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Screening Assessment and Requirements for a Comprehensive Assessment

Columbia River Comprehensive Impact Assessment

April 1997

MASTER

Prepared by the Pacific Northwest National Laboratory
and CRCIA Management Team Representatives of

U.S. Department of Energy
U.S. Environmental Protection Agency
Washington State Department of Ecology
Bechtel Hanford, Inc.
Dames & Moore

Confederated Tribes of the Umatilla Indian Reservation
Nez Perce Tribe ERWM
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Preface

The Columbia River is a critical resource for residents of the Pacific Northwest. It provides for basic needs and is interrelated with the life style and quality of life for Columbia Basin's many human and non-human residents. This resource was one of the key features that drew the Manhattan Project's planners to the site now called Hanford to produce nuclear weapon materials. Production of those materials has left behind a legacy of chemical and radioactive contaminants and materials that have affected and may be continuing to affect the Columbia River for the foreseeable future.

To evaluate the impact to the river from these Hanford-derived contaminants, the U.S. Department of Energy, U.S. Environmental Protection Agency, and Washington State Department of Ecology (the Tri-Party agencies) initiated a study referred to as the Columbia River Comprehensive Impact Assessment (CRCIA). To address concerns about the scope and direction of CRCIA as well as enhance regulator, tribal, and public involvement, the CRCIA Management Team (CRCIA Team) was formed in August 1995. The CRCIA Team has met weekly to share information and provide input to decisions made by the Tri-Party agencies concerning CRCIA. Representatives from the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, Yakama Indian Nation, Hanford Advisory Board, Oregon State Department of Energy, Tri-Party agencies, and Hanford contractors are active participants on the team.

Purpose and Objectives of the Comprehensive Assessment

The purpose of the Columbia River Comprehensive Impact Assessment (CRCIA) is to assess the effects of Hanford-derived materials and contaminants on the Columbia River environment, river-dependent life, and users of river resources for as long as these contaminants remain intrinsically hazardous.

For CRCIA to be comprehensive, representatives of the major community groups (non-U.S. Department of Energy) on the CRCIA Team have agreed that the following objectives must be achieved if the results and conclusions are to be acceptable by all concerned:

- ◆ estimate, with useful certainty, river-related human health and ecological risks for the time period that Hanford materials and contaminants remain intrinsically hazardous
- ◆ evaluate the sustainability of the river ecosystem, the interrelated cultural quality of life, and the viability of socio-economic entities for the time period that Hanford materials and contaminants remain intrinsically hazardous
- ◆ provide results that are useful for decision making on Hanford waste management, environmental restoration, and remediation

Project Approach

To address CRCIA objectives, the CRCIA Team has agreed to conduct CRCIA using a phased approach. The initial phase, which is required and described in Tri-Party Agreement milestones M-15-80 and M-15-80-T01, includes two components: 1) a screening assessment to evaluate the potential impact to the river, resulting from current levels of Hanford-derived contaminants in order to support decisions on

Interim Remedial Measures, and 2) a definition of the essential work remaining to provide an acceptable comprehensive river impact assessment. The results of the screening assessment are described in Part I of this report. The requirements for the essential work remaining are described in Part II of this report.

Additional phases of CRCIA will be identified and decisions made regarding the conduct of the remaining work based on submittal of information as required by Tri-Party Agreement milestones M-15-80A, M-15-80B, and M-15-80B-T01.

The primary contractor conducting the screening assessment is the Pacific Northwest National Laboratory. Bechtel Hanford, Inc. provides technical and public involvement coordination with environmental restoration activities. Independent technical peer reviewers are evaluating the initial phase of the CRCIA work under the guidance of the Directors of the Oregon Water Resources Research Institute and State of Washington Water Research Center. Eight of these reviewers were chosen by the Directors based on nominations from the public, regulatory agencies, and contractors. Also, the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, and Yakama Indian Nation each chose a reviewer. The reviewers evaluate CRCIA work independently. There is no intent to coordinate consensus opinion among the reviewers.

Background

The Hanford Site occupies approximately 1450 square kilometers (560 square miles) in the southeastern portion of Washington State. It is located northwest of the Tri-Cities of Richland, Kennewick, and Pasco. The site is partially bordered on the north and east by the Columbia River and includes a buffer zone north of the river referred to as the Wahluke or North Slope.

From 1944-1987, the U.S. Department of Energy (DOE) conducted nuclear production operations at the Hanford Site along the Hanford Reach of the Columbia River. The Hanford Reach extends 85 kilometers (51 miles) downstream from Priest Rapids Dam to the head of Lake Wallula (created by McNary Dam) near the City of Richland, Washington. These past nuclear operations resulted in the release of hazardous chemicals and radionuclides to the Columbia River and into the soil. These operations also resulted in the storage of wastes and nuclear materials, some of which have escaped containment or have the potential for doing so depending on the effectiveness of DOE waste management decisions and activities. Current conditions of the Columbia River reflect that contamination is reaching the river primarily via the groundwater pathway.

In addition to contamination resulting from past and present Hanford operations, there is the potential for more contamination because the Hanford Site is being used for storage and disposal of nuclear materials, radioactive waste, chemically hazardous waste, and mixed waste (nuclear materials mixed with hazardous chemicals). For example, presently two-thirds of the nation's high-level defense nuclear waste is being stored at the Hanford Site with continuing shipments of nuclear waste being received (DOE 1993). Much of this nuclear waste may remain at the Hanford Site. The storage of these nuclear wastes could potentially contribute to the contamination of the Columbia River (depending on the performance of the chosen containment solution) for thousands of years.

As a result of the known contamination in 1989, four areas of the Hanford Site (the 100, 200, 300, and 1100 Areas) were placed by the U.S. Environmental Protection Agency (EPA) on the national priorities list for cleanup. The national priorities list is a component of the *Comprehensive Environmental Response*,

Compensation, and Liability Act of 1980 (CERCLA) (42 USC 9601) enacted by the U.S. Congress. Because the 1100 Area has since been cleaned up, it was removed from the national priorities list.

To address the cleanup needs mandated by CERCLA and to address the requirements for handling currently stored/generated wastes as mandated by the *Resource Conservation and Recovery Act of 1976* (RCRA) (42 USC 6901), DOE entered into a *Federal Facility Agreement and Consent Order* (unofficially known as the Tri-Party Agreement) (Ecology et al. 1994) in 1989 with EPA and the State of Washington. Milestones have been adopted for the Tri-Party Agreement that identify actions needed to ensure acceptable progress toward Hanford Site compliance with CERCLA, RCRA, and the *Washington State Hazardous Waste Management Act* (RCW 1985).

During 1993, the Tri-Party agencies began work toward a comprehensive assessment of the impact of Hanford operations (past and present) on the current conditions of the Columbia River (DOE 1994). In January 1994, the Tri-Party Agreement was revised to reflect this project. This revision included a new Milestone, M-13-80B (later changed to M-15-80), that established CRCIA. In December 1995, the CRCIA milestone was revised, enhancing the review process and specifying target dates. In April and December 1996, changes to the Tri-Party Agreement provided additional time to perform the work in the initial phase.

How to Use This Report

The CRCIA report is divided into two parts. Part I describes the results of the screening assessment. Part II defines the requirements for the essential work remaining to provide an acceptable comprehensive assessment of impact to the Columbia River. The lists of references and appendixes can be found at the end of each part.

Part I of the CRCIA report is organized according to the process followed in the screening assessment. First the contaminants to be assessed were determined (Section 2.0). Then the data were gathered for those contaminants (Section 3.0). Next the species to be studied were selected (Section 4.1) and the risk to these species assessed (Section 4.2). Finally the scenarios to be studied were selected (Section 5.1) and the risk to humans assessed (Section 5.2). A synthesis of the results is provided in Section 6.0

Supporting information relative to the respective sections and appendixes in Part I has been published on diskettes, which have been issued with limited distribution. In addition, because numerous changes have occurred in Volume II of the draft data report since its initial publication in June 1996, a revised Volume II is being issued also with limited distribution. The CRCIA report with its diskettes and the updated version of Volume II of the June 1996 data report with its diskettes are available on the Internet at <http://www.hanford.gov/crcia/crcia.htm>. Both the diskettes and hard copies of Volume II are also available from S.D. Cannon (509-372-6210).

Part II of the CRCIA report is organized according to four key components of the requirements necessary for a comprehensive assessment: What the assessment must include (Section 1.0), how good the impact assessment results must be (Section 2.0), analytical approach and methods (Section 3.0), and conducting and managing the assessment (Section 4.0). The detailed requirements corresponding to each section are found in the respective appendixes: Appendix II-A contains the requirements for Section 1.0, Appendix II-B for Section 2.0, Appendix II-C for Section 3.0, and Appendix II-D for Section 4.0.

This draft report is being issued for public comment. Once comments have been received, the comments will be incorporated and the screening assessment and requirements for a comprehensive assessment will be published as a final report.

References

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RCW - Revised Code of Washington. 1985. "Hazardous Waste Management Act." RCW 70.105, Olympia, Washington.

Executive Summary

Introduction

The Columbia River is a critical resource for residents of the Pacific Northwest. It provides for basic needs and is interrelated with the life style and quality of life for the Columbia Basin's many human and non-human residents. This resource was one of the key features that drew the Manhattan Project's planners to the site now called Hanford to produce nuclear weapon materials. Production of those materials has left behind a legacy of chemical and radioactive contaminants and materials that have affected and may be continuing to affect the Columbia River for the foreseeable future.

To evaluate the impact to the river from the Hanford-derived contaminants, the U.S. Department of Energy, U.S. Environmental Protection Agency, and Washington State Department of Ecology (the Tri-Party agencies) initiated a study referred to as the Columbia River Comprehensive Impact Assessment (CRCIA). To address concerns about the scope and direction of CRCIA as well as enhance regulator, tribal, stakeholder, and public involvement, the CRCIA Management Team (CRCIA Team) was formed in August 1995. The CRCIA Team has met weekly to share information and provide input to decisions made by the Tri-Party agencies concerning CRCIA. Representatives from the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, Yakama Indian Nation, Hanford Advisory Board, Oregon State Department of Energy, Tri-Party agencies, and Hanford contractors are active participants on the team.

We are conducting the Columbia River Comprehensive Impact Assessment in phases. The first phase is a screening assessment, the results of which are presented in Part I of this report. In the screening assessment, we evaluated the potential impact to the Columbia River resulting from current levels of Hanford-derived contaminants. The results of the screening assessment will be used to support decisions on Interim Remedial Measures. Part II of this report defines the requirements to conduct a comprehensive assessment of the Columbia River.

The CRCIA Team has agreed to conduct CRCIA using a phased approach. The initial phase, which is required and described in Tri-Party Agreement milestones M-15-80 and M-15-80C-T01 (Ecology et al. 1994), includes two components: 1) a screening assessment to evaluate the potential impact to the river, resulting from current levels of Hanford-derived contaminants in order to support decisions on Interim Remedial Measures, and 2) a definition of the essential work remaining to provide an acceptable comprehensive river impact assessment. The screening assessment is described in Part I of this report. The essential work remaining is described in Part II of this report.

Additional phases of CRCIA will be identified and decisions made regarding the conduct of the remaining work based on submittal of information as required by Tri-Party Agreement milestones M-15-80A, M-15-80B, and M-15-80B-T01.

Part I. Screening Assessment

The purpose of the CRCIA screening assessment is to support decisions on Interim Remedial Measures and to focus a subsequent and more comprehensive assessment. The objective of the screening assessment is to identify areas where the greatest potential exists for adverse effects on humans or the environment. The Hanford Reach of the Columbia River was evaluated in the screening assessment in a way that will be useful in the CERCLA process but not necessarily in strict accordance with CERCLA procedures (for example, risk assessment methodology and remedial decision making). The screening assessment focused on a sub-set of potential contaminants, selected from a relatively broad set of possible contaminants. Part I of this report discusses the scope, technical approach, and results of the screening assessment. The screening assessment was conducted by the Pacific Northwest National Laboratory in consultation with the CRCIA Team.

Scope

The scope of the CRCIA screening assessment is to evaluate potential risk to the environment and human health resulting from current levels of Hanford-derived contaminants. The study area for the screening assessment (see Figure 1 in the Site Characterization section) extends from upstream of the Hanford Site in areas unaffected by Hanford Site operations down to McNary Dam, which is the first dam downstream of the Hanford Site. The specific parameters of the scope are:

- ◆ Human health risk
- ◆ Ecological risk
- ◆ Columbia River and adjacent riparian zone (vicinity of Priest Rapids Dam to McNary Dam)
- ◆ Current conditions: January 1990-June 1996 (most recent date of data used in the screening assessment)
- ◆ Contaminants of interest
 - Radionuclides: tritium (hydrogen-3), carbon-14, cobalt-60, strontium-90, technetium-99, iodine-129, cesium-137, europium-152, europium-154, uranium-234, uranium-238, neptunium-237
 - Carcinogenic chemicals: benzene, chromium
 - Toxic chemicals: ammonia, chromium, copper, cyanide, diesel constituents (diesel oil, kerosene, xylenes), lead, mercury, nickel, nitrates, nitrites, phosphates, sulfates, zinc

◆ Environmental media

- Direct use: Columbia River water, riverbank seep water, river and seep sediment, external radiation
- Indirect use: groundwater (surrogate for seep water), riparian soils, aquatic and riparian biota (used for model comparison, verification)

Technical Approach

A screening assessment by its very nature is a limited assessment. Such limited assessments are used to indicate whether the issues under study warrant further investigation. Screening assessments are often used to express risk in relative terms rather than absolute because of the number and type of assumptions required to drive risk models, the degree of uncertainty inherent in the input to the models, and the limitations in available environmental data. The assumptions, uncertainties, and limitations are applied consistently across the study area, resulting in useful information relative to risk.

