use scenario, and neither of the contaminants show a risk above the threshold for ingestion under the occasional-use scenario.

The results for inorganic contaminants are presented in two tables. Table 3-2d contains estimates of the noncarcinogenic HQs for inorganic contaminants. Three contaminants, arsenic, chromium, and nitrate/nitrite, show HQs in excess of 1.0 for the frequent-use scenario, with the HQ for chromium exceeding two orders of magnitude. None of these contaminants has an HQ greater than unity under the occasional-use scenario. The carcinogenic risk from inorganic contaminants is presented in Table 3-2e. The risk exceeds $1\text{E-}06$ for arsenic for both the frequent- and occasional-use scenarios.

The risk from radioactive contaminants is presented in Table 3-2f. Six radionuclides have an estimated risk in excess of $1\text{E-}06$ for the frequent-use scenario. These are carbon-14, strontium-90, technetium-99, tritium, uranium-233/234, and uranium-238. Only tritium and carbon-14 have ICRs in excess of $1\text{E-}06$ for the occasional-use scenario.

3.4 UNCERTAINTY IN EXPOSURE AND TOXICITY ASSESSMENT

Two scenarios have been evaluated to provide estimates of hazard or risk based on frequent use exposure (e.g., residential water ingestion) or occasional use (e.g., recreational water ingestion). Neither of these scenarios currently occurs in the 100-K Area. The QRA is based on a potential exposure to the maximum representative concentration, assuming that it will not increase or decrease over the 30-year assumed lifetime for the exposure calculation. Therefore, there is uncertainty in the risk results because the use of a maximum representative concentration may not be indicative of the actual concentration over time.

The risk characterization focuses on only the ingestion of water and the inhalation of volatile organic compounds from groundwater use. Exposure through other pathways such as external exposure from submersion in radionuclide-contaminated waste may result in additional risk, though it is not known if the additional risk would be significant. In general, for most inorganics and radionuclides, exposure through the ingestion route is greater than for other routes of exposure to contaminants in water.

Intake and risk due to the inhalation of volatile organics are calculated for the residential scenario only. These exposures assume inhalation of volatiles from water use within a residence. Recreational exposure to volatiles could occur during recreational use of groundwater. Factors needed to evaluate such exposures have not been developed. However, given the lower frequency of recreational exposures, the potential risks for recreational receptors from inhalation of volatiles would be at least an order of magnitude less than the risks estimated for residential receptors due to the difference in exposure durations for the two scenarios.

Despite the uncertainties in the various steps of the risk assessment, the effect of the assumptions provides an upper bound of risk. That is, the actual risks for human health as a result of the 100-KR-4 groundwater operable unit are less than the estimated risks.

Table 3-1a. Exposure Factors for the Occasional-Use Scenario.¹

	Route	Daily intake rate	Exposure Frequency (d/yr)	Exposure Duration (yr)	Body Weight (kg)	Averaging Time (yr x d/yr)	Conversion Factors
Noncarcinogens	Ingestion	1 L	7	6	16	6 x 365	--
Non-Radioactive Carcinogens	Ingestion	2 L	7	30	70	70 x 365	--
Radioactive Carcinogens	Ingestion	2 L	7	30	--	--	--

¹DOE-RL, 1993, *Hanford Site Baseline Risk Assessment Methodology*, DOE/RL-91-45, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Table 3-1b. Exposure Factors for the Frequent-Use Scenario.¹

	Route	Daily intake rate	Exposure Frequency (d/yr)	Exposure Duration (yr)	Body Weight (kg)	Averaging Time (yr x d/yr)	Conversion Factors
Noncarcinogens	Ingestion	1 L	365	6	16	6 x 365	--
	Inhalation	15 m3	365	30	70	30 x 365	0.5 L/m3
Non-Radioactive Carcinogens	Ingestion	2 L	365	30	70	70 x 365	--
	Inhalation	15 m3	365	30	70	70 x 365	0.5 L/m3
Radioactive Carcinogens	Ingestion	2 L	365	30	--	--	--

¹DOE-RL, 1993, *Hanford Site Baseline Risk Assessment Methodology*, DOE/RL-91-45, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Table 3-2a. Human Health Risk Calculations for Noncarcinogenic Effects of Ingestion of Organics.

Analyte	Maximum Concentration (mg/L)	Oral RfD (mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Hazard Quotient	Daily Intake (mg/kg-d)	Hazard Quotient
Chloroform	0.017	1.00E-02	2.04E-05	0.002	1.06E-03	0.1
Trichloroethene	0.019	6.00E-03	2.28E-05	0.004	1.19E-03	0.2
Total HI from ingestion of organics				0.006		0.3

Table 3-2b. Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Organics.

Analyte	Maximum Concentration (mg/L)	Oral SF 1/(mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Risk	Daily Intake (mg/kg-d)	Risk
Chloroform	1.70E-02	6.10E-03	3.99E-06	2.44E-08	2.08E-04	1.27E-06
Trichloroethene	1.90E-02	1.10E-02	4.48E-06	4.91E-08	2.33E-04	2.56E-06
Total Risk from Ingestion of Organics				7.34E-08		3.83E-06

Table 3-2c. Human Health Risk Calculations for Carcinogenic Effects of Inhalation of Organics.

Analyte	Maximum Concentration (mg/L)	Inhalation SF 1/(mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Risk	Daily Intake (mg/kg-d)	Risk
Chloroform	1.70E-02	8.10E-02	—	—	7.81E-04	6.32E-05
Trichloroethene	1.90E-02	6.00E-03	—	—	8.72E-04	5.23E-06
Total Risk from Inhalation of Volatile Organics						6.85E-05

Table 3-2d. Human Health Risk Calculations for Noncarcinogenic Effects of Ingestion of Inorganics.

Analyte	Maximum Concentration (mg/L)	Oral RfD (mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Hazard Quotient	Daily Intake (mg/kg-d)	Hazard Quotient
Arsenic	1.04E-02	3.00E-04	1.25E-05	0.042	6.50E-04	2.17
Cadmium	2.20E-03	1.00E-03	2.84E-06	0.003	1.38E-04	0.14
Chromium	1.95E+00	5.00E-03	2.34E-03	0.467	1.22E-01	24.38
Lead	7.60E-03					
Manganese	6.96E-02	5.00E-03	8.34E-05	0.017	4.35E-03	0.87
Vanadium	2.38E-02	7.00E-03	2.85E-05	0.004	1.49E-03	0.21
Zinc	4.61E-01	3.00E-01	5.53E-04	0.002	2.88E-02	0.10
Nitrate/Nitrite	2.60E+01	1.60E+00	3.12E-02	0.019	1.63E+00	1.02
Total HI from Ingestion of Inorganics				0.554		28.87

Table 3-2e. Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Inorganics.

Analyte	Maximum Concentration (mg/L)	Oral SF 1/(mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Risk	Daily Intake (mg/kg-d)	Risk
Arsenic	1.04E-02	1.70E+00	2.44E-06	4.15E-06	1.27E-04	2.16E-04
Total Risk from Ingestion of Inorganics				4.15E-06		2.16E-04

Table 3-2f. Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Radionuclides.

Analyte	Maximum Concentration (pCi/L)	Oral SF (1/pCi)	Occasional		Frequent	
			Lifetime Intake (pCi)	Lifetime ICR	Lifetime Intake (pCi)	Lifetime ICR
Carbon-14	2.30E+04	9.00E-13	9.66E+06	8.69E-06	5.04E+08	4.53E-04
Strontium-90	3.60E+01	3.60E-11	1.51E+04	5.44E-07	7.88E+05	2.84E-05
Technetium-99	4.60E+01	1.30E-12	1.93E+04	2.51E-08	1.01E+06	1.31E-06
Tritium	1.90E+06	5.40E-14	7.98E+08	4.31E-05	4.16E+10	2.25E-03
Uranium-233/234	3.30E+00	1.60E-11	1.39E+03	2.22E-08	7.23E+04	1.16E-06
Uranium-235	2.90E-01	1.60E-11	1.22E+02	1.95E-09	6.35E+03	1.02E-07
Uranium-238	2.60E+00	2.80E-11	1.09E+03	3.06E-08	5.69E+04	1.59E-06
Total Risk from Ingestion of Radionuclides				5.24E-05		2.73E-03

4.0 ECOLOGICAL EVALUATION

This chapter presents the ecological evaluation for the 100-KR-4 groundwater operable unit. The ecological evaluation is concerned with the potential risks to riparian and aquatic ecosystems associated with the discharge of contaminants in groundwater to the Columbia River. No ecological data were collected for the LFI; therefore, the effects of contaminants are estimated.

This evaluation was conducted in three phases: problem formulation, analysis, and risk characterization. A short evaluation of uncertainty in the results follows these phases.

4.1 PROBLEM FORMULATION

This phase identifies the environmental stressors and their characteristics, ecosystems potentially at risk, and potential ecological effects. Also, endpoints are selected and a conceptual model is developed. The major purpose of the problem formulation phase is to understand the movement of contaminants of potential concern, and the receptors that are likely to be impacted.