While more detailed than typical screening level assessments, limitations to the CRCIA screening assessment have been identified. The CRCIA screening assessment was restricted to 1) current conditions, 2) the Columbia River and adjacent riparian zone between Priest Rapids Dam and McNary Dam, 3) a limited number of contaminants, 4) a limited amount of monitoring data, 5) a limited number of species, and 6) a limited number of scenarios. For the results of the assessment to be useful, these limitations and the process through which the study was conducted must be understood.

The screening assessment technical approach is summarized through the following activities:

- ◆ Determining study domain and spatial scale
- ◆ Identifying contaminants to be assessed (resulting in 26 contaminants, 28 when accounting for various constituents of those contaminants)
- ◆ Identifying a variety of species to evaluate ecological exposure to the contaminants (resulting in 52 species)
- ◆ Identifying a variety of exposure scenarios to evaluate human exposure to the contaminants (resulting in 12 scenarios)
- ◆ Identifying, collecting, and preparing monitoring data available for the contaminants
- ◆ Assessing risk to human health and the environment posed by exposure to the contaminants

Study Domain and Spatial Scale

The study area was first broken down into 27 segments to best represent the current environmental conditions and the state of knowledge relative to contaminant concentrations in the river environment. The segmentation also provides meaningful information associated directly with the site operable units that will be useful in evaluating future remedial actions. Selection of the segments was based in part on environmental measurement densities, existing data representativeness, historical operations, and site knowledge of contaminated groundwater plumes entering the river. Some adjustments in the borders and size of individual segments were made as a result of CRCIA Team consultation and recommendations. Human health and ecological risk assessments were performed on the segments individually to provide a consistent basis on which to determine areas of potential concern.

Contaminants of Interest

The approach to estimating risk to the environment and humans began by determining which contaminants should be evaluated in the screening assessment. Contaminants of interest were identified prior to completing the source term data collection activity to focus the data gathering efforts on the specific contaminants to be evaluated in the assessment. This contaminant identification process, described in Section 2.2, consisted of a review of easily available records and was based on process knowledge and environmental measurements in surface water, riverbank seeps, soils, sediments, and groundwater. The initial list contained nearly 100 potential Hanford-origin contaminants.

The initial list of 100 potential contaminants was screened (using a multi-stage screening process described in Section 2.3) to a manageable number of contaminants likely to produce the greatest environmental or human health risks. This process was based on screens for human toxicity, human carcinogenicity, acute and chronic aquatic biota toxicity, and water quality standards. The final contaminants of interest list was established to provide reasonable assurance that the dominant contributors to human and ecological risk were included in the screening assessment. Additional consideration was given to contaminants known to be of public, stakeholder, or tribal concern. As a result, a list of 26 contaminants of interest was established that would be included in the human health and ecological assessments.

Species of Interest

A master species list, consisting of 368 species known to exist between Priest Rapids Dam and McNary Dam, was established that became the basis for the selection of the species to be included in the screening assessment. From the master list, a Tier I list of 93 species was generated by ranking the master list against 6 criteria. The CRCIA Team added 88 additional species to the Tier I list. Tier II ranking, a qualitative ranking of the Tier I list, resulted in the selection of 52 species to be included in the screening assessment. The Tier II ranking provided for balance across taxonomic groups and exposure pathways. The list of 52 species includes (see Section 4.1 and Appendix I-C):

Algae - periphyton, phytoplankton

Amphibians - Woodhouse's toad

Aquatic invertebrates - clams/mussels/snails, crayfish, fresh water shrimp, mayfly, water flea

Birds - American coot, American kestrel, American white pelican, bald eagle, California quail, Canada goose/mallard, cliff swallow, common snipe, diving ducks, Forster's tern, great blue heron, northern harrier

Emergent vegetation - tule

Fish - channel catfish, common carp, largescale sucker, mountain sucker, mountain whitefish, Pacific lamprey, salmon, small mouth bass, trout, white sturgeon

Fungi - as a taxon

Macrophytes - Columbia yellowcress, water milfoil

Mammals - beaver, coyote, mule deer, muskrat, raccoon, weasel, western harvest mouse

Reptiles - side-blotched lizard, western garter snake

Terrestrial vegetation - black cottonwood, dense sedge, ferns, reed canary grass, rushes, white mulberry

Scenarios of Interest

Although the scope of the screening assessment is current conditions, the scenarios developed for the human health assessment considered potential uses. Twelve human exposure scenarios were developed that covered a wide range of potential exposures. The scenarios included basic Hanford Site Risk Assessment Methodology (HSRAM) scenarios as well as several CRCIA scenarios developed to evaluate variables such as short-to-long exposure times, small-to-large ingestion rates of local foods, and multiple combinations of exposure pathways. CRCIA Team input was critical in the definition of Native American scenarios. Scenarios included in the human health screening assessment are listed below (see Section 5.1):

Industrial/commercial scenarios - industrial worker, fish hatchery worker

Wildlife refuge/wild and scenic river scenarios - ranger, avid recreational visitor, casual recreational visitor

Native American scenarios - subsistence resident, upland hunter, river-focused hunter and fisher, gatherer of plant materials, Columbia River island user

General population scenarios - resident, agricultural resident

Data Collection and Processing

A detailed search for environmental measurements collected from 1990 through early 1996 was made. Hanford and non-Hanford sources were queried, including Hanford contractors, local municipalities, the States of Washington and Oregon, and federal agencies. Data were collected for contaminant measurements in Columbia River water, riverbank seep water, Columbia River sediment, riverbank seep sediment, interstitial water (interface between groundwater and the river within the river bottom), riparian zone soils, aquatic and riparian zone biota, external radiation, and Hanford Site groundwater. Near river groundwater was used as a surrogate for riverbank seep water in those segments not having any results on the seep water itself. As a result of the data queries, a very large CRCIA database was established.

While the CRCIA database was extensive, there were many locations where contaminant measurements were not made during the time period of interest. Consequently, data were not always available for all contaminants of interest in all segments. For these cases, a series of surrogation and extrapolation rules were devised to allow approximation of the local contamination levels. Surrogate data were used where contaminant data from one medium were substituted for another medium within the same segment. For instance, groundwater data were used where no riverbank seep data existed. Extrapolated data were used for the same medium where contaminant data from one segment were substituted for another. In these cases, river water from an upstream segment was used in downstream segments.

Once the database was established, the data were prepared for use in the screening assessment. A data outlier test removed a maximum of one data point from each contaminant/medium/segment combination as appropriate. A trend analysis was also performed on these combinations to determine the most representative maximum data point. If an obvious downward trend was observed, the most recent data point was selected. Datasets were prepared for each segment for use in the deterministic and stochastic assessments. The deterministic assessment utilizes maximum contaminant concentrations within each segment for the various media. The deterministic assessment employs reasonable maximum individual parameters, tends to generate larger (conservative) exposures, and is commonly used in typical regulatory risk assessment methodology. The stochastic assessment, on the other hand, utilizes the geometric mean and geometric standard deviation, which describe the distribution of the contaminant concentrations for each segment. The stochastic assessment output includes a range of risk exposures and risk coefficients, which describe the distribution of potential risks for each segment.

Ecological and Human Health Assessments

Computational models were developed for both the ecological and human health assessments. A complex spreadsheet application was utilized in the ecological assessment while a computer code application was used in the human health assessment. To the extent possible, ecological and human input parameters were kept consistent. Transfer factors in human health models were derived from the ecological model results. The models and input parameters are described in Sections 4.2 and 5.2 and the appendixes. The models were tested and verified prior to their use.

To attempt to quantify the uncertainty, two calculation methods were used: deterministic and stochastic. For the deterministic method, the equations were calculated with single, high values of the parameters to identify potential worst case results. For the stochastic method, the equations were calculated with all possible combinations of parameter values, resulting in an output distribution rather than a single value.

For the human health assessment, both deterministic and stochastic calculations were performed for all contaminants, all scenarios, and all river segments. The contaminants assessed fall into one of three categories (carcinogenic chemicals, toxic chemicals, and radionuclides), each of which result in a different type of risk. Individual calculations for each of these contaminant/scenario/segment combinations are compared with toxicity or carcinogenicity indices as appropriate.

For the ecological risk analysis, deterministic calculations were performed for all species/contaminant/segment combinations. However, stochastic calculations were only performed for those combinations that resulted in an Environmental Hazard Quotient (EHQ) greater than 1.0. Results of the stochastic calculations were compared with toxicological benchmarks, including the lowest observed effect level (LOEL) and the lethal concentration (LC_{50}).

A benefit of the use of stochastic calculations was that it enabled the results to be subjected to statistical comparisons. In these comparisons, the stochastic distribution of concentrations and resulting risk in each Hanford-influenced river segment could be compared to those in a background segment upstream and out of the influence of the Hanford Site. These comparisons provide insight into the nature and magnitude of the incremental risks posed by Hanford releases and identify areas of concern.

Supporting information relative to the respective sections and appendixes in Part I has been published on diskettes, which have been issued with limited distribution. In addition, because numerous changes have occurred in Volume II of the draft data report since its initial publication in June 1996, a revised Volume II is being issued, also with limited distribution. The CRCIA report with its diskettes and the updated version of Volume II of the June 1996 data report with its diskettes are available on the Internet at <http://www.hanford.gov/crcia/crcia.htm>. Both the diskettes and hard copies of Volume II are also available from S.D. Cannon (509-372-6210).

Results and Discussion

The results of the ecological and human health screening assessments are provided in Sections 4.2 and 5.2, respectively. As a result of Hanford Site operations as well as from other human activities upstream of the Hanford Site, environmental levels of some contaminants do appear to be elevated. Both the ecological modeling and human exposure simulations identify contaminants and locations for which risk to both the environment and humans is evident and for which further analyses or measurements would be worthwhile.

Figure S.1 is a high-level summary of the findings of the ecological risk and human health risk assessments. The contaminants and affected segments of the Columbia River that pose a potential risk according to the results of either the ecological or human risk assessments are identified. The overlapping

		Minimal risk																										
		Ecological risk above threshold defined in Section 6.3																										
		Human risk above threshold (>IE-6 lifetime risk >0.01 hazard index)																										
		Above both ecological and human risk thresholds																										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Hom	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Casc.	Wata R	Res.	
Ammonia																												
Benzene																												
C-14																												
Cs-137																												
Cr/Car																												
Co-60																												
Copper																												
Cyanide																												
Diesel																												
Eu-152																												
Eu-154																												
I-129																												
Kerosene																												
Lead																												
Mercury																												
Np-237																												
Nickel																												
Nitrate																												
Nitrite																												
Phosphate																												
Sr-90																												
Sulfate																												
Tc-99																												
Tritium																												
U-234																												
U-238																												
Xylene																												
Zinc																												

Figure S.1. Summary of the Screening Assessment of Risk to the Ecosystem and Human Health (The reporting thresholds in this figure identify potentially hazardous contaminants, chronic and acute effects to all plants and animals, and toxic and carcinogenic impacts on human health for all scenarios considered in this report.)

results of the two assessments are also identified. For most of the contaminants, segments identified by the ecological risk analysis were also identified by the human health analysis, but sometimes the contaminants were in media that affect biota more directly than humans, so that human risk for those contaminant/segment combinations is below the reporting threshold. Conversely, segments identified via the human health analysis having indications of increased potential risk were not always identified in the ecological analysis.

The reporting thresholds used in Figure S.1 to identify potentially hazardous contaminants include consideration of chronic and acute effects on the environment and toxic and carcinogenic impact on humans. For the chronic ecological effects, a contaminant is identified if the number of stochastic simulation results exceeding a chronic toxicity benchmark is more than 5 percent greater than the number estimated in the background segment for the contaminant (denoted by yellow in Figure 4.19 of Section 4.2). For the acute ecological effects, a contaminant is identified as potentially hazardous if the sum of acute risk indices across all species for a contaminant is more than twice the equivalent total for the background segment (denoted by red in Figure 4.19 of Section 4.2). For humans, a contaminant is identified as potentially hazardous if the estimated hazard index for a given contaminant for any scenario is greater than 0.01 or if the estimated lifetime risk for any scenario is greater than 10^{-6} .

The contaminants identified in Figure S.1 as potentially hazardous are listed in Table S.1 with additional details about the magnitude and sources of the potential risk. Table S.1 presents the contaminants of highest potential risk identified in either the ecological risk assessment or the human health risk assessment, the segments in which they were identified, the medium or media that provided the dominating component of the risk, and the range of estimated human risk. To demonstrate the range of human risk, the median stochastic values of lifetime risk (carcinogenic chemicals and radionuclides) and hazard index (toxic chemicals) for both the Ranger and Native American Subsistence Resident scenarios are given.

The ecological assessment identified the types of organisms most likely to be adversely affected. Terrestrial species that are potentially most affected by contaminants in the study area are swallows, mallards, American coots, harvest mice, Canada geese, and raccoons. However, risk within the study area that is above background levels is limited to only a few locations within the study area (see Figure 4.22 in Section 4.2). The other species, including bald eagles, have relatively low risk in both absolute and relative (to background) terms. Aquatic species most likely to be affected by acute or chronic toxic effects from contaminants of Hanford Site origin are Columbia pebblesnail, hyalella, daphnia magna, crayfish, Woodhouse's toad, suckers, clams, mussels, and salmon/trout larvae. Most of these aquatic organisms have a benthic life style, spending all or a high proportion of their life in direct contact with sediment or pore water, and the pore water concentrations tend to drive their body burdens. A key pathway of exposure for the terrestrial organisms is predation of the aquatic species with high body burdens, which is also ultimately related to the concentration of contaminants in pore water.