4.1.1 Stressor Identification

Broadly defined, a stressor is any physical, chemical, or biological entity that can induce an adverse response. However, for the purposes of the ecological evaluation, a stressor is limited to hazardous chemicals and radionuclides. The potential stressors in the groundwater from the near-river wells are the constituents in Table 2-2 that were retained for further analysis. The constituents that are potential stressors from the springs and Columbia River in the vicinity of the 100 K Area are listed in Table 2-3.

4.1.2 Ecosystems Potentially at Risk

Contaminants of potential concern (COPC) can migrate through the groundwater to springs and ultimately enter the Columbia River. Potentially affected ecosystems are discussed in the conceptual model description and Appendix B.

4.1.2.1 Conceptual Model. 100-KR-4 is a groundwater operable unit, and the potentially affected ecosystems evaluated were riparian and aquatic systems. These ecosystems are generalized in a conceptual model along with the key ecological receptors (Appendix B, Figures B-1 and B-2). In this model, contaminant transport is assumed through the groundwater to the springs and then into the Columbia River. Contaminant uptake into the aquatic foodweb is by algae and other primary producers. Organism exposure results from both food uptake and direct exposure in the river. Selected organisms potentially affected in the Columbia River and riparian zone are aquatic plants, fish, crustaceans, ducks, and herons.

Figure B-1 illustrates a foodweb conceptual model of the Columbia River biota. The center of the Columbia River ecosystem consists of the water and dissolved nutrients that nourish the photosynthetic organisms (which are the primary producers) in the river. The ecosystem also contains sediments and heterotrophic bacteria. The sediments provide a physical substratum for rooting as well as a source of chemical nutrients for the rooted aquatics. The heterotrophic bacteria play a

major role in recycling nutrients (tied up in dead organisms) into a dissolved state that can be used by plants. The bacteria are also food organisms for some consumers.

The conceptual model proposes that the maximum representative near-river well concentrations are the exposure point concentrations for the aquatic and riparian ecosystems. It does not allow for dilution in river water nor for accumulation in sediments. It is assumed that the organisms are exposed to these concentration levels irrespective of their habitat (water column, sediment or riparian zone) and that all contaminants are 100% biologically active and bioavailable. Further, it is assumed that contaminants will bioaccumulate in aquatic organisms, such as fish, through direct uptake from the water column and foodweb, although other pathways exist. The direct uptake exposure pathway is expected to dominate the other pathways.

4.1.2.2 Endpoints. An endpoint is a measurable effect to an organism from exposure to a stressor (Suter 1991). For example, increased mortality in fish is a measurable endpoint. Other possible measurement endpoints are (1) adverse effect of radiological dose to riparian and aquatic organisms, and (2) systemic toxicity of nonradiological contaminants to riparian and aquatic organisms. However, no biota were sampled to evaluate these measurement endpoints in the ecological evaluation. Environmental concentrations were compared to generic (not species-specific) benchmark concentrations that are associated with these endpoints. The generic benchmarks are based on DOE Order 5400.5 and national water quality criteria [EPA (1987), 40 CFR 131] for radionuclides and nonradionuclides, respectively.

4.1.3 Potential Ecological Effects

Ionizing radiation and hazardous chemicals can impact riparian and aquatic organisms depending on the level of exposure. Exposure can be either acute or chronic. Acute and chronic exposures can result in organism mortality. Mortality is generally characterized as the LC_{50} , the concentration to cause 50% mortality in a specified period of time. Other possible effects from acute or chronic exposure include behavioral, physiological, and morphological changes, and developmental, growth, and reproductive effects.

Exposure can result from external environmental sources and internal dosage. For radionuclides, all exposure pathways are added in determining total organism dose. The regulatory limit for exposure to radionuclides for native aquatic organisms is a dose of 1 rad/day (DOE Order 5400.5). The DOE Order 5400.5 limit of 1 rad/day is supported by work presented in IAEA (1992), *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*. That document makes several notable conclusions: (1) irradiation at chronic dose rates of 0.1 rad/day or less does not appear likely to cause observable changes in terrestrial animal populations, (2) aquatic organisms are no more sensitive than other organisms (i.e. 0.1 rad/day is applicable), (3) no appreciable effects were seen at the population level below the threshold levels (0.1 to 1.0 rad/day) in the IAEA document (note that these levels do not have a final built-in safety factor), and (4) the review indicated that the dose rate range 0.5-10 rad/day would encompass the level at which a variety of low-level effects on reproduction, development, and genetic integrity are detectable in sensitive tissues and organisms. Thus, based on the IAEA document, the DOE benchmark of 1.0 rad/day is protective at the population level for most organisms. The suite of organisms at Hanford, however, may contain some of the species for which the 1.0 rad/day is not protective at the population level. In addition, there are special status species exposed to 100-KR-4 groundwater contaminants for which assessment at the individual rather than the population level is appropriate.

For hazardous chemicals, toxicity is typically expressed as an LC_{50} . This follows a dose/response relationship--similar to radionuclides--for a variety of aquatic organisms. These criteria consider the effects of bioaccumulation and are protective of most species in a balanced, healthy aquatic community. The applicable regulatory limits are the contaminant-specific ambient water quality criteria (AWQC) (EPA 1986c) for acute and chronic lowest observable effect levels (LOEL). The AWQC were developed by the EPA after their review of numerous toxicity tests that evaluated metal and organic toxicity under various test conditions.

4.2 ANALYSIS

This phase evaluates the potential effects of exposure to contaminants of potential concern on receptor organisms.

The primary scenario in the ecological evaluation uses the maximum representative contaminant concentrations from the near-river wells, with no dilution, to establish an upper bound river exposure. The near-river wells reflect potential contaminant concentrations most likely entering the river via groundwater flow. It is assumed that organisms are exposed to the concentrations in the springs and Columbia River; however, the spring and river samples were collected only one time and are not considered representative.

For radionuclides, doses are calculated based on the CRITR2 computer code developed by Baker and Soldat (1992). The steady-state model embodied in the CRITR2 code uses generic aquatic and riparian plants and animals and assumes exposed organisms reach an equilibrium with the water concentration or food uptake. Multiple receptors are evaluated at various levels of the aquatic foodweb. The organisms evaluated using CRITR2 are aquatic plants, fish, crustacean, a plant-eating duck, a fish-eating duck, and a heron. All of these organisms are present on the Hanford Site. The transfer of contaminants to aquatic plants is evaluated via Hanford Site-specific bioconcentration factors or transfer ratios from water to plant (Baker and Soldat 1992). Animal uptake is evaluated using transfer ratios, biological half-lives, and food intake rates.

For constituents other than radionuclides, the dose/response relationship is based on the toxicity criteria, i.e., the acute and chronic LOELs, as thresholds. If a chemical exceeds the threshold LOEL, it is assumed that some component of the ecosystem may be adversely affected.

4.3 RISK CHARACTERIZATION

In this phase of the ecological evaluation, exposure information and toxicity data are integrated to produce estimates of risks to riparian and aquatic organisms. This forms the basis for characterizing the ecological hazards from hypothetical exposures to contaminants of potential concern detected in the 100-KR-4 groundwater.

The likelihood of an adverse effect to one or more organisms is expressed in the form of an environmental hazard quotient (EHQ). The EHQ is defined as the ratio of the contaminant dose to a limiting dose (1 rad/day or the LOEL).

For example, in the case of ionizing radiation for a radionuclide,

$$\text{EHQ} = \frac{\text{organism's dose}}{\text{criteria or benchmark}}$$

where the criterion is 1 rad/day. The EHQ is calculated for the nonradiological chemicals by dividing the source (e.g., near-river well concentration) by the corresponding LOEL.

For nonradionuclides (chemicals),

$$\text{EHQ} = \frac{\text{groundwater concentration}}{\text{LOEL}}$$

EHQs for aquatic and riparian receptors from internal exposure to radionuclides assuming the concentrations found in the near-river wells are shown in Table 4-1. The EHQs are the same as the calculated doses because the criterion for radionuclides is 1 rad/day. The "Totals" row represents the sum of EHQ for the listed radionuclides for each organism. In addition, immersion and sediment exposures were calculated for each organism; however, they contribute little, if any, to the total EHQ and were omitted from the table.

The highest EHQ of 1.1 resulted from exposure of fish-eating duck to carbon-14. The next highest EHQ of 0.69 resulted from exposure of heron to carbon-14. In fact, carbon-14 dominates the exposure for all organisms. Carbon-14 is a naturally occurring radionuclide and the background levels of this radionuclide in groundwater have not yet been established. Also, although carbon-14 was not analyzed in the springs and river, all other (analyzed) radionuclides had lower concentrations in the springs and river than in the near-river wells. Using this trend, the concentration of carbon-14 in the springs and river and the resulting ecological hazard are likely lower than these estimates suggest.