Contaminants of interest pose potential hazards to some plants, herbivores, omnivores consuming riverine organisms (especially insects as prey), and weasels in some areas. The primary contaminants driving the risk are cesium-137, chromium, cobalt-60, lead, mercury, technetium-99, and zinc. The media contributing most to risk are pore water and sediment. For aquatic species, the organisms most at risk are

Table S.1. Potentially Hazardous Contaminants Identified by River Segment and Contaminating Media
(This table presents the contaminants by river segment and media and the estimated range of human risk.)

Contaminant	Ecological Risk		Human Risk					
	River	Medium	River	Medium	Ranger Scenario		Native American Sc.	
	Segment		Segment		Haz Index	Risk	Haz Index	Life Risk
Benzene			5	SP				2.60E-05
			13	SP				2.60E-05
Carbon-14			4	SP				2.90E-05
			6	SP				1.20E-05
Cesium-137			2	SW				7.01E-06
			3	SW(2)				7.46E-06
			4	SW(2)				1.06E-05
			5	SW(2)				1.32E-05
			6	SW				1.76E-05
	7	SD	7	SW(6)				2.16E-05
			8	SW				2.78E-05
			9	SW(8)				2.81E-05
	10	SD	10	SW(8)				3.06E-05
			11	SW(8)				2.94E-05
	12	SD	12	SW(8)				2.92E-05
			13	SW(8)				3.32E-05
			14	SW(8)				2.43E-05
			15	SW(8)				2.39E-05
			16	SW(8)				2.63E-05
			18	SW				1.34E-05
			19	SW(18)				2.05E-05
			21	SP(GW)				1.59E-05
Chromium	2	SD+SP	2	SW+SD		2.60E-04	2.32E-02	2.58E-01
	4	SD+SP	4	SD+SP		2.10E-04	3.30E-02	1.09E-01
	5	SD+SP	5	SD		2.10E-04	1.43E-02	6.30E-02
			6	SW		5.90E-05		4.23E-02
			7	SD		1.50E-04		6.94E-02
			8	SW+SP		5.60E-05	1.35E-02	8.66E-02
	9	SD+SP	9	SD+SP		1.00E-04	2.46E-02	6.72E-02
	10	SD+SP	10	SD+SP		1.40E-04	1.71E-02	5.90E-02
			13	SD		7.20E-05		5.28E-02
			18	SD		1.90E-04		3.89E-02
			19	SD		2.50E-04		1.05E-01
			20	SD		1.60E-04		7.03E-02
			27	SD		1.50E-04		1.64E-02
Cobalt-60			2	SD				3.54E-06

Table S.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk				
	River		River		Ranger Scenario		Native American Sc.
	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index Life Risk
(Diffuse)			3	SW(2)			2.22E-06
			4	SW(2)			2.96E-06
			5	SW(2)			2.71E-06
	6	SD	6	SD			1.08E-05
	7	SD	7	SD			2.58E-06
	8	SD	8	SW			3.71E-06
	9	SD	9	SD			2.49E-06
			10	SW(8)			1.86E-06
			11	SW(8)			2.16E-06
	12	SD	12	SW(8)			2.04E-06
	13	SD	13	SP(GW)			6.61E-06
			14	SW(8)			1.55E-06
			15	SW(8)			2.08E-06
			16	SW(8)			2.08E-06
			17	SP			2.15E-06
			18	SW			3.49E-06
			19	SW(18)			8.46E-06
			21	SP(GW)			2.89E-06
Copper	4	SP	4	SD			2.35E+00
			11	SD			2.57E+00
			14	SD			2.79E+00
			17	SD			2.51E+00
	20	SP					
			23	SW			6.51E+00
			24	SW(23)			4.28E+00
			25	SW(23)			6.32E+00
			26	SW(23)			5.30E+00
			27	SW(23)			6.90E+00
Cyanide	20	SP(GW)					
	21	SP(GW)					
Europium-152			13	SP(GW)			6.30E-05
Europium-154			6	SP			2.92E-06
			8	SP			9.23E-06
			13	SP(GW)			1.26E-05

Table S.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index	Life Risk
			17	SW				3.13E-06
			18	SW(17)				3.15E-06
			20	SP				1.68E-06
			21	SP(GW)				1.47E-05
Iodine-129			19	SP(GW)				2.20E-06
Lead	2	SD+SP						
	3	SD+SP						
			4	SD			4.30E-01	
	5	SD+SP	5	SD			3.65E-01	
	7	SD+SP						
	9	SD+SP						
	13	SD+SP						
	17	SD+SP	17	SD			1.22E+00	
	19	SD+SP	19	SD			6.47E-01	
	20	SD+SP	20	SD			4.74E-01	
	21	SD+SP						
			22	SW(21)			3.78E-01	
Mercury	3	SD						
	4	SD						
	6	SD						
	8	SD						
	9	SD						
	10	SD						
	12	SD						
	13	SD						
	14	SD						
	15	SD						
	16	SD						
	19	SD+SP						
	20	SD+SP						
Neptunium-237			8	SD				6.50E-05
			9	SD				8.30E-05
Nickel	20	SD

Table S.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index	Life Risk
Nitrates			4	SP			1.56E-01	
			10	SP			1.05E-01	
			12	SP(GW)			8.88E-02	
			14	SP			1.42E-01	
			17	SP			1.38E-01	
			20	SP			2.39E-01	
Nitrites			19	SP			1.08E-02	
Strontium-90			2	SD				8.35E-06
			3	SD				6.72E-05
			4	SW(3)				1.07E-05
			5	SD				1.28E-04
			6	SD				6.72E-04
			8	SP				1.79E-05
			9	SW				1.41E-05
			10	SD				1.10E-04
			12	SW(10)				6.43E-06
			13	SD				4.38E-05
			15	SD				5.95E-05
			16	SW				2.97E-05
			20	SW				6.09E-06
			21	SW				5.36E-06
			24	SW(21)				6.45E-06
			26	SW(21)				5.83E-06
			27	SW(21)				6.57E-06
Sulfates			7	SP(GW)			1.14E-02	
Technetium-99			3	SD				2.84E-06
	8	SD	8	SD				1.18E-06
	9	SD	9	SD				9.61E-07
	10	SD	10	SD				2.80E-06
	14	SD						
			17	SD				1.34E-06
	19	SD	19	SD				2.51E-06
Tritium (Hydrogen-3)			2	SP				1.31E-05
			4	SP(GW)				6.70E-06

Table S.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
	Segment	Medium	Segment	Medium	Haz Index	Risk	Haz Index	Life Risk
			6	SP				1.70E-05
			8	SP				5.05E-06
			9	SP				4.31E-06
			17	SP				2.15E-04
			19	SP(GW)				2.38E-05
			20	SP				8.91E-06
Uranium-234			12	SD				4.62E-05
			14	SP				7.34E-05
			17	SP				7.62E-05
			20	SP				9.34E-04
Uranium-238			4	SD				5.18E-05
			10	SD				1.51E-04
			11	SD				4.93E-05
			12	SD				4.54E-05
			14	SP				6.49E-05
			17	SD				5.81E-05
			19	SW+SP				1.07E-04
			20	SP+SD				8.67E-04
Zinc	4	SP+SD	4	SD			1.72E-01	
	7	SP+SD						
	8	SP+SD						
			12	SP(GW)			3.78E-01	
			16	SD			1.47E-01	
	17	SP+SD	17	SD			1.59E-01	
			19	SD			2.29E-01	
	20	SP+SD						
GW = Groundwater SP(GW) = Seep water surrogated with groundwater								
SD = Sediment SW = Surface water								
SP = Seep water SW(21) = Surface water extrapolated from upstream Segment 21								
Note: Only human risk values greater than 1.0E-6 or a hazard index of 0.01 are shown.

benthic species or life stages. Contaminants contributing to their risk are chromium, copper, cyanide, lead, mercury, and zinc. The media contributing most to this risk are pore water and sediment, with pore water most significant.

The segments presenting the greatest potential ecological risk are Segment 2 (chromium and lead at the 100-B/C Area), Segment 4 (chromium, copper, mercury, and zinc at the 100-K Area), Segment 5 (chromium and lead), Segment 6 (cobalt-60 and mercury at the 100-N Area), Segment 7 (cesium-137, cobalt-60, lead, and zinc at the 100-D Area), Segment 8 (cobalt-60, mercury, and technetium-99), Segment 9 (chromium, cobalt 60, lead, and mercury), Segment 10 (cesium-137, chromium, mercury, and technetium-99 at the 100-H Area), Segment 12 (cesium-137, cobalt-60, and mercury), Segment 13 (cobalt-60, lead, and mercury at the 100-F Area), Segment 14 (mercury and technetium-99), Segment 16 (cobalt-60 and mercury), Segment 17 (lead, but results suspect and zinc), Segment 19 (lead and mercury), Segment 20 (cyanide, lead, mercury, technetium-99, and zinc at the 300 Area—all results suspect), and Segment 21 (cyanide and lead).

Segments with potential acute ecological risk are Segment 4 (chromium and zinc), Segment 5 (lead), Segment 8 (mercury), Segment 9 (chromium, lead, and mercury), Segments 10 and 14 (mercury), Segment 13 (lead and mercury), Segment 17 (lead), and Segment 20 (copper and zinc). Data were insufficient to assess ecological risk of any contaminant in Segments 11, 18, and 22-27. Risk from nitrite, sulfate, and phosphate was not evaluated because of the general lack of toxicity benchmarks. They present no risk from food-chain exposure, however, because they are readily metabolized. Risk from neptunium-237 and carbon-14 was not evaluated because of the lack of pore water data. Surface water data for europium-152 were absent in Segments 1-18, so risk from this isotope was not estimated in those segments. Risk from certain other contaminants was not evaluated in all segments because of missing pore water data (see Figure 4.19 in Section 4.2).

The human health analysis identified the categories of humans most likely to be affected. Humans in the region of the Hanford Site may have a wide variety of exposures, from low to high (see Figures 5.1-5.3 in Section 5.2.3.1). Generally speaking, the scenarios for the Fish Hatchery Worker, Industrial Worker, and Ranger have the lowest exposures and, therefore, are lowest in terms of health risk. As defined in Section 5.1, none of the people involved in these scenarios consume foods grown in the Columbia River riparian zone or drink seep water. Therefore, the exposures are mostly incidental external exposures and inhalation of resuspended materials, though the Fish Hatchery and Industrial workers also consume a moderate amount of Columbia River water. The risk to workers from these pathways is quite low in comparison to those projected for people potentially exposed in other ways. At the other extreme, people postulated to live along the Columbia River, to eat substantial quantities of foods grown in the riparian zone, to eat fish and wildlife from the river, and to drink seep water have much larger potential exposures and, thus, estimated health risk. This category encompasses nearly all of the remainder of the scenarios described in Section 5.1. From a risk assessment standpoint, very few differences appear between any of the Native American scenarios and recreational/residential scenarios.

The segments presenting the greatest potential human health risk for any given scenario are as follows (these are identified using the estimated hazard index greater than 1.0 and/or an estimated lifetime risk greater than $1E-4$): Segment 2 (chromium), Segment 4 (chromium and copper), Segments 5 and 6

(chromium and strontium-90), Segments 7-9 (chromium), Segment 10 (chromium, strontium-90, and uranium-238), Segment 11 (copper), Segment 13 (chromium), Segment 14 (copper), Segment 17 (copper, lead, and tritium), Segment 18 (chromium), Segment 19 (chromium and uranium-238), Segment 20 (chromium and uranium-238), Segments 23-27 (copper).

Data were not available in every segment for all contaminants in all media. Data availability is discussed in Section 3.0, where lack of specific contaminant data is identified by segment. Surface water data for europium-152 were absent in Segments 1-18, so risk from this isotope was not estimated in those segments. Segments 11, 18, and 22-27 did not have sufficient seep water data (or a groundwater surrogate), so this medium was not included in the human health assessment in these segments. Seep water was generally not the primary contributor to potential human health risk, however, as indicated in Table S.1. Surface water data were extremely limited downstream of Segment 21 and were, therefore, extrapolated from Segment 21 for Segments 22-27 with few exceptions.

Uncertainty is inherent in any risk assessment. The uncertainty within the ecological and human health assessments is discussed in Sections 4.2.10 and 5.2.3.3, respectively. Uncertainties include those associated with the exposure models, measured media data, representativeness of the data, use of surrogate and extrapolated data, exposure scenarios, accuracy of modeled processes, and toxicological and dose response references.

Hanford and Non-Hanford Sources of Contaminants

Contaminants present in the Columbia River environs result from operations at Hanford as well as from human activities upstream of the Hanford Site. Contaminants for which a Hanford source appears to be indisputable include ammonia, cesium-137, chromium, cobalt-60, europium-152, europium-154, nitrates, strontium-90, technetium-99, tritium (hydrogen-3), and uranium isotopes. Other contaminants for which the Hanford Site may be a contributor, at least at specific locations, include copper, cyanide, lead, mercury, and zinc. The analyses indicate relatively high potential risk from these latter contaminants. However, the upstream risk from these contaminants is also high, and the Hanford Site increment over the upstream value is generally factors of two to three or less, making exact identification difficult.

Potentially Hazardous Contaminants

The contaminants discussed here are those identified by the ecological and human health screening assessments to be potentially hazardous (see Figure S.1 and Table S.1). The intent of the discussion of each potentially hazardous contaminant is to enhance the understanding of the potential risks and focus possible remedial decisions on those contaminants and media with the potential for the greatest risk reductions.

Benzene. Benzene is seen in low concentrations in seep water, frequently in conjunction with xylenes. It is a measurement surrogate for petroleum hydrocarbons. Some instances of petroleum contamination are known at the Hanford Site. The highest levels are seen at the 100-K and 100-F Areas. The primary exposure pathway is consumption of seep water.

Carbon-14. Carbon-14 is not detected in surface water. The Native American and Resident scenarios are uniformly controlled by ingestion of carbon-14 derived from seep water. Seep water was surrogated with groundwater in almost all segments along the Hanford Site. A single, particularly high value in the 100-K Area is evident in the deterministic data.

Cesium-137. Cesium-137 is a constituent of worldwide fallout and is present in soil and river sediment both upstream and downstream of the Hanford Site. While the concentrations of cesium-137 in sediment are similar upstream, along, and downstream of the Hanford Site (Dirkes and Hanf 1996), there is greater variability in the measurements along and downstream of the site, indicating that localized zones of increased concentration may exist. The primary risk is to biota that burrow into or live on the sediment. The primary pathway is external irradiation of these biota. For humans, the scenarios with high fish consumption show somewhat elevated risks from surface water, but this is largely driven by the surrogation process from a very few measured segments.

Chromium. This metal is identified as existing in elevated concentrations in several Hanford Reach river segments. For biota, the primary media of concern are sediment and pore water within the sediment (modeled using measurements of seep water or groundwater), and for humans the primary media are also sediment and the associated seeps. This indicates that the primary problem is groundwater contamination inland of the areas of the seeps, which is resulting in contamination of the sediment around the point where the groundwater issues into the river.

Cobalt-60. This radionuclide exists in both discrete particulate form and as generalized diffuse contamination. The particles have higher discrete activity and are somewhat easier to detect, but the more significant problem is with the diffuse sources. As with cesium-137, the primary ecological problem is direct external irradiation of biota that burrow into the sediment contaminated with diffuse cobalt-60 contamination.

Copper. In general, the risk to humans or biota from copper is similar upstream and downstream of the Hanford Site. However, in absolute terms, this metal is one of highest risk to biota and humans. The modeling indicates that pore water (modeled using groundwater measurements) in the 100-K Area may be elevated, thus exposing biota. Copper is one of the metals that may also be enhanced from upstream sources.

Cyanide. The excess risk calculated for this chemical compound is associated with pore water (modeled using groundwater) for biota and with seep water (also modeled using groundwater) for humans.

Europium-152. Europium-152 is an activation product, similar in source to cobalt-60. Although discernible above background throughout the Hanford Reach in sediment, the risk to humans from europium-152 is primarily from ingestion of seep water in Segment 13.

Europium-154. Like europium-152, the activation product europium-154 is slightly elevated throughout the Hanford Reach. The primary exposures are via seep water, though the primary mechanism in Segments 17 and 18 is via surface water.

Iodine-129. Iodine-129 is detectable above background at very low levels in Hanford surface water, but the primary pathway of exposure is via drinking seep water. The only segment with concentrations measured sufficiently high to score over a risk of $1E-6$ is Segment 19.

Lead. The risk to biota from lead is dominated by concentrations in sediment and pore water, and the risk to humans is dominated by concentrations in sediment. Lead is one of the metals that may also be enhanced in sediment from upstream sources, but there are signs that lead may be somewhat enhanced in Hanford Site groundwater, particularly in the vicinity of the old Hanford townsite.

Mercury. The risk from mercury is primarily to biota from sediment. Mercury is one of the metals that may also be enhanced from upstream sources.

Neptunium-237. The only positive measurements for neptunium-237 occur in sediment in Segments 8 and 9, which in the modeling lead to small ingestion intakes. These are single point measurements and do not represent wide area contamination.

Nickel. The ecological modeling identifies nickel in sediment as a possible problem in the 300 Area only.

Nitrates. The risk to humans from nitrates is derived from the pathway of drinking seep water. Nitrates are known to be elevated in Hanford Site groundwater with samples in groundwater above the U.S. Environmental Protection Agency drinking water standards in several of the reactor areas (see, for example, Dirkes and Hanf 1996).

Strontium-90. The primary risk to humans from strontium-90 comes from consuming foods grown in contaminated sediment. Risk from consumption of seep water comes in a close second. It is likely that the concentrations in the sediment are related to the seep water concentration at most of the locations that are coincident with reactor areas.

Sulfates. Sulfates are measured in surface water and seeps in numerous locations. The primary pathway is direct ingestion. The concentrations averaged in Segment 7 are slightly higher than elsewhere, but the risk from sulfates is generally low.

Technetium-99. Environmental concentrations of technetium-99 are not high, but the soil-to-plant uptake factor for technetium is very large. Vegetation has a strong propensity to concentrate technetium from soil. The key medium for technetium-99 is sediment. In the case of the ecological results, the risk is actually related to the chemical toxicity of technetium in plants. For the human health results, the risk is associated with consumption of food plants grown in the technetium-contaminated sediment in the riparian zone.

Tritium (Hydrogen-3). Tritium is widely distributed in Hanford Site groundwater. However, it has a low biological uptake and generally short retention time in plants and animals because it is associated with

water. The primary route of exposure to humans is via consumption of seep water. The most extensive region where seep water contaminated with tritium enters the Columbia River is the vicinity of the old Hanford townsite.

Uranium-234/238. Although uranium is also ubiquitous in the environment, several areas have concentrations elevated above background levels. The media of interest include sediment and seep water near the 300 Area. A prominent pathway is the consumption of prey animals by animals farther up the food chain.

Zinc. The risk to biota is predominantly influenced by pore water and sediment. This metal provides the highest absolute contribution of risk to biota, but the median relative ratio to the upstream value is generally less than one for risk to humans. Zinc is one of the metals that may also be enhanced from upstream sources.

Screening Assessment Conclusions

By agreement with the Tri-Parties and the CRCIA Team, this screening assessment addressed the current potential for ecological and human risk, resulting from known levels of contaminants in the Columbia River or in its immediate vicinity.

The screening study posed the general questions:

- ◆ Do current levels of contaminants in Columbia River water, sediment, and riparian zone materials pose a potential risk to ecological resources?
- ◆ Do current levels of contaminants in Columbia River water, sediment, and riparian zone materials pose a potential risk to humans who might be exposed to them?

When taken in the context of the screening assessment, the answers to the two main assessment questions are yes. As a result of Hanford operations as well as from other human activities upstream of the Hanford Site, environmental levels of some contaminants do appear to be elevated. Both the ecological modeling and human exposure simulations identify further analyses or measurements would be worthwhile.

Through the use of multiple exposure scenarios, the possible activities of people who could come into contact with the contaminants were evaluated. In general, risk to people today is low because of restricted access to the Hanford Site. Casual visitors and even people working in jobs associated with the Columbia River are not at risk unless they frequent limited areas and consume seep or spring water in which high concentrations of contaminants are present. However, potentially increased risk is possible if people were to move onto the Hanford Site and derive large percentages of their daily food intake from crops and animals in the river's riparian zone. In most instances, this higher risk is limited in extent to a few regions of highest contamination. Although there are numerous cultural differences between the general population and Native Americans, the common pathways of food and water consumption could affect both groups. These common pathways are the ones by which most exposure would be received. The key differences come in the source of the water and food products.

Because of scientific uncertainty, the overall potential impact on the riparian ecosystems is not known. There is insufficient knowledge about the distribution of species, their migration patterns, and their interactions over the entire Hanford Reach. It is possible to say that there is a risk to individual members of certain species, those that frequent the locations of highest contamination.

Perspective

The CRCIA screening assessment was, by definition, limited in some respects. The screening assessment was restricted to current conditions, the area between Priest Rapids Dam and McNary Dam, a limited number of contaminants, a limited amount of monitoring data, a limited number of species, and a limited number of scenarios. For the results of the assessment to be useful, these limitations, the assumptions in the study, and the process through which the study was conducted must be understood and considered in context with the intended use. Site-specific considerations should be added to the general results presented here during the decision-making process to ensure responsible actions that are protective of the Columbia River.

The analyses completed for the screening assessment are based on the currently available data. Information is not available for all contaminants in all river segments during this time period. Where appropriate, data were extrapolated or surrogated to fill some of the data gaps, but others remain. The final results of the screening assessment, therefore, are limited by the scope constraints and the available information. The assessments have indicated that there are portions of the Hanford Reach of the Columbia River in which concentrations of contaminants, particularly in sediment and groundwater, are relatively high, pose a potential risk to human and ecological receptors under some scenarios, and may warrant additional investigation.

The density of data available for the assessment is illustrated in Section 3.0. For some river segments, relatively few data were available during the study period. These are areas for which additional sampling may be advisable. However, before proceeding with additional sampling or any remedial action, considerations must be made of additional information not used in this analysis and of the likelihood of acquiring additional useful information. For example, systematic radiological surveys have been made in the past (Sula 1980, EG&G 1990) that indicate the potential for finding additional highly radiologically contaminated areas along the river is small.

The spatial extent of the river segments as defined for the analysis is large enough to partially mask the presence of hot spots. The stochastic risk results tend to average out over segments as much as a few miles long. As a result of this and the data density issue discussed above, it is not possible to state categorically that elevated levels of contaminants do not exist in areas other than those previously identified.

Recent studies of rivers other than the Columbia also provide indications that the Hanford Reach is not unique (Pinza et al. 1992). Contaminants in Columbia River water, groundwater, seep water, sediment, and soil may have potential for impact on human or ecological health in areas immediately adjacent to the Hanford shorelines or throughout the Hanford Reach. However, there are sources of contaminant, primarily heavy metal, releases to the Columbia River upstream of Hanford. Thus, there are amounts of these metals, particularly chromium, copper, lead, mercury, and zinc, in sediment and water being

transported through the Hanford Reach from operations such as mining upstream (Munn et al. 1995, Serdar 1993, Johnson et al. 1990). Recent events (Tri-City Herald 1997) have shown that upstream tributaries of the Columbia River may carry very high levels of metals, particularly during periods of high runoff. The concentrations are sufficient to be acutely toxic to wildlife. The source of contaminants must be considered when evaluating Interim Remedial Measure alternatives.

Contaminant metals tend to sorb to fine-grained sediments, which deposit in slack water areas. Sizable quantities of sediments are deposited in the study area in the Hanford sloughs as well as behind both Priest Rapids Dam upstream (a portion of Segment 1) and McNary Dam downstream (Segments 22-27). This variation in sediment deposition and the variation in the sediment composition (grain size and organic content) may help explain some of the assessment results. A clear understanding of these complex relationships is essential to ensuring the environmental data and the resultant analyses using these data are accurately interpreted.

In addition, the bioavailability of some of these heavy metals has been identified as a significant source of uncertainty in the ecological assessment. These metals serve as nutrients and are known to be self-regulated, depending on the amount of the nutrient/contaminant present in the environment. As a result, transfer factors for these contaminants are highly variable and often times over- or underestimated when used in ecological assessments. A better understanding of the bioavailability of these contaminants in the Hanford Reach would allow for a more accurate estimate of the risk associated with these contaminants.

The scenarios used to establish the potential for human exposure, defined in Section 5.1, all have a common starting assumption: the individual described performs all of the described activities within the selected segment and within the river or immediately adjacent riparian zone. The likelihood of a person's actually deriving all of her or his food and water from the riparian zone has not been included in the scenario definitions. However, to simplify the analyses and provide a common basis for comparison, the same assumptions have been used for all river segments. Thus, while the results discussed above may indicate potential risk for various residential scenarios, the probability of occurrence of such activities is not considered in this assessment.

The ecological risk evaluated is for injury to individual plants or animals. The current state of scientific knowledge does not allow extrapolation to impact on the ecosystem with this level of information. Human risk is limited to individual toxic response or long-term carcinogenicity. The scenarios do not address cultural impact or multigenerational impact of the exposures.

The CRCIA screening assessment has provided an extensive amount of information relative to the human health and ecological risk associated with Hanford-origin contaminants in the Columbia River environment. The assessment has been successful in identifying contaminants that pose a significant potential risk. In addition to humans, ecological receptors most likely to be exposed to elevated levels of contaminants have been identified. The assessment has also identified in what media the contaminants are concentrated and through what pathway the contaminants reach the receptors. In addition, the locations of the problem areas have been identified within the spatial scale provided for in the assessment. Finally, the assessment defines the activities that could result in an adverse exposure to the contaminants. Clearly, the

screening assessment provides relevant and meaningful information to support Interim Remedial Measure decisions, to help guide ongoing environmental surveillance programs, and to focus a subsequent and more comprehensive assessment.

Part II. Requirements for a Comprehensive Assessment

As the screening assessment documented in Part I was being conducted, the assessment specified in Part II was developed by the CRCIA Team. Active participants on the CRCIA Team have been representatives from the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, Yakama Indian Nation, Hanford Advisory Board, Oregon State Department of Energy, Tri-Party agencies, and Hanford contractors. The CRCIA Team developed Part II to explicitly require any future assessment of Hanford impact on the Columbia River to embody, at a minimum, the methods, characteristics, and controls described in Part II. Those analyses involving the Columbia River that adhere to the spirit and substance of these requirements are far more likely to be acceptable to the governments and institutions that authored this section and far more meaningful in guiding cleanup decisions.