For chemicals, the acute or chronic LOELs are used to assess risk and serve as a limiting dose for calculation of EHQs. An EHQ at or above 1 (exceeding or meeting the LOEL) would indicate a potentially measurable risk. Table 4-2 shows maximum representative concentrations, acute and chronic aquatic LOELs for inorganic nonradioactive contaminants, and the corresponding acute and chronic EHQs. Sulfate, ammonia, and other general water quality parameters were not evaluated as COPC as there are no LOELs to serve as limiting concentrations. Cadmium, chromium, lead, silver, and zinc have chronic EHQs > 1.0 for near-river wells in the 100 K Area (see Table 4-2). Chromium, iron, silver, and zinc have acute EHQs > 1.0. Chromium was detected in the springs, but not in the river (Table 2-3).

4.4 UNCERTAINTY EVALUATION

Significant uncertainty exists in the ecological evaluation because undiluted source terms are used and all of a contaminant is assumed available for bioaccumulation. No allowance is made for environmental fate that would affect contaminant bioavailability in the Columbia River. The radiological doses were calculated using the conservative assumptions that the organism and its food source spend 100% of their time in the area containing the maximum groundwater concentrations. Actual exposure point concentrations of radioactive and nonradioactive contaminants are below these concentrations.

Most of the available information on ionizing radiation is for acute dose and not for low dose exposure and chronic effects (Rose 1992). The use of acute data extrapolated to chronic levels is not always appropriate and must be viewed with caution. For example, during chronic exposure, there is a point where competition between injury and natural organism repair mechanisms are balanced resulting in no effect (Ophel et al. 1976).

Risk is expressed as an EHQ, which implies a single conclusion has been reached. This EHQ is the result of the interaction, uncertainty, and conservatism of many different factors that enter into the risk characterization. The environmental relevancy of the characterization will depend on the accuracy of these factors.

Table 4-1. Environmental Hazard Quotients for Radionuclides in the Near-River Groundwater Wells.

Analyte	Plant	Fish	Crustacean	Duck-P	Duck-F	Heron
Carbon-14	1.8E-1	3.7E-1	3.7E-1	2.7E-1	1.1E+0	6.9E-1
Strontium-90	6.3E-3	1.1E-4	2.1E-4	6.6E-2	2.2E-3	1.4E-3
Technetium-99	3.8E-4	1.2E-6	7.6E-6	9.4E-6	5.6E-8	4.0E-8
Tritium	1.0E-5	1.0E-5	1.0E-5	1.5E-5	3.0E-5	2.0E-5
Uranium-233/234	5.2E-4	2.9E-5	5.8E-5	3.5E-4	3.8E-5	2.5E-5
Uranium-235	2.1E-5	1.2E-6	2.4E-6	1.4E-5	1.6E-6	1.0E-6
Uranium-238	3.8E-4	2.1E-5	4.2E-5	2.5E-4	2.8E-5	1.8E-5
Totals	1.9E-1	3.7E-1	3.7E-1	3.3E-1	1.1E+0	7.0E-1

NOTE: The EHQ is calculated as the ratio of the calculated dose and a benchmark radiological dose of 1 rad/day. Dose is calculated using the CRITR2 computer code (Baker and Soldat 1992).

Table 4-2. Environmental Hazard Quotients for Nonradionuclides in the Near-River Groundwater Wells.

Analyte	Maximum Concentration (ug/L)	Acute LOEL (ug/L) ¹	Chronic LOEL (ug/L) ¹	Acute EHQ	Chronic EHQ
Aluminum	72.1	1894 ²	146.7 ²	<0.1	0.5
Cadmium	2.2	3.9	1.1	0.6	2.0
Chloride (mg/L)	21.6	860 ³	230 ³	<0.1	<0.1
Chromium (VI)	261	16	11	16.3	23.7
Iron	1230	1000	NA	1.2	--
Lead	5.8	82	3.2	<0.1	1.8
Manganese	69.6	NA	NA	--	--
Nickel	9.9	1400	160	<0.1	<0.1
Nitrate/Nitrite (mg/L)	26	NA	NA	--	--
Silver	5.2	4.1	0.12	1.3	43.3
Total Dissolved Solids (mg/L)	374	NA	NA	--	--
Vanadium	19.1	NA	NA	--	--
Zinc	461	120	110	3.8	4.2
Trichloroethene	19	45000	21900	<0.1	<0.1
Chloroform	17	28900	1240	<0.1	<0.1

NA - No data available

LOEL - Lowest Observable Effect Level (EPA 1986c)

EHQ - Environmental Hazard Quotient

-- No calculation made

¹Derived from EPA ambient water quality criteria, except as noted

²Derived from EPA *Ambient Quality Criteria for Aluminum* (EPA)

³Derived from 53 FR 19028

5.0 SUMMARY AND CONCLUSIONS

This chapter provides a summary of the QRA and key uncertainties associated with the results of the QRA.

5.1 RESULTS OF HUMAN HEALTH EVALUATION

Two exposure scenarios (frequent- and occasional-use) and two pathways (groundwater ingestion and inhalation of volatile organics from groundwater use) for the QRA have been discussed and selected by the 100 Area Tri-Party Agreement unit managers for evaluation in the QRA. There is currently no human consumption of groundwater and that the consumption of surface water could be expected to be less than the consumption levels and exposure duration indicated in either the frequent- or occasional-use scenarios. Thus, the risks presented in the QRA are not actual risks but estimates of potential risks under high-frequency or low-frequency use. The frequent- and occasional-use scenarios were evaluated using the residential and recreational exposure parameters from the risk assessment methodology (DOE-RL 1993).

The risk assessment results for the COPC for human health are summarized in Tables 5-1 and 5-2. Table 5-1 presents a list of COPC in descending order of the noncarcinogenic HQ, and Table 5-2 presents a list of COPC in descending order of carcinogenic risk. The contaminant ranking in these tables is based on the results of assessment using the frequent-use scenario.

5.1.1 Noncarcinogenic Hazard

Table 5-1 summarizes the noncarcinogenic hazard for both frequent- and occasional-use scenarios and includes:

- an indication of whether the HQ exceeded 1.0
- percent of total hazard index (HI) (sum over contaminants of the HQs) contributed by the contaminant
- cumulative percent of total HI contributed by the contaminants.

Three COPC for noncarcinogenic risk (chromium, arsenic, and nitrate/nitrite) have HQs that > 1.0 under the frequent-use scenario. For all COPC, the HQ is < 1.0 under the occasional-use scenario.

5.1.2 Carcinogenic Risk

Table 5-2 summarizes the carcinogenic risk for both frequent- and occasional-use scenarios and includes:

- a qualitative risk estimation
- percent of total risk contributed by the contaminant
- cumulative percent of total risk contributed by the contaminants.

The qualitative risk estimations presented in Table 5-2 are assigned values of high

(ICR $\geq 1E-02$), medium ($1E-04 \leq \text{ICR} < 1E-02$), low ($1E-06 \leq \text{ICR} < 1E-04$), and very low ($\text{ICR} < 1E-06$), based on the results presented in Chapter 3. In general, the risk is two orders of magnitude (one level) lower for occasional-use than for frequent-use scenarios, because the only difference in the risk calculations is the exposure frequency (7 days/year for occasional use versus 365 days/year for frequent use). This difference holds except when a contaminant has both an oral and inhalation SF. If this is the case, the risk is summed across pathways for the frequent-use scenario, but only the ingestion risk applies for the occasional-use scenario.

There are 10 COPC for carcinogenic risk. Under the frequent-use scenario, the total risk is medium. Three contaminants (tritium, carbon-14, and arsenic) have medium risk estimations. There were only two samples that showed arsenic in excess of background (equal to the contract required detection limit), therefore, the identification of arsenic as a Hanford-related contaminant is doubtful. The risk estimate for six contaminants (chloroform, strontium-90, trichloroethene, uranium-238, technetium-99, and uranium-233/234) is low. The risk estimate for uranium-235 is very low. There is uncertainty associated with the identification of chloroform and arsenic as COPC. Chloroform is considered a common laboratory contaminant, and it is likely that the concentrations reported for this compound are not representative of 100-KR-4 groundwater.

The total risk under the occasional-use scenario is low. The risk for the top three contaminants (tritium, carbon-14, and arsenic) is low, and the risk for the remaining contaminants is very low.

5.1.3 Risk From Background Levels of COPCs

The risk assessment methodology (DOE-RL 1993) prescribes that the risk from background concentrations of contaminants of concern be addressed in characterizing risk. The only COPC that have both background values and RfDs for noncarcinogenic hazard assessment are arsenic, manganese, vanadium, and nitrate/nitrite. Under the frequent-use scenario, only the HQ for arsenic > 1.0 . The HQ are < 1.0 for all contaminants under the occasional-use scenario.

An evaluation was done for the carcinogenic contaminants of concern to determine the risk associated with the levels of the contaminant background concentrations. Only arsenic and total uranium have both background values and SF. The risk estimate for arsenic background is $> 10^{-4}$ for both frequent- and occasional-use scenarios. There is a medium risk under the frequent-use scenario, and a low risk under the occasional-use scenario. The risk for total uranium is low under the frequent-use scenario and is very low under the occasional-use scenario.