The authority underpinning these requirements for a comprehensive assessment of Hanford impact on the Columbia River is the U.S. Department of Energy's (DOE's) need for acceptance of cleanup decisions and this assessment's results by the affected people. DOE is providing only publications services for Part II of this report. It is not issued as an expression of DOE's endorsement. Like DOE, the other Tri-Party agencies (Washington State Department of Ecology and the U.S. Environmental Protection Agency), are members of the CRCIA Team that originated these requirements. However, these requirements have been promulgated by the CRCIA Team, not by the Tri-Party agencies, even though preparation of these requirements is the subject of Tri-Party Agreement commitments (milestone M-15-80).

This is the only composite assessment of how effective the cleanup of the Hanford Site will be as expressed in terms of impact to the Columbia River. Other analyses address only some of the elements of the needed assessment. This is a composite assessment because, in part, all potentially harmful radioactive and chemical materials within the Hanford Site boundary (those planned by DOE, to exist at the completion of cleanup) are included in a single evaluation of impact resulting from potential exposure. The purpose of

WHAT IS DOE's COMMITMENT TO CRCIA AND THESE REQUIREMENTS?

DOE is pursuing follow-on work based on the "Requirements for a Comprehensive Assessment." As part of completing TPA Milestones M-15-80A, M-15-80B, and M-15-80B-T01, DOE is working with the CRCIA Team to identify specific work tasks that 1) are necessary for a comprehensive assessment, 2) are prioritized and address the most dominant risk factors first, and 3) can be performed within budget guidelines. Agreed to tasks will be included in the multi-year work plan packages for FY 1998 and beyond.

CRCIA is to assess the effects of Hanford-derived materials and contaminants on the Columbia River environment, river dependent life, and users of river resources for as long as these contaminants remain intrinsically hazardous. This purpose is envisioned to be carried out by developing a suite of integrated analysis tools, which would be used for each revision of DOE's intended waste disposal plans defining the Hanford Site's final state. As such, CRCIA becomes a major, critical part of the Hanford Site's final baseline risk assessment. CRCIA is

also seen as a tool with which effectiveness can be estimated for each of the alternatives considered in strategic planning exercises, environmental impact statements, and the various projects' studies. This assessment was defined and this part of the report was prepared by the CRCIA Team (not DOE or its contractors) under a new public involvement paradigm described later in this summary, in Section 4.0, and in Appendix II-D.

In facing the question of what constitutes a comprehensive assessment, a serious problem soon became apparent: How can the assessment include all of the factors significant to potential river impact while keeping the effort to a manageable size which can be funded? Using expert judgment to "assume the assessment down-to-size" was rejected as an acceptable solution to this problem. Instead, a principle (specified as a requirement in Part II) was borrowed from other industries that routinely deal with large, complex problems yet have only limited resources. This principle requires the study's planning process be based on sensitivity analyses and parametric analyses that sort the dominating factors from the smaller contributors to impact. Consequently, for any given level of resources allocated to this assessment, the biggest contributors to potential river impact will always be addressed. The challenge for analyst and manager alike is not to arbitrarily discard parts of the assessment to cut it down to size but rather to ensure that no factor is left out that would dominate the study results. Care has been taken in developing Part II to be fiscally responsible in defining the requirements for the technical work that must be conducted regardless of speculations on probable funding availability or limits presumed to exist in analytical methods, data collection techniques, or related technologies. Every effort has been made to ensure that the assessment will always focus on major contributors in such a way as to avoid obfuscation by the enormous number of smaller considerations.

Because the screening assessment in Part I of this report was scoped to be a less-than-comprehensive, limited-resource effort focused on identifying the most significant existing effects on the Columbia River, the comprehensive assessment in Part II subsumes the screening assessment in identifying both existing and future effects from the composite of all Hanford activities. In spite of the care in developing this report, it is recognized that it can and should be improved on, especially in view of inevitable changes in waste disposal plans and experience gained in conducting this and similar assessments. It is intended that this be a living document with changes controlled by the authoring institutions.

Part II defines a new paradigm for predecisional participation by those affected by Hanford cleanup decisions. The CRCIA Team developed the requirements in Part II as well as the approach and structure for conducting and managing future assessment work. Appendix II-D describes this new paradigm and the associated management requirements. It is recognized that some time may be needed to make the adaptations in existing Hanford practices this new paradigm calls for. An implementation period is anticipated during which special attention will be given to working within existing policies and procedures while adaptations are being made.

Following the Introduction and the discussion of Principles and General Requirements, Part II is divided into four key sections: *WHAT* is to be analyzed, *HOW WELL* must the results represent actual and future impact to the Columbia River, technically *HOW* is the assessment to be performed, and what is the *MANAGEMENT* structure for the analysis work. Explanations and descriptions of these four areas are

found below. Lists of the technical requirements parallel this structure in Appendixes II-A, II-B, II-C, and II-D. The parallel sections/appendixes are:

- ◆ Section 1.0/Appendix II-A, What the Assessment Must Include. These sections specify *WHAT* factors must be included in assessing river impact. They include the extent of Hanford Site activities and materials to be addressed, transport mechanisms and travel times, and contaminant introduction into the river. The requirements also address the distribution of the contaminants within the Columbia River as well as identification of habitat or other water uptake locations. The requirements specify potential species, ecosystems, human populations, and cultures that could be affected by Hanford-derived contaminants in the Columbia River. These sections also include probable scenarios for the time frame of interest in which substantive change occurs to the river or ecosystem and cultural dependency on the river.
- ◆ Section 2.0/Appendix II-B, How Good the Impact Assessment Results Must Be. Requirements in these sections prescribe how complete the assessment results must be and *HOW GOOD* the analysis must be to produce the needed results.
- ◆ Section 3.0/Appendix II-C, Analytical Approach and Methods. Given the factors specified in the first two sections (1.0 and 2.0), these sections stipulate *HOW* the technical analyses are to be planned to ensure no dominant contributor is overlooked. Analytical methods, modeling requirements, data quality, uncertainty, and verification requirements are among the specifications included. While these requirements avoid specifying what tasks must be done or in what sequence work is to be performed, it is clear that this section must heavily influence how the assessment work is to be defined and the preparatory work that must precede the start of the analysis.
- ◆ Section 4.0/Appendix II-D, Conducting and Managing the Assessment. *MANAGEMENT* requirements are addressed in these sections to include methods to determine funding prioritization, sequence of technical work, roles of peer reviewers, integration with Hanford Site strategic planning and other analyses, and support of environmental impact statement preparations. These sections also address the continuing involvement and authority of affected people and groups.

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Glossary

100 Areas	site of the Hanford production reactors, which include B, C, D, DR, F, H, KE, KW, and N Reactors (see Figure 1 in the Site Characterization Section for the reactor areas)
200 Areas	sites of the Hanford chemical separations plants, which include the bismuth phosphate process plants (B and T Plants), plutonium uranium extraction plant (A Plant/PUREX), and reduction and oxidation plants (S Plant/REDOX)
300 Area	site of the research, development and fuel-fabrication operations (see Figure 1 in the Site Characterization section)
400 Area	site of the Fast Flux Test Facility (see Figure 1 in the Site Characterization section)
600 Area	all land within the Hanford Site not occupied by the 100, 200, 300, 400, 1100, or 3000 Areas
1100 Area	site of the warehouse, vehicle maintenance, and transportation operations center (see Figure 1 in the Site Characterization section)
3000 Area	site of engineering, construction, and research and development activities (see Figure 1 in the Site Characterization section)
abiotic	inorganic (not living) material and not derived from living material
aCi	attocurie, one quadrillionth of a curie or 10^{-18}
analytes	substances for which an analysis is made
anthropomorphic	created by humans
aquatic ecosystem	ecological system containing species that live in water
background level	measured level at which the concentration of a hazardous substance is consistently present in the environment that has not been influenced by local human activities
BCF	bioconcentration factor

beta particle	high energy electron emitted from a radioactive nucleus
bioconcentration factor	ratio of the body burden of an aquatic species to the water concentration where uptake is limited to respiration
biomagnification factor	ratio of the body burden in a species to the average body burden of its prey
biomagnifying	having a tendency to increase in concentration at higher food chain levels through dietary accumulation
biota	living organisms
biotic	referring to living organisms and their products
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i> (42 USC 9601 et seq. as amended)
cfs	cubic feet per second
chemicals (carcinogenic)	chemicals with a cancer causing or promoting agent
chemicals (toxic)	chemicals with a poisonous agent
Ci	curie, see definition under "curie"
concentration	amount of substance in a given quantity of material (for example, micrograms of chromium per liter of groundwater)
conceptual model	conceptual representation of a process or entity generalized from particular instances
coulomb	unit of electric charge; amount of electric charge that crosses a surface in 1 second when a steady current of 1 absolute ampere is flowing across the surface
CPOM	coarse particulate organic matter
CRCIA	Columbia River Comprehensive Impact Assessment
CRCIA Team	Columbia River Comprehensive Impact Assessment Management Team

curie	unit of radioactivity corresponding to 3.7×10^{10} (37 billion) disintegrations per second (abbreviated Ci), 1 curie = 3.7×10^{10} Becquerel
data files	electronic files of data for use in the screening assessment
final data file	final sets of data with substituted data included for use in the screening assessment
media files	data organized by media and prepared for use in the screening assessment prior to inclusion of substituted data
raw data files	unprepared data gathered for use in the screening assessment
deterministic analysis	single calculation performed with a single value selected for each parameter, such as a concentration value of a contaminant entering the river; in contrast, see stochastic analysis
deterministic value	single value used in a calculation; for example, 20 miles per gallon is used to estimate the fuel efficiency of a car; actual gas mileage varies considerably but averages to be this value so it is the one used in calculations
disposal plan	official document formally approving a specific closure or disposal method for Hanford materials and contaminants; each cleanup project will have a different disposal plan
DOE	U.S. Department of Energy
dose	amount of radiation; often distinguished as absorbed dose, dose equivalent, or effective dose equivalent
absorbed dose	amount of energy deposited by radiation in a given amount of material, such as tissue; expressed in units of rad or gray (1 gray = 100 rad)
dose equivalent	quantity calculated to compare relative biological effectiveness of different kinds of radiation, using a common numerical scale; determined by multiplying absorbed dose by a quality factor and other modifying factors; expressed in units of rem/mrem (a millirem is one-thousandth of a rem) or sievert (1 sievert = 100 rem)

effective dose equivalent	value used to account for the fact that a rem of radiation to one organ in the body does not have the same potential health impact as a rem of dose to another organ; it is the sum of the dose to all organs of the body from internal deposition of radionuclides and the dose from external radiation exposure; expressed in units of rem or sievert (1 sievert = 100 rem)
drive point	method used to place a sampling tube in sediment (pointed tip driven into sediment)
Ecology	Washington State Department of Ecology
EHQ	Environmental Hazard Quotient
EIS	environmental impact statement
endangered species	species which is in danger of extinction throughout all or a significant portion of its range
endpoints	biological resources and attributes that are to be protected and maintained within ecosystems potentially at risk
assessment endpoints	attributes of interest for the species; an explicit expression of the environmental value that is to be protected; an assessment endpoint includes both an ecological entity and specific attributes of that entity; for example, salmon are a valued ecological entity; reproduction and population maintenance of salmon form an assessment endpoint (EPA 1996)
measurement endpoint values	toxicological response used to represent the assessment endpoint; a measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint (EPA 1996)
EPA	U.S. Environmental Protection Agency
ERC	Environmental Restoration Contractor (Bechtel Hanford, Inc.; CH2M Hill Hanford, Inc.; IT Hanford, Inc.; Thermo Hanford, Inc.)
exposure	process by which the temporally and spatially distributed concentrations of a chemical or radionuclide in the environment result in a dose
internal exposure	contact with materials taken into the body through inhalation or ingestion

external exposure	contact with materials on the outside of the body, as from submersion in water or immersion in air
extrapolation	method used to fill data gaps with substitute data from the same medium but from a different location
fission	nuclear reaction in which the nucleus of an atom breaks up into two or more nuclei and releases energy (radiation)
food web	network of foraging relationships among species in a community
foraging guild	broad group of organisms that have a similar dietary composition; examples include carnivore and omnivore
Geographic Information System	computerized system designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information
geometric standard deviation	standard deviation of the log-transformed median values
grab sample	sample randomly collected from a single location at a specific time
gross beta	total activity of beta-emitting radionuclides that can not be distinguished separately by instrumentation or radiochemical analyses
GW	groundwater
half-life	time required for an initial number of radioactive atoms to be reduced to half that number by radioactive decay
Hanford Reach	segment of the Columbia River that extends 85 kilometers (51 miles) downstream from Priest Rapids Dam to the head of the McNary Pool near the City of Richland, Washington
hazard ranking	semi-quantitative listing in order of potential hazard
HEAST	Health Effects Assessment Summary Tables, a compilation of toxicity values published in health effects documents issued by EPA
HEIS	Hanford Environmental Information System; an electronic database that consolidates the data gathered during environmental monitoring and restoration of the Hanford Site

Henry's Law	air/water partition coefficient at low concentrations of a chemical in water; it relates the chemical concentration in the gas phase to its concentration in the water phase
herbivore	organism that feeds on plants
holdup time	length of time a parent radionuclide spends in the reactor core, usually expressed in seconds; also length of time between harvest and consumption of food products
HSRAM	Hanford Site Risk Assessment Methodology (DOE 1995)
HUMAN	computer code used to estimate risk to human health
ionizing radiation	high-energy radiation capable of ionizing the substances through which it passes
Interim Remedial Measures	corrective actions taken at Hanford Site operable units under CERCLA or RCRA at any time prior to initiation of final remedial actions; examples are pumping and treating contaminated groundwater, excavating contaminated soil, restricting access to contamination via warning signs and fences
IRIS	Integrated Risk Information System, an EPA database that provides data on chronic health hazards (reference dose values), carcinogenicity (unit risk factors or slope factors), EPA regulatory actions, supplementary data, and a bibliography for each listed chemical
irradiation	exposure of an object to radiation
isopleth	line drawn through points on a graph at which a given quantity has the same numerical value or occurs with the same frequency as a function of the two coordinate variables
isotope	one of two or more atoms having the same atomic number but different mass
Kcal	kilocalorie
LC₅₀	chemical concentration reported to be lethal to 50 percent of the exposed organisms after some period of exposure, usually a few hours to a few days

LD₅₀	dose reported to be lethal to 50 percent of the exposed organisms after some period of exposure, usually a few hours to a few days
LFI	limited field investigation conducted as part of Tri-Party Agreement activities to identify those Hanford waste sites that are recommended to remain as candidates for interim remedial measures
LOEL	lowest observed effective level
lognormal distribution	data distribution where the logarithms of the data form a normal distribution
maximum representative value	highest concentration value that is considered representative of the sampling location
mean (arithmetic)	average value of a set of numbers
mean (geometric)	average value of a set of lognormal data
median	middle value in a series of values arranged in order of size
MEPAS	Multimedia Environmental Pollutant Assessment System, a computer code that can be used to estimate the transport and fate of environmental pollutants
model	representation of a process or entity; the representation may be graphical or a set of mathematical equations that simulate the process or entity being modeled; see also conceptual model
monitor species	Washington State Department of Fish and Wildlife classification for species that either 1) were at one time classified as endangered, threatened, or sensitive; 2) require habitat that has limited availability during some portion of the species' life cycle; 3) are indicators of environmental quality; 4) require further field investigations to determine population status; 5) have unresolved taxonomic issues which may bear upon their status classification; 6) may be competing with and impacting other species of concern; or 7) have significant popular appeal
mrاد	millirad, one-thousandth of a rad
mrem	millirem, one-thousandth of a rem

natural uranium	naturally occurring mixture of uranium (0.7 percent uranium-235 and 99.3 percent uranium-238)
nCi	nanocurie, one billionth of a curie or 10^{-9}
NEPA	<i>National Environmental Policy Act of 1969</i> (42 USC 4321 et seq. as amended)
non-biomagnifying	remaining at the same concentration or decreasing in concentration at higher levels in the food chain
NPDES	National Pollution Discharge Elimination System
NPL	National Priorities List
omnivore	organism that feeds on both plants and animals
operable unit	term used to identify specific areas designated for cleanup
ORDOE	Oregon State Department of Energy
order of magnitude	order of 10, term used to describe relative size; for example, two orders of magnitude is equal to two orders of 10 or 100
outlier	data value determined to be outside the range of unlikely values in the given distribution
PCB	polychlorinated biphenyl
pCi	picocurie, one-trillionth of a curie or 10^{-12}
pdf	see probability density function
piscivore	organism that feeds on fish
plume	volume of air, soil, or water containing contaminants released from a contaminant source
PNNL	Pacific Northwest National Laboratory
pore water	water in the interstitial spaces of the substrate that forms the bottom of the Columbia River; for example, groundwater in springs between rocks

ppb	parts per billion
predator (fish)	
first-order	fish that consume primarily herbivorous species; includes perch, crappie, punkinseed, and bluegill
second-order	fish that consume other fish; includes bass, trout, and squawfish
probability density function	set of all possible values of a parameter and their associated likelihoods
production operations	activities connected with the production reactors in the 100 Areas (B, C, D, DR, F, H, KE, KW, or N reactors) in which uranium or other fuel was irradiated with neutrons to produce radioactive materials; used primarily at Hanford to produce plutonium for weapons; used also for research
proton	positively charged particle which, in conjunction with the neutron, forms all atomic nuclei
punch point	seep well, which is an open-end pipe driven into the river bank
rad	radiation absorbed dose, unit of measurement used to describe absorbed dose
radioactivity	spontaneous emission of radiation (alpha, beta, gamma rays, and/or neutrons) by some nuclides as they transform into other nuclides
radionuclide	radioactive isotope of an element
RCRA	<i>Resource Conservation and Recovery Act of 1976</i> (42 USC 6901 et seq. as amended)
reference dose	estimate established by the U.S. Environmental Protection Agency for specific chemicals (with uncertainty spanning perhaps an order of magnitude) of the daily exposure of the human population to a potential hazard that is likely to be without risk of deleterious effects during a lifetime
release	discharge of a substance into the environment
release factor	ratio of amount released to the amount processed

rem	roentgen equivalent man, unit of measurement used to describe dose equivalence
retention time	length of time effluent water was held in a retention basin before discharge to the Columbia River; normally expressed in hours
RfD	reference dose; for definition, see "reference dose"
RI/FS	remedial investigation/feasibility study
riparian ecosystem	ecological system on banks of a body of water; in this report, the banks of the Columbia River in the transition zone between the aquatic and terrestrial ecosystems within which plants are dependent on a perpetual source of water
risk	term relating to the consequences of exposure, measured for humans using either hazard index or lifetime risk
hazard index	risk from toxic chemicals, which is a ratio between the reference dose determined by EPA to be safe and the dose that has been estimated
lifetime risk	when applied to carcinogenic chemicals, the risk of cancer occurring; when applied to radionuclides, the risk of death from cancer
risk assessment	process used to estimate the severity and likelihood of harm to human health or the environment from hazardous substances, activities, and conditions
RISKS	computer code to implement statistical tests for comparing the estimated results of risk to human health with those estimated for an upstream and, therefore, presumably minimally contaminated location
riverine	habitat in the river, in this case the Columbia River
roentgen	unit of exposure of ionizing radiation that produces a charge of 1 coulomb of electric charge per kilogram of dry air
microroentgen	one-millionth of a roentgen
milliroentgen	one-thousandth of a roentgen
RTECS	Registry of Toxic Effects of Chemical Substances

scientific notation	used to express very large or very small numbers; for example, the number 1 billion could be written as 1,000,000,000 or using scientific notation as 1E+09 or 1×10^9 ; translating from scientific notation to a more traditional number requires moving the decimal point either left or right from the number; if the value given is 2E+03 (2.0×10^3), the decimal point should be moved three numbers (insert zeros if no numbers are given) to the right of its present location; the number would then read 2,000; if the value given is 2E-05 (2.0×10^{-5}), the decimal point should be moved five numbers to the left of its present location; the result would become 0.00002
screen	a simple test to rapidly identify potentially critical components and exposure pathways by eliminating those of known lesser significance by applying conservative assumptions and model parameters that attempt to deliberately overestimate the risks
screening assessment of risk	risk assessment with limited scope; the limitations of the CRCIA screening assessment were that it was restricted to 1) current conditions, 2) the area between the vicinity of Priest Rapids Dam and McNary Dam, 3) a limited number of contaminants, 4) a limited amount of monitoring data, 5) a limited number of species, and 6) a limited number of scenarios
SD	sediment
seeps	discharge zones located above river water level where the flow rate is very low
semi-aquatic ecosystem	ecological system containing those species that live partially in water and partially on land
sensitive species	species which is likely to become endangered or threatened in a significant portion of its range
sensitivity	susceptibility of an organism to adverse effects resulting from exposure to contaminants
sensitivity analysis	determination of the parameters and pathways that contribute most to the uncertainty in exposure or effects calculations
SESP	Surface Environmental Surveillance Project

sink	medium in which contaminants are deposited and from which there is little or no short-term contaminant migration (for example, sediment immediately upstream from McNary Dam)
site planning baseline	specification of a method of disposal for each waste site; where no baseline exists, the guidance of the responsible agency shall be used with regulator concurrence and CRCIA Board approval; in that case, the baseline would be the current condition
slope factor	estimate of the excess probability of developing cancer per unit exposure to a carcinogen over a lifetime
source	medium from which contaminants migrate into the surrounding environment (for example, seeps and springs in the riparian area of the Columbia River)
source term	amount of radioactivity (curies) of a radionuclide or amount of a chemical released to the environment from a facility at a given time
SP	seep water
spent fuel	irradiated fuel discharged from a reactor
springs	discharge zone located above river water level
SST	single-shell tank
stack	tall chimney that was the primary release point of exhaust air from a reactor or separations plant building
stochastic analysis	set of calculations performed using randomly selected parameter values from probability distributions for each parameter; in contrast, see deterministic analysis
stochastic variability	natural random variation of a measured quantity around a central value; for example, in a room full of people, there is an average height with some being taller and some shorter; the stochastic variability of that group is described by the differences between the individuals' heights and the average; see deterministic value
Supply System	Washington Public Power Supply System
surrogate (measurement)	estimated value used when actual measurement is unavailable

surrogation	method used to fill data gaps with substitute data from the same location but from a different medium
SW	surface water
Thiessen polygon	subdivision of space around points of measurement; the polygon defines all points that lie nearer the contained measurement point than measurement points outside the polygon; in the screening assessment the Thiessen polygon was used to define the area represented by the data from a groundwater well and, thereby, refine the segmentation of the river
threatened species	species which is likely to become endangered in the foreseeable future
TLD	thermoluminescent dosimeter; identified as "external radiation" in the text of this report
TLV	Threshold Limit Value used to estimate an effective reference dose for inhalation
toxicological benchmark	reference value from toxicity tests that is used as a basis of comparison for estimated exposures
TPA	Tri-Party Agreement; officially, <i>Hanford Federal Facility Agreement and Consent Order</i> (Ecology et al. 1994)
Tri-Party agencies	Three government agencies (U.S. Department of Energy, U.S. Environmental Protection Agency, and the Washington State Department of Ecology) that are signatories to the Tri-Party Agreement
TSD	treatment, storage, and disposal facilities or units at the Hanford Site
TWRS	tank waste remediation system
uncertainty	measure of the likelihood of a certain amount of variability in model parameters or dose estimates
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey
UST	underground storage tank

VOC	volatile organic compounds
WADOH	Washington State Department of Health
WHC	Westinghouse Hanford Company

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Site Characterization

Overview of Historical Operations

Many reports, documents, and books have been written about the Hanford Site and its history. The following is excerpted from a summary of the 1994 Hanford Site environmental report (Hanf et al. 1996). An anthology of early Hanford history provides additional information that may be of interest (Gerber 1993).

The Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 1). The Hanford Site occupies an area of about 1,450 km² (approximately 560 mi²) located north of the City of Richland and the confluence of the Yakima River with the Columbia River. This large area has restricted public access and provides a buffer for the smaller areas onsite that historically were used for production of nuclear materials, waste storage, and waste disposal. Only about 6 percent of the land area has been disturbed and is actively used. The Columbia River flows eastward through the northern part of the Hanford Site and then turns south, forming part of the eastern boundary. The Yakima River flows along part of the southern boundary and joins the Columbia River downstream from the City of Richland. Land in the surrounding environs is used for urban and industrial development, irrigated and dry-land farming, and grazing.

The Hanford Site was established in 1943 to produce raw materials (plutonium) for nuclear weapons and was the first nuclear production facility in the world. The Hanford Site was selected by the U.S. Army Corps of Engineers because it was remote from major populated areas and had ample electrical power from Grand Coulee Dam, a functional railroad, clean water available from the Columbia River, and plenty of sand and gravel available onsite for construction. The Hanford Site was divided into a number of operational areas. Figure 1 denotes the various reactor areas. For example, 100-D is the location for the D and DR reactors.

Operations at the Hanford Site resulted in the production of liquid, solid, and gaseous wastes. Most wastes resulting from Hanford Site operations have had at least the potential to contain radioactive materials. From an operational standpoint, radioactive liquid wastes were originally categorized as "high-level," "intermediate-level," or "low-level" depending on the level of radioactivity present. High-level liquid wastes were first stored in large underground single-shell tanks. The contents of some of these tanks have since leaked into the soil. In later years, high-level liquid wastes were stored in double-shell tanks, which have not leaked waste into the soil. Intermediate-level liquid waste streams were usually routed to underground structures of various types called "cribs." Occasionally, trenches were filled with the liquid waste and then covered with soil after the waste had soaked into the ground. Low-level liquid waste streams were usually routed to surface impoundments (ditches and ponds). In most cases, intermediate- and low-level liquid wastes were allowed to penetrate the soil to the groundwater. Some of the contaminants that reached the groundwater have subsequently flowed with the groundwater into the Columbia River.

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Figure 1. The Hanford Site and Surrounding Area

300 Area

From the early 1940s to the present, most research and development activities were carried out in the 300 Area located just north of Richland. The 300 Area was also the location of nuclear fuel fabrication. Nuclear fuel in the form of pipe-like cylinders (fuel slugs) was fabricated from purified uranium shipped in from offsite production facilities. Metallic uranium was extruded into the proper shape and encapsulated. Copper metal was an important material used in the extrusion process, and substantial amounts of copper, uranium, and other heavy metals ended up in 300 Area liquid wastes. Such low-level liquid wastes were routed to ponds located along the shoreline of the Columbia River. In more recent times, the low-level liquid wastes were shipped to a solar evaporation facility in the 100-H Area (100-H Storage Basins).

100 Areas

The fabricated fuel slugs were shipped by rail from the 300 Area to the 100 Areas. The 100 Areas are located on the shore of the Columbia River, where up to nine nuclear reactors were in operation. The main part of the nuclear reactors consisted of a large stack (pile) of graphite blocks that had tubes and pipes running through it. The tubes housed the fuel slugs while the pipes carried cooling water that was eventually returned to the Columbia River. The large collection of slightly radioactive uranium in the reactor piles resulted in an extensive radiation field and a radioactive chain reaction that caused some uranium atoms to be converted into plutonium atoms.