5.2 RESULTS OF ECOLOGICAL EVALUATION

The ecological evaluation for the 100-KR-4 operable unit was completed for selected riparian and aquatic organisms expected to be in or associated with the Columbia River. Estimated receptor doses were compared to criteria such as DOE Order 5400.5 and AWQC (EPA 1986c). The objective of the ecological evaluation was to screen for adverse ecological effects to assist in the evaluation of whether an IRM is necessary. To achieve this objective, it was necessary to perform the assessment with limited operable-unit-specific analytical and ecological data. The risks developed in the ecological evaluation are not actual risks, but estimates of potential risk under high frequency use by the organism. The actual use is not known, however, it can be assumed that exposure would be less than presented in this evaluation.

The 100-KR-4 operable unit is a groundwater unit, which affects the Columbia River. There is only one sampling round of data for the K Area springs and Columbia River, so these data are not used directly in the ecological evaluation, but are presented for comparison purposes. Source term information was developed from near-river groundwater well constituent concentrations. The groundwater concentrations establish an upper bound exposure for the organisms that were analyzed.

It is assumed that the values from near-river wells represent concentrations entering the K Area springs and then the Columbia River. In the K Area springs, concentrations are below the adverse effect levels, except for chromium, silver, and aluminum. Once contaminants enter the Columbia River, dilution should result in rapid reduction of the concentrations to levels below any possible risk level. This appears to be the case, even for chromium, silver, and aluminum, which were not detected in the Columbia River. As a point of comparison, Table 5-3 presents the concentrations of the COPC for the groundwater wells, the near-river wells, the K Area springs, and the Columbia River near the K Area.

5.2.1 Radionuclide Hazard

Radionuclide doses were calculated for the potentially affected organisms in the Columbia River and riparian zone. These organisms are aquatic plants, fish, crustacean, plant-eating duck, fish-eating duck, and heron. An EHQ was calculated using the criterion of 1 rad/day established by Order DOE 5400.5.

For all constituents evaluated, only carbon-14 exceeded an EHQ of 1.0. This occurs only for a single organism, the fish-eating duck. The resulting EHQs for the fish-eating duck are presented in Table 5-4. Carbon-14 is a COPC from the near-river wells. Carbon-14 was not analyzed for in samples taken from the K Area springs and the Columbia River near the K Area.

5.2.2 Nonradionuclide Hazard

The ecological summary for nonradionuclides (hazardous chemicals), Table 5-5, indicates that the chronic EHQs based on near-river well concentrations were exceeded for cadmium, chromium, lead, silver, and zinc. Acute EHQs were exceeded for chromium, iron, silver, and zinc. As is shown in the concentration summary table, Table 5-3, the concentrations of chromium and zinc decrease significantly in the springs; however, the concentration of chromium and silver found in the springs exceeds both the acute and chronic LOELs. Neither silver nor chromium was detected in the river water samples. Lead was not included in the analyses of the spring and river water samples. The primary concern posed by chromium in the K Area springs is that the 100 Area is a known area of chinook spawning and, if the spring concentrations exceed the acute and chronic LOEL for hexavalent chromium, there is an increased likelihood of risk to young chinook salmon and trout (Becker 1990).

5.3 SUMMARY OF UNCERTAINTY

Uncertainty in the evaluation of data, human health risk, and ecological risk are discussed in this section.

5.3.1 Uncertainty in Data

The data used to conduct the QRA are LFI data from four rounds of sampling. Confidence levels are estimated for the data based on available knowledge of the waste site. Confidence in the contaminant identification is based primarily on the quality of the data used in the QRA. The confidence in the concentrations is based on the data quality and confidence in the representativeness of that data. Confidence levels used are high, medium, and low.

A high confidence rating is given for contaminant identification at the 100-KR-4 groundwater operable unit since the LFI data used in the QRA were collected specifically for characterization of the 100-KR-4 operable unit groundwater, and the data are of known quality. The confidence in the concentrations is given a high rating as well since four sampling rounds of data were used. A low confidence rating was given to the spring and river data, as only one round of sampling was performed.

In general, the use of maximum concentrations to calculate risk for the QRA may result in an overestimation of risk. The data represent a snapshot of concentration at a given time. Also, the effect of the Columbia River on the groundwater concentrations at the K Area is not fully known.

5.3.2 Uncertainty in Human Health Evaluation

This report estimates risk that might occur under frequent-use (i.e., residential) or occasional-use (i.e., recreational) scenarios based on the common approach agreed to by the 100 Area Tri-Party Agreement unit managers. While these risks are based on the best knowledge of current contaminated conditions, they do not represent actual risks since no human consumption of groundwater currently occurs at the operable unit. The scenarios evaluated for the 100-KR-4 operable unit are based on assumed receptors under current contaminant conditions. The effect on humans from consumption of plants or animals that have assimilated 100-KR-4 contaminants was not considered. For some radionuclides, radioactive decay over time can significantly reduce the concentrations to which a receptor may be exposed.

Uncertainty is associated with the toxicity values and the toxicity information available to assess potential adverse effects. This uncertainty in the information and the lack of specific toxicity information contribute to uncertainty in the toxicity assessment. For nonradioactive contaminants identified at the 100-KR-4 operable unit, there is relatively good information for potential exposures through the oral route. However, toxicity values and information to evaluate the inhalation route of exposure is more limited.

Lead, although known to be quite toxic to sensitive individuals, does not have either an RfD or an SF. The concentrations of lead detected at the 100-KR-4 operable unit exceed the EPA assigned maximum contamination level goal of 0 mg/L (40 CFR 141), and the hardness-dependent criteria established for ecological effects of 0.0036 mg/L (EPA 1986c).

Uncertainty exists as to whether chromium is in the hexavalent or trivalent state. Hexavalent chromium is assumed for the QRA because it provides the most conservative evaluation and was the form used (e.g., sodium dichromate) at some 100 K Area waste units.

The estimated risks or hazard quotients by themselves do not fully characterize the risk impacts associated with environmental contamination. Such an evaluation must be understood in light

of the uncertainties presented. The risk estimates are based on single-point estimates from LFI data assuming two different sets of exposure assumptions (i.e., residential and recreational).

Uncertainty in the risk characterization results from summing cancer risks or HQs across contaminants and pathways, which gives equal weight to toxicity information derived from different sources or species. Exposures to multiple contaminants may result in additive effects or effects that are greater or less than additive.

5.3.3 Uncertainty in Ecological Evaluation

The ecological evaluation depicts the potential exposure of select riparian and aquatic life to contaminants present in groundwater near the river. This creates two primary uncertainties for the ecological evaluation, the source term and the conceptual model. In the case of the ecological evaluation, the maximum representative groundwater concentration in the near-river wells was used as the source term and river dilution was not factored into the exposure calculations. The selected organisms used to evaluate the risk do not represent the river's entire ecosystem; however, this limited conceptual model was agreed to by the Tri-Party Agreement unit managers as a sufficient scenario for an IRM decision (February 8, 1993).

Additional uncertainties associated with toxicity values also are significant, particularly for nonradiological contaminants. Benchmark or toxicity values (LOEL) were developed based on laboratory tests and are extrapolated to the environment. The effects of chronic exposure of organisms to radionuclides is not known. At low dose levels, organisms can repair damage to correct for radiological dose. However, existing dose/response relationships were developed at high dose levels and extrapolated to chronic levels. In addition, no regulatory criteria exist for radionuclides other than the 1 rad/day reported by the DOE.

Risk is expressed as an HQ, which implies a single conclusion has been reached. As discussed above, this HQ is the result of the interaction, uncertainty, conservatism, and non-conservatism of many different factors that enter into the risk characterization. The environmental relevancy of the characterization will depend on the accuracy of these factors. The HQ would be more accurately represented as a range of values than as a single point estimate.

5.4 CONCLUSIONS

The QRA is used in the LFI process to (1) screen out contaminants from the remedial action list, and (2) assess the need for IRM. The QRA results suggest that some unacceptable risks might exist from exposure to groundwater at the 100-KR-4 operable unit. While it is reasonable to conservatively estimate the risks from contaminants for these purposes, none of the calculated risks are based on current exposure scenarios, and future land uses have not yet been determined.

The RME estimates of risk, even with their associated uncertainties, are sufficient to support an initial decision for the 100-KR-4 operable unit. The average risk from the groundwater at the K Area is potentially less than the risk estimates presented in this QRA.

Table 5-1. Human Health Risk Summary - Noncarcinogenic Effects.

Analyte	Occasional			Frequent		
	Comparison of HQ to 1.0	Percent of Total HI	Cumulative Percent of Total HI	Comparison of HQ to 1.0	Percent of Total HI	Cumulative Percent of Total HI
Chromium ^a	BELOW	83.4	83.4	ABOVE	83.5	83.5
Arsenic ^b	BELOW	7.5	90.9	ABOVE	7.4	91.0
Nitrate/Nitrite ^c	BELOW	3.4	94.3	ABOVE	3.5	94.5
Manganese	BELOW	3.0	97.3	BELOW	3.0	97.4
Vanadium	BELOW	0.7	98.0	BELOW	0.7	98.2
Trichloroethane	BELOW	0.7	98.8	BELOW	0.7	98.8
Cadmium	BELOW	0.5	99.3	BELOW	0.5	99.3
Chloroform	BELOW	0.4	99.6	BELOW	0.3	99.7
Zinc	BELOW	0.4	100.0	BELOW	0.3	100.0
Lead	No Data	NA	-	No Data	NA	-
Total Hazard Index	BELOW			ABOVE		

^aThe toxic effects of chromium is dependent on the valence state and route of exposure. The route evaluated here is oral ingestion. The effects of chromium exposure by routes other than oral ingestion were not considered because no other pathway for exposure exists. Chromium VI is classified a group A human carcinogen based on evidence that it causes lung tumors or skin tumors in animals when inhaled or injected (IRIS).

^bThe critical noncarcinogenic effects of chronic oral exposure to inorganic arsenic are hyperpigmentation, keratosis, and possible vascular complications. The level of confidence in the RfD for arsenic is listed as medium (IRIS).

^cThere is a high level of uncertainty associated with the nitrate/nitrite evaluation. The nature of the contaminants, whether soluble or elemental, is unknown; therefore, the toxicity values used may not be appropriate.

Table 5-2. Human Health Risk Summary - Carcinogenic Effects.

Analyte	Occasional			Frequent		
	Qualitative Risk	Percent of Total Risk	Cumulative Percent of Total Risk	Qualitative Risk	Percent of Total Risk	Cumulative Percent of Total Risk
Tritium ^a	LOW	76.1	76.1	MEDIUM	74.4	74.4
Carbon-14 ^b	LOW	15.3	91.4	MEDIUM	15.0	89.4
Arsenic ^c	LOW	7.3	98.8	MEDIUM	7.1	96.5
Total Chloroform	VERY LOW	<0.1	98.8	LOW	2.1	98.7
Strontium-90	VERY LOW	1.0	99.8	LOW	0.9	99.6
Total Trichloroethene	VERY LOW	0.1	99.9	LOW	0.3	99.9
Uranium-238	VERY LOW	<0.1	99.9	LOW	0.1	99.9
Technetium-99	VERY LOW	<0.1	100.0	LOW	<0.1	100.0
Uranium-233/234	VERY LOW	<0.1	100.0	LOW	<0.1	100.0
Uranium-235	VERY LOW	<0.1	100.0	VERY LOW	<0.1	100.0
Total Risk	LOW			MEDIUM		

^aThe half-life of tritium is approximately 12 years. The risk estimate is appropriate for 1993.

^bSince the background level for the Hanford Site has not been established, the relative contribution of naturally occurring carbon-14 cannot be evaluated.

^cInorganic arsenic is classified as group A human carcinogen. Arsenic caused an increased incidence of skin cancer in several populations consuming drinking water containing high concentrations of arsenic (IRIS).

Table 5-3. Comparison of Concentrations for Contaminants of Potential Concern.

	All Groundwater Wells		Near-River Groundwater Wells		K-Area Springs		K-Area Columbia River	
Organics (All Concentrations in ug/L)								
Chloroform	17		17		NA		NA	
Trichloroethene	19		19		NA		NA	
Inorganics (All Concentrations in ug/L, except as noted)								
Aluminum	844	J*	72.1	B	255		ND	
Arsenic	10.4		6.6	B	NA		NA	
Cadmium	2.2	B	2.2	B	ND		ND	
Chloride (mg/L)	21.6		21.6		6.01		0.86	
Chromium	1950		261		68.7		ND	
Iron	5430	J*	1230		243		171	
Lead	7.6		5.8	WJ	NA		NA	
Manganese	69.6		69.6		8.7	B	19.6	
Nickel	18.7		9.9		ND		ND	
Nitrate/Nitrite (mg/L)	26		26		1.47	J	0.5	J
Silver	7.1	B	5.2	B	5.5	B	ND	
Total Dissolved Solids (mg/L)	453		453		221		89	
Vanadium	23.8	B	19.1	B	10.7	B	ND	
Zinc	461	E	461	E	ND		6.4	B
Radionuclides (All Concentrations in pCi/L)								
Carbon-14	23000		16000		NA		NA	
Strontium-90	36		36		8.8		0.7	J
Technetium-99	46		11	R	5.2		2	
Tritium	1900000		35000		8900		ND	
Uranium-233/234	3.3		2.3		NA		NA	
Uranium-235	0.29		0.16	J	NA		NA	
Uranium-238	2.6		1.9		NA		NA	
Total Uranium	NA		NA		1.1		0.49	

B - Value below the contract required detection limit

J - Estimated value

* - Duplicate analysis not within control limits

R - Rejected for administrative reasons

W - Out of control limits

ND - Not Detected

NA - No Data Available

Note: Springs and Columbia River data are from DOE-RL 1992b

Table 5-4. Ecological Summary for Radionuclides
Organism: Fish-Eating Duck.

Analyte	Near-River Groundwater Wells		
	Comparison to EHQ = 1.0	Percent of Total EHQ	Cumulative Percent of Total EHQ
Carbon-14	ABOVE	99.8	99.8
Strontium-90	BELOW	0.2	100.0
Uranium-233/234	BELOW	<0.1	100.0
Tritium	BELOW	<0.1	100.0
Uranium-238	BELOW	<0.1	100.0
Uranium-235	BELOW	<0.1	100.0
Technitium-99	BELOW	<0.1	100.0
Total EHQ	ABOVE		

Table 5-5. Ecological Summary for Nonradionuclides.

Analyte	Near-River Groundwater Wells	
	Comparison to Acute EHQ = 1.0	Comparison to Chronic EHQ = 1.0
Chromium	ABOVE	ABOVE
Silver	ABOVE	ABOVE
Zinc	ABOVE	ABOVE
Iron	ABOVE	NA
Cadmium	BELOW	ABOVE
Lead	BELOW	ABOVE
Aluminum	BELOW	BELOW
Nickel	BELOW	BELOW
Chloroform	BELOW	BELOW
Trichloroethene	BELOW	BELOW
Chloride	BELOW	BELOW
Vanadium	NA	NA
Manganese	NA	NA
Nitrate/Nitrite	NA	NA
Total Dissolved Solids	NA	NA

NA - No Data Available

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APPENDIX A
HUMAN HEALTH TOXICOLOGICAL INFORMATION

INTRODUCTION

Appendix A presents toxicological information for contaminants of potential concern identified at the 100-KR-4 operable unit. The categories of information include:

- general background information
- exposure route
- chronic toxicity
- carcinogenicity.

Data sources for the information provided in the appendix include EPA documents and standard reference texts. These sources are:

- EPA Integrated Risk Information System [(IRIS)] (EPA 1992a)
- EPA Health Effects Assessments Summary Tables [HEAST] (EPA 1992b)
- Toxicological Profiles for Individual Compounds, Agency for Toxic Substances and Diseases Registry
- Casarett and Doull's Toxicology, the Basic Science of Poisons (Amdur, et al. 1991)

NONRADIOACTIVE CONTAMINANTS OF POTENTIAL CONCERN

INORGANIC COMPOUNDS

ALUMINUM

Aluminum comprises approximately 8% of the earth's crust in combination with oxygen, fluorine, silicon, and other constituents. Aluminum metal has a wide variety of uses, including as a structural material in the construction, automotive, electrical, and aircraft industries. Although it is widely used for medicinal purposes, aluminum is not thought to be toxic to humans in these forms. However, excess exposure to this metal may be harmful to sensitive subpopulations which include pregnant mothers and Alzheimer's patients. The inhalation and dermal exposures of healthy individuals to aluminum are not associated with significant adverse health effects. But inhalation of aluminum dust may cause respiratory problems, while the ingestion of water containing high levels of this metal may result in neurological, teratogenic, and skeletal problems.

An interim oral RfD of 1.0 mg/kg-d has been recommended for aluminum by the EPA. The critical effects associated with exposure to this metal are decreased body weight and neurotoxicity.

ARSENIC

Measurable concentrations of arsenic are commonly found in the western United States (Fetter 1993). The Hanford arsenic background has been determined to be 10 µg/L (DOE-RL 1992c). Environmental sources of arsenic include sedimentary rocks derived from volcanic sources and geothermal systems. Burning of coal and smelting of ores are examples of anthropomorphic sources of arsenic.

Although the EPA notes a range of SF values for arsenic, the value reported in the IRIS database is 3×10^{-4} mg/kg-d. The adverse effects associated with oral arsenic exposure include hyperpigmentation, keratosis, and at high doses, possible vascular complications. The uncertainty of the oral RfD value spans nearly an order of magnitude with published RfD ranging from 1×10^{-4} to 8×10^{-4} mg/kg-d (EPA 1992a).

The EPA has a Group A-human carcinogen weight of evidence classification for arsenic (EPA 1992a). The assigned arsenic oral SF is $1.7 \text{ (mg/kg-d)}^{-1}$. Skin cancer is the most common cancer from resulting from oral exposure to arsenic.