The first eight reactors, constructed between 1944 and 1955, used water from the Columbia River for direct cooling. Large quantities of water were pumped through the piles and discharged back into the river. The discharged cooling water contained radioactive materials that escaped from the fuel slugs, tube walls, etc. during the irradiation process. The radiation field in the pile also caused some of the impurities in the river water to become radioactive from neutron activation. The ninth reactor, N Reactor, was completed in 1963 and was of a slightly different design. Purified water was recirculated through the reactor pile in a closed-loop cooling system. Beginning in 1966, heat from the closed-loop system was used to produce steam, which was sold to the Washington Public Power Supply System to generate electricity at the adjacent Hanford Generating Plant. Although N Reactor did not produce heated cooling water that was returned directly to the Columbia River, the reactor did use a large crib near the shoreline for the disposal of radioactive water. Drainage from the crib interfaced with the groundwater and created artificial springs along the shoreline that contained radioactive materials.

When fresh fuel was pushed into the front of the reactor's graphite pile, irradiated fuel slugs were forced out the rear into a deep pool of water called a fuel storage basin. After brief storage in the basin and further storage in special freight cars on a railroad siding, the irradiated fuel was transported by rail to the 200 Areas, where the plutonium was recovered. Most of the irradiated fuel produced at N Reactor from the mid-1970s to late 1983 was transported by railcar to the 100-K East and 100-K West fuel storage basins for temporary storage where some of it remains today.

200 Areas

The 200 East and 200 West Areas are located on a plateau about 11 and 8 kilometers (7 and 5 miles), respectively, south of the Columbia River. These areas housed facilities called separations plants that received and dissolved irradiated fuel and then separated out the valuable plutonium. The REDOX (reduction oxidation) Plant and the PUREX (plutonium-uranium extraction) Plant were the two main separations plants. These plants produced large quantities of waste nitric acid solutions that contained radioactive materials. High-level wastes were neutralized and stored in large underground tanks. Intermediate-level wastes containing fission products, activation products, and nitrate ion were discharged to cribs. Low-level wastes and cooling water from the plants were distributed by open ditch to surface ponds for evaporation and percolation into the ground.

Because the high-level waste stored in tanks was not acidic, various chemicals and radioactive materials precipitated and settled to the bottom of the tanks. This phenomenon was later used to advantage—the liquid waste was heated in special facilities (evaporators) to remove excess water and concentrate the waste into salt cake and sludge, which remained in the tanks. The condensed water contained radioactive tritium (hydrogen-3) and was discharged to cribs.

The REDOX and PUREX separations plants produced uranium nitrate for recycle and plutonium nitrate for weapon component production. Uranium oxide was prepared for reuse and packaged for offsite shipment at the Uranium-TriOxide (UO-3) Plant. The UO-3 Plant discharged wastes containing nitrate ion and uranium to cribs and discharged cooling water to a pond. Plutonium nitrate was received for further processing at one of several buildings collectively known as Z Plant. Processes at Z Plant used nitric acid, hydrofluoric acid, carbon tetrachloride, and various oils and degreasers. Varying amounts of all these materials ended up in intermediate-level waste streams that were discharged to cribs. Cooling water was sent to a pond by an open ditch.

400 Area

In addition to research and development activities in the 300 Area, the Hanford Site has supported several test facilities. The largest of these was the Fast Flux Test Facility, a special nuclear reactor designed to test various types of nuclear fuel. The facility operated for about 13 years and has been shut down since 1993. The reactor was of a unique design that used liquid metal sodium as the primary coolant. The heated liquid sodium was cooled with atmospheric air in heat exchangers. Generated wastes were transported to the 200 Areas.

Richland Areas

Areas near north Richland provide Hanford Site support services. The 1100 Area, about 5 kilometers (3 miles) west of the Columbia River, is the location of general stores and the transportation maintenance facility for the Hanford Site. Operations at the transportation maintenance facility resulted in ground contamination from several chemicals, oils, and greases. No radioactive waste was discharged to the ground in the 1100 Area. The U.S. Army Corps of Engineers completed remedial actions to remove hazardous waste from the 1100 Area in September 1995.

Other Areas

Several areas of the Hanford Site, totaling 665 km² (257 mi²), have been set aside for special uses. The Fitzner/Eberhardt Arid Lands Ecology Reserve, used for ecological research, was established in 1967 on land between the southern boundary of the Hanford Site and Highway 240. In 1975, that portion of the Hanford Site located north of the Columbia River was permitted for use by two government agencies. The U.S. Fish and Wildlife Service manages the Saddle Mountain National Wildlife Refuge, and the Washington State Department of Game manages a game reserve known as the Wahluke Slope Wildlife Recreation Area. Public access to the wildlife refuge is controlled, whereas the recreation area is open to the public during daylight hours for hunting, fishing, and recreation.

Non-DOE nuclear operations and activities include commercial power production by the Washington Public Power Supply System's WNP-2 Reactor (near the 400 Area) and commercial low-level radioactive waste burial at a site leased and licensed by the State of Washington and operated by US Ecology (near the 200 Areas). Near the southern boundary of the Hanford Site, north of Richland, Siemens Power Corporation operates a commercial nuclear fuel fabrication facility, and Allied Technology Group Corporation operates a low-level radioactive waste decontamination, super-compaction, and packaging disposal facility.

Environmental Setting

Information in the following discussions was summarized from National Environmental Policy Act documentation related to the Hanford Site (Cushing 1995) and other references as noted.

Climate and Meteorology

General climatic conditions for the Hanford Site are recorded at the Hanford Meteorological Station located on the 200 Areas Plateau between the 200 East Area and 200 West Area (Figure 1). Data have been collected at this location since 1945, and historical data summaries have been published by Stone et al. (1972) and Hoitink and Burk (1995). The general climate of the region is influenced by the mountains and hills located west of the Hanford Site. Because of a rain shadow effect caused by the Cascade Mountains, rainfall in the region is limited. The average annual rainfall is 16 centimeters (6.3 inches), and more than half of that occurs from November through February. The hills west of the Hanford Site are a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site. Winds along the Columbia River are influenced by the river's topography and are frequently from the west and northwest. Westerly winds occur frequently in the southern part of the Hanford Site. Occasional strong winds out of the southwest at any time of the year can be hazardous to boats on the Columbia River. Fog is common along the Columbia River in the fall when the water is warm and the air is cool.

Geology, Topography, and Soils

The Hanford Site lies within the Pasco Basin of the Columbia River Plateau. The Basin is a structural and topographic low into which the Columbia, Snake, and Yakima rivers drain. Outflow from the basin to

the Pacific Ocean is provided by the Columbia River. Through geologic time, a relatively thick sequence of fluvial, lacustrine, and glaciofluvial sediments have accumulated in the Basin. The Hanford formation is the uppermost sedimentary unit covering much of the Hanford Site. Hanford formation sediments consist primarily of sand and gravel deposited by cataclysmic floods during the last ice age. Below these deposits lies the Columbia River Basalt Group, a sequence of continental flood basalts covering more than 160,000 km² of Washington, Oregon, and Idaho. The Basin boundaries include the Saddle Mountains to the north, the Umtanum and Yakima ridges to the west, and Rattlesnake Mountain and Horse Heaven Hills to the south and southwest. A variety of topography is found on the Hanford Site, including ridges, lower slopes, valleys, ephemeral and discontinuous creeks, and a river.

Fifteen soil types have been identified on the Hanford Site, varying from sand to silty and sandy loam (Hajek 1966). The most important soils associated with the Columbia River include:

- Rupert Sand—primarily coarse, sandy, alluvial deposits overlain by windblown sand located along extensive areas on the west shoreline of the river from near the 100-F Area to the southern boundary of the Hanford Site
- Burbank Loamy Sand—a mantle of loamy sand over gravel located primarily in the vicinity of 100-D Area to 100-H Area
- Ephrata Stony Loam—a medium-textured soil over gravel characterized by topographic hummocks containing many boulders, located near the 100-N Area and 100-K Area
- Ephrata Sandy Loam—a medium-textured soil over deep gravel deposits, occurring from the western boundary of the Hanford Site to the vicinity of 100-B/C Area
- Riverwash Soil—small areas consisting of sand, gravel, and boulder deposits in wet, periodically flooded areas that make up overflowed islands and shoreland
- Dune Sand—hills and ridges of sand-sized particles that drift into the river upstream of the Washington Public Power Supply System facilities during periods of strong, southwesterly winds

Surface Water

The Columbia and Yakima rivers are the principal surface-water features associated with the Hanford Site. Other onsite surface-water bodies include springs, streams, West Lake, and a number of artificial ponds and ditches. Onsite sources of recharge to these surface water bodies include precipitation, overland flow, groundwater, and direct discharge of water from Hanford facilities (Cushing 1995, Dirkes and Hanf 1996, DOE 1988, Becker 1990).

Columbia River

The Columbia River is the second largest river (measuring total flow) in the continental United States and is the dominant surface-water body on the Hanford Site. Originating in the mountains of eastern British Columbia, Canada, the river flows south through a gap in the Saddle Mountains, then turns east

near Priest Rapids Dam and flows into the northern portion of the Hanford Site. The Hanford Reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula (created by McNary Dam), near Richland, and is currently under consideration for designation as a National Wild and Scenic River. No tributaries enter the Columbia in the Hanford Reach. The bank along the eastern shore of the Hanford Reach in places rises over 150 meters (500 feet) above the surface of the Columbia River forming the White Bluffs. In total, the water level of the Columbia River drops about 20 meters (70 feet) along its path through the Hanford Site. The Yakima River runs along part of the southern boundary of the Hanford Site and joins the Columbia River downstream from the City of Richland. Local watershed boundaries reveal that approximately two-thirds of the Hanford Site drains into the Columbia River; the remaining one-third, in the western and southern portions of the Hanford Site, drains into the Yakima River. However, because of the small amount of annual precipitation in the region, it is unlikely the Hanford Site contributes appreciable overland flow into the rivers under normal conditions.

The flow of water in the Columbia River is regulated by 11 dams within the United States, seven upstream and four downstream of the Hanford Site. Priest Rapids Dam is the nearest dam upstream of the Hanford Site, and McNary Dam is the nearest downstream. Flows through the Hanford Reach fluctuate significantly and are controlled primarily by operations at Priest Rapids Dam. Annual flows below Priest Rapids Dam over the last 77 years have averaged nearly $3,360 \text{ m}^3/\text{second}$ ($120,000 \text{ ft}^3/\text{second}$) (Wiggins et al. 1995). Daily average flows, ranged from 1,152 to $7,787 \text{ m}^3/\text{second}$ ($40,700$ to $275,000 \text{ ft}^3/\text{second}$). Monthly mean flows typically peak from April through June during spring runoff from melting snow in the upriver watershed. River flow is lowest from September through October and accentuated by extensive river-water removal for agricultural irrigation in the Mid-Columbia Basin. As a result of fluctuations in discharges, the depth of the Columbia River varies significantly over time. River stage may change along the Hanford Reach by up to 3 meters (10 feet) within a few hours (Dresel et al. 1995). Seasonal changes of about the same magnitude are also observed. River stage fluctuations measured at the 300 Area are only about half the magnitude of those measured near the 100 Areas because of the effect of the pool behind McNary Dam (Campbell et al. 1993). The width of the Columbia River varies from approximately 300 meters (984 feet) to 1,000 meters (3,281 feet) within the Hanford Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of large-scale flooding recurring in the Hanford Reach has been reduced by the presence of dams upstream of the Hanford Site.

Three tributaries join the Columbia River between the Hanford Site and McNary Dam: the Yakima River at river mile 335, the Snake River at river mile 324, and the Walla Walla River at river mile 315. The mean annual discharge of the Yakima River a few miles upstream of the confluence with the Columbia River at Kiona, Washington was approximately $70 \text{ m}^3/\text{second}$ ($2,500 \text{ ft}^3/\text{second}$) for the years 1990-1994 (Wiggins et al. 1995). The Snake River mean annual discharge as measured at Ice Harbor Dam, just upstream of the confluence with the Columbia River, is approximately $1,600 \text{ m}^3/\text{second}$ ($54,000 \text{ ft}^3/\text{second}$). The mean annual discharge of the Walla Walla River measured prior to entry into the Columbia River is approximately $15 \text{ m}^3/\text{second}$ ($600 \text{ ft}^3/\text{second}$). All three contribute a significant volume of sediment to the Columbia River, most notably the Snake River.

Since construction of McNary Dam (completed in 1953), a significant amount of the sediment has been trapped behind the dam (Robertson et al. 1973). However, as is true of the other Columbia River dams, some of the trapped sediment is resuspended and transported downstream by seasonal high discharges. The primary contributor of suspended sediment to the Columbia River is the Snake River (Whetten et al. 1969), but the Yakima and Walla Walla rivers are also significant sources. Sediment contributions from these sources are highly seasonal and related to water-discharge patterns. Sedimentation rates at certain sites behind McNary Dam have been postulated to be as high as 30 centimeters/year (Robertson et al. 1973). Subsequent studies by Beasley et al. (1986) reported sedimentation rates to average 7 ± 3 centimeters/year along the Oregon shore, 4 ± 2 centimeters/year at midchannel, and 2 ± 1 centimeters/year near the Washington shore. Sediment accumulates faster on the Oregon shore than the Washington shore because sediment input from the Snake and Walla Walla rivers is constrained to the near shore (Oregon side). Based on visual observations from past sediment-monitoring samples taken for the Surface Environmental Surveillance Project characteristics of the top 1-5 centimeter portion of the bed, sediment at Priest Rapids Dam appeared to be dominated by coarse to fine sands and silts. This is in contrast to observations made along the Hanford Site sampling locations, where cobble, coarse, and fine-sand bed sediments were found, and at the McNary Dam sampling site, where silt and clay sediments were observed (Blanton et al. 1995).