CHROMIUM (+6)

Elemental chromium does not exist naturally in the environment, but is found primarily as a part of chromite ore. In compounds, this element exists in one of three valence states, +2, +3, or +6. The trivalent form is an essential human micronutrient involved in carbohydrate metabolism. Adverse effects have not been associated with the trivalent form. The hexavalent form is important industrially (typically in the form of chromates) and has been associated with serious toxicities. Human toxicity has been associated with hexavalent chromium by all routes of exposure. Long term

exposure to airborne hexavalent chromium higher than natural background levels is known to produce lung and respiratory tract cancer in humans.

The EPA has determined the oral RfD for hexavalent chromium as $5E-03$ mg/kg-d (IRIS) based on a drinking water study in rats. Hexavalent chromium is classified by EPA as a known human carcinogen (weight-of-evidence classification is Group A) by inhalation exposure. The inhalation SF is $4.1 E+01$ (mg/kg-d)⁻¹. No evidence exists to indicate that chromium is carcinogenic by the oral route.

IRON

The predominant sources of iron in the atmosphere may be attributed to natural processes, including continental dust generated by wind erosion of weathering mineral deposits, volcanic gas and dust, and forest fires. Anthropogenic sources of iron in the atmosphere include industrial emissions and the burning of fossil fuels. The major interest in iron is that it is an essential nutrient with potential for toxicity at chronic high doses. Chronic iron toxicity or iron overload in adults, following oral ingestion, is characterized by clinical effects such as disturbances in liver and endocrine functions, diabetes mellitus, and cardiovascular effects.

The EPA has recommended an ambient water quality criterion of 0.3 g/liter for iron for the protection of human welfare.

LEAD

Lead is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. It is widely distributed in the environment, and can be transported to long distances. Anthropogenic sources of lead come from gasoline additives, various metal products, ammunitions, paint, and storage batteries. The largest source of lead in air is from automobile exhaust. Children and pregnant women are the most sensitive subpopulations to chronic effects from lead exposure. The effects of lead exposure in children are reported as a decrease in IQ, neurological effects, including changes in brain function (encephalopathy) which may progress to coma. Transplacental transfer of lead from mother to fetus in humans, resulting in nervous system damage or changes, have also been reported in humans. Exposure to lead has also been linked to carcinogenic effects in laboratory animals.

The EPA has classified lead as a Group B2 carcinogen (i.e., probable human carcinogen). Although the agency has not derived a toxicity factor for lead, a range of 500-1,000 mg/kg of lead in soil has been determined by the EPA as being protective of sensitive populations.

MANGANESE

The background manganese groundwater concentration is $24.5 \mu\text{g/L}$ at Hanford (DOE-RL 1992c). Manganese is an essential human nutrient; however, toxic effects have been observed from exposures to high levels of manganese.

The EPA oral RfD for manganese is 5×10^{-3} mg/kg-d based on total dietary uptake. A separate RfD for oral groundwater exposure is being considered by EPA. Muscle tonus, tremors,

lethargy, and mental disturbances have been reported in humans exposed to high manganese levels. The EPA has given manganese the weight of evidence Group D classification (EPA 1992a). Group D is not classified as to carcinogenicity.

ZINC

Zinc is a ubiquitous metal commonly detected in the earth's crust. The Hanford background groundwater concentration for zinc is 50 $\mu\text{g/L}$ (DOE 1992c). Zinc may be encountered in a number of manufacturing processes.

The oral RfD for zinc is 3×10^{-1} mg/kg-d. The primary observed adverse effect is a reduction of blood ESOD levels, which alters metal metabolism in humans. The EPA considers zinc as a Group D - not classifiable as to human carcinogenicity for oral exposures (EPA 1992a).

ORGANIC COMPOUNDS

CHLOROFORM

Chloroform is a colorless volatile liquid at room temperature, with a sweet taste and a characteristic odor. It is used as an industrial solvent and chemical intermediate in the manufacture of other compounds. The primary route of chloroform exposure is via inhalation and ingestion of contaminated drinking water. Target organs for chloroform toxicity are the liver, kidney, and the central nervous system.

The EPA has set an oral RfD of 1×10^{-2} mg/kg-d for chloroform based on critical effects of fatty cyst formation in the liver (IRIS). Chloroform is a B $\oplus$ (probable) human carcinogen. The oral slope factor (SF) is 6.1×10^{-3} (mg/kg-d) $^{-1}$ (based on water ingestion), and the inhalation SF is 8.0×10^{-2} (mg/kg-d) $^{-1}$ (based on a gavage study) (IRIS).

TRICHLOROETHENE

Trichloroethene (also known as trichloroethylene) is a colorless liquid with an odor similar to ether or chloroform. This chemical is a man-made solvent used for degreasing metal parts, extracting caffeine from coffee, and in numerous consumer products such as typewriter correction fluid, paint removers, and spot removers.

Trichloroethane readily moves through soil and groundwater. Ingestion of contaminated water and inhalation of volatilized trichloroethane are the chief sources of exposure. Absorption is not significant from skin contact with this solvent.

Acute oral toxicity in humans is low. Death has occurred from an ingested dose of 70 mg/kg. Acute effects from inhalation of trichloroethene are associated with the central nervous system (dizziness, headache, sleepiness) and occur at a threshold of 436 to 592 mg/M 3 . Extremely high, acute exposures may produce cardiac rhythm disturbances. In animals, chronic exposure to

trichloroethene by inhalation and ingestion has produced liver and kidney damage and may affect reproductive toxicity.

Neither IRIS nor HEAST currently provide an RfD for trichloroethene and determination of an RfD is pending. Trichloroethene may induce lung cancer in animals when inhaled and may produce liver cancer in animals from oral administration. The EPA weight-of-evidence classification is B2 (probable human carcinogen) based on sufficient evidence in animals. The oral and inhalation SFs for trichloroethene have also been withdrawn from IRIS pending further review of carcinogenicity studies. However, HEAST provides an inhalation SF of $1.7\text{E-}02 \text{ mg/kg/d}^{-1}$.

The OSHA final rule limits for occupational exposure to trichloroethene and the currently recommended ACGIH exposure limits are a TWA of 269 mg/M^3 and an STEL of $1,070 \text{ mg/M}^3$. Because trichloroethene is carcinogenic, NIOSH recommends a TWA of 135 mg/M^3 . The NIOSH recommendations are considered the level that can be achieved by existing engineering controls and technology. The IDLH concentration for trichloroethene is $5,380 \text{ mg/M}^3$.

The drinking water MCL for trichloroethene is 0.005 mg/L and the MCLG is 0 mg/L . Based on water and fish consumption, the HWQHC is 0.0027 mg/L .

RADIOACTIVE CONTAMINANTS OF POTENTIAL CONCERN

CARBON-14

Carbon-14 ($Z = 6$) is a naturally-occurring as well as man-made neutron activation product. Carbon-14 is ubiquitous because carbon distributes itself quickly among the major environmental compartments (the stratosphere, troposphere, biosphere, and surface ocean waters), and has a long half-life (5730 yr). The carbon-14 content of the atmosphere is believed to exist as (gaseous) CO_2 . Therefore, it is not assigned a lung class. Carbon is assigned a GI absorption factor of 100%. The carbon-14 body burden from natural sources is on the order of $0.1 \mu\text{Ci}$, providing an estimated equivalent whole body dose of 1 mrem/yr . Carbon-14 is a low energy beta emitter, making it a relatively low hazard radionuclide from the ingestion and inhalation pathways. The EPA has derived a slope factor of 9.0×10^{-13} for oral exposures. Carbon-14 is not an external exposure hazard because it does not emit gamma rays or x-rays.

STRONTIUM-90

This fission product ($Z = 38$), along with its daughter, yttrium-90, is only an internal hazard since both radionuclides have negligible gamma emissions. Strontium-90 is a relatively important ingestion hazard (ingestion SF = $3.6 \times 10^{-11} \text{ pCi}^{-1}$). Strontium-90 has a physical half-life of 28.8 years. Yttrium-90 has a short half-life (64 hr) and, therefore, exists in equilibrium with its parent. Being chemically similar to calcium, this element deposits in the bone and is removed very slowly. Bone cancer is the primary health effect of concern from intakes of radioactive isotopes of strontium. Strontium-90 is assigned a lung class D, and a GI absorption factor of 30%. The MCL for Strontium-90 is 8 pCi/L .

TRITIUM

Tritium ($Z = 1$) exists in the environment in the form of tritiated water, and is therefore very mobile. Tritium is readily absorbed, and is distributed uniformly throughout body tissues, providing a whole body dose. It is a pure, low-energy beta emitter, and therefore represents only an internal hazard. Although tritium has a physical half-life of 12.3 yr, the biological half-life of water is approximately 10 days, significantly limiting the impact of intakes. The EPA has derived a slope factor of 5.4×10^{-14} for oral exposures. The MCL for tritium is 20,000 pCi/L.

URANIUM-238

Uranium-238 ($Z = 92$) is naturally occurring as well as man-made. Uranium-238 (half-life = 4.5×10^9 yr) is naturally present at 99.27 wt% with respect to the other uranium isotopes. Uranium-238 is the parent of a long decay chain, one daughter of which is uranium-234 (half-life = 2.4×10^5 yr). Because uranium is an alpha emitter, it is of greatest concern from the ingestion and inhalation pathways. In addition, daughters of uranium-238 are high-energy gamma emitters, and can make the decay chains important external hazards. Following ingestion or inhalation, uranium concentrates in the kidney and bone. Uranium is assigned a lung class Y and a GI absorption factor of 5%. The proposed national primary drinking water standard for uranium (30 pCi/L) is based on kidney toxicity.

WET CHEMISTRY

NITRATE/NITRITE

Nitrate is an odorless, colorless-to-white, crystalline substance. It is used as a fertilizer, in the manufacture of fireworks, ceramics, rocket propellants, or in the pickling of meats. Toxicity to nitrate has been reported from all routes of exposure (i.e., inhalation, ingestion, or dermal contact). An epidemiologic study on infants routinely fed formula prepared from nitrate-contaminated water has indicated the incidence of methemoglobinemia (i.e., the oxidation of blood hemoglobin to methemoglobin). The nitrate (nitrogen) content in the water ranged from 10 ppm to over 100 ppm. It is important to note that no incidences of methemoglobinemia occurred in drinking water containing less than 10 ppm (10 mg/L) nitrate (nitrogen). Furthermore, it is also noteworthy that subsequent epidemiologic studies have shown that populations (1 to 8 years old) who ingested water containing greater than 10 mg/L nitrate-nitrogen did not have increased levels of methemoglobin. Thus, it was concluded that the most sensitive subpopulation to nitrate toxicity is the 4-kg infant who has high gut content of nitrate-reducing bacteria; a lower enzymatic capacity to reduce the methemoglobin to hemoglobin; and has hemoglobin F, which is more susceptible to oxidation.

An oral RfD of $1.6E+00$ mg/kg-d has been derived from the EPA for exposure to nitrate/nitrite. The critical effect is the increased incidence of methemoglobinemia in infants following the consumption of nitrate-contaminated fluid.

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APPENDIX B

ECOLOGICAL EVALUATION RADIOLOGICAL DOSE CALCULATIONS

Introduction. This appendix discusses the organisms (e.g., plants, animals) living in the Columbia River and its watershed that could be affected by radionuclide contamination from the 100-KR-4 operable unit and supplements the assumptions and analyses provided in the ecological qualitative risk assessment. This appendix identifies the organisms and provides the dose-response calculations for the ecological evaluation.

Plants. Three groups of plants constitute the primary producer level of the aquatic ecosystem: phytoplankton, periphyton, and macrophytes. Two of the groups contain organisms classified as algae. The algae are (1) phytoplankton--floating, free-living algae drifting with the current in the water column and (2) periphyton--algae colonizing solid substrata, such as rocks. Although the dominant phytoplankton species in the Columbia River are true lentic (lake) forms, many species in the water column are detached periphytic forms that have been washed off of rocks. The periphyton mat commonly found on solid substrata is made up of algae and other organisms; these include microcrustaceans, rotifers, fungi, bacteria, and detritus. These communities are restricted to the margins of the river in the vicinity of the 100 Area where conditions are suitable. Phytoplankton and periphyton are present year round in the Columbia River; populations are highest in spring and summer and lowest in winter.

Macrophytes can be found rooted to the bottom of the river where the current slackens and fine sediments accumulate in sufficient amounts. Macrophytes are sparse in the Columbia River because of the strong currents, rocky bottom, and frequently fluctuating water levels. Rushes and sedges occur along the shorelines of the slack-water areas such as the White Bluffs Slough below the 100-K Area, the slough area downstream of the 100-F Area, and the Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels. Macrophytes are present during the warmer months and usually die in the winter.

Commonly found macrophytes include lemna, potamogeton, elodea, and myriophyllum, and they have considerable ecological value. Macrophytes are most important as food after they die and decompose into fine particulate detritus. These macrophytes provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. However, if some of the exotic macrophytes increase to nuisance levels, they may encourage increased sedimentation of fine particulate matter. This could negatively effect the spawning of salmonids but could increase the range for *Alosa sapidissima* (American shad) by providing more suitable spawning habitat. These changes could significantly impact the trophic relationships of the Columbia River.

Herbivores. Organisms that directly feed on the primary producers (usually macrophytes) are herbivores. The common herbivores in the area near the 100-K Area include zooplankton, immature insects, molluscs, and herbivorous fish. Zooplankton, insects, molluscs, and herbivorous fish are present at all times. The zooplankton are not abundant in this reach of the river. Immature aquatic insects are one of the basic food items and consist of the larvae and nymphs of several orders of insects. The aquatic insects are usually most abundant during fall and winter where they mature until they emerge as adults in spring and summer. Immature insects are most important as a food source in the aquatic system but are also important as adults, for insectivorous birds, such as swallows. Insects also enter the aquatic foodweb after they die if they fall back into the river. Molluscs are neither abundant nor important in terms of energy flow in the ecosystem. However, two species found in the Columbia River are listed as candidates for protection under the Endangered Species Act. These are the *Fisherola nuttalli* (shortfaced lanx), which is a state candidate, and the *Fluminicola colombiana* (Columbia pebblesnail), which is both a federal and state candidate. Herbivorous fish, such as some species of suckers, actively graze on the periphyton; Dauble (1986) reported that

Castostomus macrocheilus (large-scale suckers) in the Columbia River feed predominantly on periphyton and insect larvae.

Primary carnivores. Primary carnivores feed on the herbivores. Dominant groups found in the Columbia River include several species of forage fish, *Prosopium williamsoni* (mountain whitefish), and juvenile salmonids. The carnivores in this group use several different sources of food as shown in Figures B-1 and B-2. This group includes several species of primary concern from an economic, sport, and protected species viewpoint. These are the salmonids; this includes the *Oncorhynchus mykiss* (steelhead trout) and the various species of salmon. The steelhead provides a major sport fishing in and above the areas. Because the Hanford Reach (which is within the 100 Area) is the last mainstream spawning area for both the steelhead and salmon, the potential impacts to these migrating populations must be considered.

Secondary carnivores. Secondary carnivores feed on a variety of sources, but mainly the primary carnivores. This category includes species present in the river, such as *Micropterus dolomieu* (smallmouth bass), and other organisms in the vicinity of the river, such as *Haliaeetus leucocephalus* (bald eagles), hawks, and swallows.

Omnivores. Crayfish are omnivorous and feed on decaying animal and plant tissue. Waterfowl are also omnivores, feeding on macrophytes and primary carnivores.

Fish. Gray and Dauble (1977) list 43 species of fish in the Hanford Reach of the Columbia River. Collection of the *Ictalurus nebulosus* (brown bullhead) began after 1977, bringing the total number of fish species identified in the Hanford Reach to 44 (Table B-1). Of these species, the *Oncorhynchus tshawytscha* (Chinook salmon), *Oncorhynchus nerka* (sockeye salmon), *Oncorhynchus kisutch* (coho salmon), and steelhead trout use the river as a migration route to and from upstream spawning areas and are of great economic importance. The fall Chinook salmon and steelhead trout spawn in the Hanford Reach. The relative contribution of upper river bright stocks to fall Chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s to 50% to 60% of the total by 1988 (Dauble and Watson 1990). The destruction of other mainstream Columbia River spawning ground by dams has increased the importance of the Hanford Reach spawning (Watson et al. 1970; Watson 1973).

The upper estimates of the annual average Hanford Reach steelhead trout spawning population based on dam counts from 1962 to 1971 were about 10,000 fish. The estimated annual sport catch from 1963 to 1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2,700 fish (Watson 1973).

The American shad (*Alosa sapidissima*), a anadromous species, may also spawn in the Hanford Reach. The upstream range of the shad has been increasing since 1956 when fewer than 10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream from the Hanford Reach, has risen to many thousands per year and the young-of-the-year have been collected in the Hanford Reach. The shad is not dependent on specific current and bottom conditions required by the salmonids for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake Rivers.

Other fish of importance to sport fisherman are the whitefish, *Acipenser transmontanus* (white sturgeon), smallmouth bass, *Pomoxis annularis* and *nigromaculatus* (white and black crappie), *Ictalurus punctatus* (channel catfish), *Stizostedion vitreum vitreum* (walleye), and *Perca flavescens* (yellow perch). Large populations of rough fish including *Cyprinus carpio* (carp), *Richardsonium*

balteatus (reidside shiners), suckers, and *Ptychocheilus oregonensis* (northern squawfish) are also present.

Dose of Constituents of Concern to Aquatic Receptors. This section describes the methods used to estimate radiological dose to aquatic organisms.

The general response of aquatic organisms to ionizing radiation occurs at both the cellular and biochemical levels. The level of response is also controlled to some extent by environmental factors. Stressor-response relationships developed in a report by the National Council of Radiation Protection (NCRP) were based on *Effects of Ionizing Radiation on Aquatic Organisms* (NCRP 1991).

For ionizing radiation, the sensitivities of aquatic organisms to acute exposure during early developmental stages has a threshold of about 3 rad for the one-cell stage of development. Radiosensitivity has been reported to decrease with increasing level of embryo development. (Frank 1971). From laboratory studies, early life stages of Chinook salmon appear to be the most sensitive for fish. Damage has been reported to occur when the dose reached 9.64 rad/day over a 81-day development period (Hyodo-Taguchi 1980). Studies from Frank (1971) have shown that 224 rad reduced female germ cells in Chinook salmon. Frank has also shown that 600 rad reduced female germ cells in rainbow steelhead trout.

Few studies have evaluated the effects of chronic exposure to ionizing radiation. In a summary, the report by the NCRP (1991) stated that Chinook salmon chronically exposed to 5.1 rad/day for up to 69 days as embryos and alevins up to release as smolts produced no increase in mortality. Hershberger et al. (1978) reported lower return of spawning adult Chinook salmon after exposure of eggs and alevins to approximately 10 rad/day of gamma radiation. Gonadal development was retarded in Chinook salmon upon exposure to 10 rad/day (Bonham and Donaldson 1972). Frank (1971) also shows that spermatogenesis of adult *Ameioba splendens* was disrupted at an accumulated dose of 95 rad after 5 days.

For radionuclides, effects are assessed based upon DOE Order 5400.5, which states that dose to aquatic animals should not exceed 1 rad/day. Based upon available literature, it would appear that the DOE Order 5400.5 is sufficiently conservative with regards to dose to protect most aquatic organisms at the population level. One example qualifier to this is the work of Erickson (1973) who reported reduced male *Poecilia reticulata* (guppy) courting activity when embryos had been exposed to 0.4 rad/day. However, little information exists with regards to behavioral changes in fish from exposure to ionizing radiation.

Exposure parameters for each organism are summarized by Baker and Soldat (1992). Doses from radionuclides are calculated based on the computer code developed by Baker and Soldat (1992) for the CRITR2 computer model.

Total daily doses to an organism are estimated as the sum of doses (weighted by energy of radiation) received from all radioactive elements ingested, residing in the body, and available in the organism's environment. CRITR2 is a steady state model which assumes exposed organisms reach an equilibrium with the water concentration or food uptake.

The internal total-body dose rate to an organism for N radionuclides is given as

where R_c = dose rate to total body of organism c (rad/day)

$$R_c = \sum_{i=1}^N b_{i,c} E_{i,c} \quad (C-1)$$

$b_{i,c}$ = specific body burden of nuclide i in organism c (Ci/kg)

$E_{i,c}$ = effective absorbed energy rate for nuclide i per unit activity in organism c (kg-rad/ci-day).

$$E_{i,c} = \epsilon_{i,c}(\text{MeV/dis}) \times 3.70 \times 10^{10} (\text{dis/s-Ci}) \times 86,400 (\text{s/day}) \times 1.602 \times 10^{-11} (\text{kg-rad/MeV}) = 5.12 \times 10^{-4} \epsilon_{i,c}$$

where ϵ = effective absorbed energy for nuclide i in organism c.

For a primary organism,

$$b_{i,c} = C_{i,c} B_{i,c} \times CF \quad (C-2)$$

where $C_{i,c}$ = concentration of nuclide i in water to which organism c is exposed (Ci/L)

$B_{i,c}$ = bioaccumulation factor for nuclide i and organism c (m^3/kg).

CF = conversion factor [0.001 (L/m^3)]

Combining equations (C-1) and (C-2) yields the dose rate (rad/day) to the primary organism.

$$R_c = \sum_{i=1}^N C_{i,c} B_{i,c} \epsilon_{i,c} \quad (C-3)$$

For the secondary organism, such as herbivores and carnivores, an expression can be written for a single radionuclide equating the change in body burden to the uptake and removal of the radionuclide.

$$\frac{db^*}{dt} = \frac{P}{M} - \lambda b^* \quad (C-4)$$

where b^* = specific body burden of the secondary organism (Ci/kg)

M = mass of secondary organism (kg)

P = rate of uptake of radionuclide by body of organism (Ci/d)

λ = $(\lambda_b + \lambda_r)$ effective decay constant in secondary organism (d^{-1}),

where $\lambda_b = \ln(2)/T_b$ is the biological removal rate constant for the nuclide in the secondary organism

$\lambda_r = \ln(2)/T_r$ is the radiological decay constant for the nuclide.

The secondary organism uptake rate is given by

$$P_i = b_i U_i f_{i,1} \quad (C-5)$$

where b = body burden of primary organism (Ci/kg)
 U = intake rate of primary organism by predator (kg/d)
 f_i = fraction of radionuclide initially retained in total body of secondary organism (unitless).

Solving equation (C-4) with $b^* = 0$ when $t = 0$:

$$b^* = \frac{P_i (1 - e^{-\lambda_i T_e})}{M \lambda_i} \quad (C-6)$$

where T_e = period of exposure (d).

Then, for a secondary organism c , the dose rate in terms of the body burden of the primary organism or prey for N radionuclides is

$$R_c = \sum_{i=1}^N \frac{b_{i,c} U_c f_{i,1}}{M_c} \frac{(1 - e^{-\lambda_{i,c} T_e})}{\lambda_{i,c}} E_{i,c} \quad (C-7)$$

where U_c = intake rate of primary organism by secondary organism c (kg/d)

M_c = mass of secondary organism c (kg)

$\lambda_{i,c}$ = effective decay constant of nuclide i in secondary organism c (d^{-1})

In the absence of specific data, the removal constants, $\lambda_{i,c}$, and uptake fractions, $f_{i,1}$, are taken to be that of standard man as derived from Publication 2 of the International Commission on Radiological Protection (ICRP 1959). The values of effective energy, $\epsilon_{i,c}$, were determined knowing the effective radius of the organism. The exposure time, T_e , is usually assumed to be 1 year for regulatory purposes, and the concentration is averaged over 1 year.

Figure B-1. Columbia River Aquatic Ecosystem.

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Figure B-2. Conceptual Model of Foodweb Relationships.

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Indicates a transfer of contaminant from a source and requires a corresponding transfer coefficient and/or bioaccumulation factors

Table B-1. Fish Species in the Hanford Reach of the Columbia River.

Common Name	Scientific Name
White sturgeon	<i>Acipenser transmontanus</i>
Bridgelip sucker	<i>Catostomus columbianus</i>
Largescale sucker	<i>Catostomus macrocheilus</i>
Mountain sucker	<i>Catostomus platyrhynchus</i>
Pumpkinseed	<i>Lepomis gibbosus</i>
Bluegill	<i>Lepomis macrochirus</i>
Smallmouth bass	<i>Micropterus dolomieu</i>
Largemouth bass	<i>Micropterus salmoides</i>
White crappie	<i>Pomoxis annularis</i>
Black crappie	<i>Pomoxis nigromaculatus</i>
American shad	<i>Alosa sapidissima</i>
Prickly sculpin	<i>Cottus asper</i>
Mottled sculpin	<i>Cottus bairdi</i>
Plute sculpin	<i>Cottus beldingi</i>
Reticulate sculpin	<i>Cottus perplexus</i>
Torrent sculpin	<i>Cottus rotheus</i>
Chiselmouth	<i>Acrocheilus alutaceus</i>
Carp	<i>Cyprinus carpio</i>
Pearmouth	<i>Mylocheilus caurinus</i>
Northern Squawfish	<i>Ptychocheilus oregonensis</i>
Longnose dace	<i>Rhinichthys cataractae</i>
Leopard dace	<i>Rhinichthys falcatus</i>
Speckled dace	<i>Rhinichthys osculus</i>
Redside shiner	<i>Richardsonius balteatus</i>
Tench	<i>Tinca tinca</i>
Burbot	<i>Lota lota</i>
Threespine stickleback	<i>Gasterosteus aculeatus</i>
Black bullhead	<i>Ictalurus melas</i>
Yellow bullhead	<i>Ictalurus natalis</i>
Brown bullhead	<i>Ictalurus nebulosus</i>
Channel catfish	<i>Ictalurus punctatus</i>
Yellow perch	<i>Perca flavescens</i>
Walleye	<i>Stizostedion vitreum vitreum</i>
Sand roller	<i>Percopsis transmontana</i>
Pacific lamprey	<i>Entosphenus tridentatus</i>
River lamprey	<i>Lampetra ayresi</i>
Lake whitefish	<i>Coregonus clupeaformis</i>
Coho salmon	<i>Oncorhynchus kisutch</i>
Sockeye salmon	<i>Oncorhynchus nerka</i>
Chinook salmon	<i>Oncorhynchus tshawytscha</i>
Mountain whitefish	<i>Prosopium williamsoni</i>
Cutthroat trout	<i>Oncorhynchus clarki</i>
Rainbow trout (steelhead)	<i>Oncorhynchus mykiss</i>
Dolly Varden	<i>Salvelinus malma</i>

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