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

Columbia River Springs

Seepage of groundwater into the Columbia River has been known to occur for many years. Riverbank springs, defined as groundwater discharge zones located above the water level of the Columbia River, were documented along the Hanford Reach long before Hanford Site operations began (Jenkins 1922). McCormack and Carlisle (1984) walked the 66-kilometer (41-mile) stretch of the Hanford Reach shoreline of the Columbia River in 1983 and identified 115 springs. They reported that the predominant areas of groundwater discharge at that time were in the vicinity of the 100-N Area, the old Hanford townsite, and the 300 Area. The predominance of springs in the 100-N Area is no longer valid due to declining water-table elevations in response to a decrease in liquid-waste discharges to the ground. Select springs in the 100-B, 100-D, 100-H, 100 K, and 100-N Areas, the old Hanford townsite, and the 300 Area have been sampled routinely by PNNL's Surface Environmental Surveillance Project since 1988 (Figure 2). However, it has become increasingly difficult to locate springs in the 100-N Area because of the reduction in volume of liquid-waste discharges there (Dirkes and Hanf 1996).

The presence of springs along the shoreline depends on the height of the water level of the Columbia River. Dresel et al. (1994) reported that groundwater levels in the 100 and 300 Areas were heavily influenced by fluctuations in river stage from operations at Priest Rapids Dam. Water flows into the aquifer (that is, bank storage) as river stage rises, and water flows from the aquifer as river stage falls.

Figure 2. Springs, Ephemeral Streams, Temporary Ponds, and a Ditch on the Hanford Site

Following an extended period of low river discharge, groundwater discharge zones located above the water level of the Columbia River may cease to exist once the level of the groundwater comes into equilibrium with the level of the river. Thus, springs are most readily identified immediately following a decline in river stage. Bank storage of river water also affects the concentration of contaminants in the spring water. When river stage is high, river water flows into the aquifer and overlays or mixes with groundwater. Typically, this inland flow of river water is restricted to within several hundred feet of the shoreline (McMahon and Peterson 1992). Spring discharge immediately following a river stage decline generally consists of river water or a river water and groundwater mix. The percent contribution of groundwater to spring discharge increases over time. Because of the effect of bank storage on groundwater discharge and contaminant concentration, it is difficult to estimate the volume of contaminated groundwater that is discharged to the Columbia River within the Hanford Reach.

Onsite Springs and Streams

Few naturally occurring springs and streams exist on the Hanford Site (Figure 2). All are located in the vicinity of the basalt ridges in the western and southwestern portions of the Hanford Site (Dresel et al. 1995). Rattlesnake Springs and Snively Springs on the Fitzner/Eberhardt Arid Lands Ecology Reserve form small surface streams. Rattlesnake Springs is the largest and flows for approximately 3 kilometers (1.6 miles) before disappearing into the ground.

Onsite Ponds and Ditches

Several ponds and ditches have been created on the Hanford Site for the disposal of process and plant cooling waters (Meinhardt and Frostenson 1979, ERDA 1975, Gephart et al. 1976, Summers 1975). The number of ponds and ditches has declined steadily since the shutdown of Hanford Site production facilities. Only two onsite ponds and one ditch remain active in support of current Hanford Site operations. The East Powerhouse Ditch and the 216-B-3C Pond are both located in the 200 East Area, and the Fast Flux Test Facility Pond is located near the 400 Area. The 216-B-3C Pond is one of four ponds (216-B-3, -3A, -3B, and -3C) that are collectively referred to as B Pond. B Pond (Figure 2) was originally excavated in the mid-1950s for disposal of cooling water from B Plant and was expanded in the 1980s. The 216-B-3 and -3A Ponds were decommissioned in 1994, and the 216-B-3B Pond was never activated. The Fast Flux Test Facility Pond was excavated in 1978 for the disposal of cooling water and sanitary water in the 400 Area (Dirkes and Hanf 1995). The 216-B-3C Pond is the only surface disposal facility currently receiving radioactive liquid effluents (Gleckler 1996).

West Lake, the only naturally occurring pond on the Hanford Site, is located north of the 200 East Area (Gephart et al. 1976). West Lake has not received direct effluent discharges from Hanford Site facilities. Its existence is a result of the intersection of the elevated water table with the land surface in a topographically low area south of Gable Mountain and north of the 200 East Area. An artificially elevated water table occurs under much of the Hanford Site and reflects the artificial recharge from Hanford Site operations. The elevation of the water table beneath the 200 Areas has declined since the decommissioning of U Pond in 1984 (200 West Area), Gable Mountain Pond in 1987 (200 East Area), and the shutdown of other production facilities (Dresel et al. 1994). As a result, the water level in West Lake has dropped such that the pond is often dry during summer and fall.

Yakima River

The Yakima River, which borders a small length of the southern portion of the Hanford Site, has a low annual flow compared to that of the Columbia River. The average annual flow of the Yakima River at Kiona, Washington, for water years 1990 through 1994 was approximately 70 m³/second (2,500 ft³/second); daily average flows ranged from 15 to 614 m³/second (523 to 21,700 ft³/second) (Wiggins et al. 1995). The Yakima River is generally regarded as a source of recharge to groundwater of the unconfined aquifer in the southern part of the Hanford Site and in the Richland area.

Other Surface Water

The Columbia and Yakima rivers and riverbank springs are the only naturally occurring surface-water bodies on or adjacent to the Hanford Site. However, artificial canals, ponds, and wetlands associated with irrigation are also present onsite north of the Columbia River. Offsite, excess irrigation water and drainage water are returned to the Columbia and Yakima rivers at various locations, mostly through canal wasteways. The Ringold Springs Fish Hatchery, is a state owned fish hatchery located on the east shore of the Columbia River up stream from the 300 Area east of the 400 Area. The hatchery uses groundwater from springs created by irrigation.

Groundwater

Both confined and unconfined aquifers are present beneath the Hanford Site. The unconfined aquifer forms the uppermost groundwater zone and has been directly impacted by waste-water disposal at Hanford. The Columbia River is the primary discharge area for the unconfined aquifer. Thus, groundwater beneath the Hanford Site provides a pathway to the Columbia River for contaminants derived from the Hanford Site. The following information on Hanford Site hydrology was summarized from Cushing (1995), Dirkes and Hanf (1996), Dresel et al. (1996), DOE (1988) and other references as noted.

Hydrology

An unconfined aquifer and a sequence of confined aquifers underlie most of the Hanford Site. Perched water-table conditions have been encountered in sediments above the unconfined aquifer in the 200 West Area (Airhart 1990, Last and Rohay 1993) and in irrigated offsite areas east of the Columbia River (Brown 1979). The unconfined aquifer is generally located in unconsolidated to semiconsolidated sediments that overlie the basalt bedrock and is commonly referred to as the Hanford unconfined aquifer. The confined aquifers are located on the tops of basalt flows and sedimentary interbeds located between basalt flows of the Columbia River Basalt Group (Spane and Raymond 1993).

In general, the unconfined aquifer is located in the upper parts of the geological Ringold Formation. Because the sand and gravel of the Ringold Formation are generally more consolidated, contain more silt, and are less well-sorted, they are about 10 to 100 times less permeable than the sediments of the overlying Hanford formation. Before waste-water disposal operations began at the Hanford Site in 1944, the uppermost aquifer was almost entirely within the Ringold Formation, and the water table extended into the Hanford formation at only a few locations near the Columbia River (Newcomb et al. 1972). However,

waste-water discharges caused the water table elevation to rise into the Hanford formation in the vicinity of the 200 Areas and in a wider area near the Columbia River. This rise in water table elevation resulted in an increase in the rate of groundwater flow because of the greater thickness and high permeability of Hanford formation sediments. Depth to the water table ranges from 0 meter (water level of the Columbia River) to more than 106 meters (348 feet) near the 200 Areas. The Columbia River is the primary discharge zone for the unconfined aquifer beneath the Hanford Site (Luttrell et al. 1992).

Recharge to the unconfined aquifer originates from several sources, both natural and artificial (Graham et al. 1981). Natural recharge occurs from the infiltration of precipitation and irrigation in areas west of the Hanford Site and from the Yakima River along the southern boundary of the site. Most onsite artificial recharge of groundwater is from current Hanford Site operations in both the 200 Areas and the 300 Area. Since 1944, the artificial recharge from Hanford Site waste-water disposal operations in the 200 Areas has been significantly greater than natural recharge. However, the groundwater in the southeastern portion of the Hanford Site is impacted more by offsite activities than by Hanford Site operations. Artificial recharge occurs at the City of Richland recharge basins (used to store Columbia River water for later use) and from crop irrigation west of the 1100 Area. Recharge rates at the Hanford Site have been estimated by Fayer and Walters (1995).

Recharge to groundwater across the Columbia River from the Hanford Site is primarily from irrigation and irrigation canal leakage. The water-table elevation to the east of the Columbia River is from 100 to 150 meters (328 to 492 feet) higher than the water-table elevation on the Hanford Site.

Water-Table Levels

Figure 3 is a map of June 1995 water-table elevation contours for the unconfined aquifer underlying the Hanford Site. The locations of measurement points used in preparing the map are also shown. The contour interval is 2 meters (6 feet) in the Hanford Site area west and south of the Columbia River and 50 meters (164 feet) in the area north and east of the Columbia River where the variation in water-table elevations is much greater. The lowest water-table elevations are found near the Columbia River, which indicates that the river is the major discharge area for the unconfined aquifer. Water-table elevations decrease approaching the Columbia River from either side, showing that ground-water flow converges at the river. Water-table changes for the years 1950 through 1980 were documented by Zimmerman et al. (1986).

Future Water-Table Levels

The volume of water discharged to the ground has been greatly reduced since 1987. As a result, the water table throughout the Hanford Site has begun to decline. The greatest declines of up to 9 meters (30 feet) have been measured in and around the 200 Areas (Kasza et al. 1994). Water levels are expected

Figure 3. Water-Table Elevations for the Unconfined Aquifer at the Hanford Site and in Adjacent Areas East and North of the Columbia River, June 1995

to continue to decline as the unconfined groundwater system reaches equilibrium with the new level of artificial recharge (Wurstner and Freshley 1994). The largest water level declines are expected to occur around the 200 Areas, but the overall direction of flow should remain the same. As waste-water discharges decrease, the flow system in the unconfined aquifer will approach pre-Hanford Site conditions.

Ecology

The Hanford Site encompasses 1450 km² (560 mi²) of shrub-steppe habitat that is adapted to the region's mid-latitude semiarid climate. Shrub-steppe vegetation in this area typically consists of a shrub overstory with a grass understory. The Columbia River is the dominant aquatic habitat in the area and supports a large and diverse community of plants and animals. Although agriculture and livestock grazing were prevalent at the turn of the century on what would become the Hanford Site, these activities ended when the Hanford Site was established in 1943. Public access to the Hanford Site has been limited since 1943, and most (more than 90 percent) of the land has laid idle allowing vegetation and wildlife to exist relatively undisturbed. For many years, access to the Columbia River was restricted from the Vernita Bridge to the powerline crossing near the point where the Hanford Site boundary crossed the Columbia River upstream of the 300 Area. The discussion on ecology presented below was summarized from Cushing (1995) with additional sources as noted.

Terrestrial Ecology

In the early 1800s, native vegetation of the shrub-steppe was dominated by big sagebrush and underlain by perennial Sandberg's bluegrass and bluebunch wheatgrass. With the arrival of settlers and agriculture, species of non-native vegetation became established and soon dominated the landscape. Approximately 20 percent of all plant species on the Hanford Site are considered non-native. Perennial grasses were mostly replaced with introduced species of annuals such as cheatgrass and Russian thistle (tumbleweed). Annual species remain dominant today in areas that were severely disturbed either by wildfire or human activities such as historical agricultural practices and current and past construction. A broad definition of vegetation types that occur on the Hanford Site include shrublands, grasslands, tree zones, riparian areas, and unique habitats.

Shrublands occupy the largest area in terms of acreage and comprise seven of the nine major plant communities on the Hanford Site (Sackschewsky et al. 1992). Of the shrubland types, sagebrush-dominated communities predominate, with other shrub communities varying in composition with changes in soil and elevation. In addition to sagebrush, there are five predominant species of shrubs on the Hanford Site: green rabbitbrush, gray rabbitbrush, antelope bitterbrush, spiny hopsage, and snow buckwheat.

True grasslands are not present on the Hanford Site, although grasses do occur as an understory in shrub-dominated plant communities. Cheatgrass has replaced many native perennial grass species and is well-established in many low-elevation (less than 244 meters/800 feet) or disturbed areas (Rickard and Rogers 1983). Grass species that prefer moist locations and are associated with the Columbia River include bentgrass, meadow foxtail, lovegrasses, and reed canarygrass (DOE 1996).

Trees are unique on the Hanford Site. Before settlement, the landscape lacked trees. Homesteaders planted trees near agricultural areas. Currently, approximately 23 species of trees occur on the Hanford Site. Surviving species (for example, cottonwood, poplar, Russian olive, willow, mulberry, and Siberian elm) are aggressive colonizers and have become common and well-established along the Columbia River (DOE 1996).

Riparian areas include sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River flood plain. Vegetation that occurs along the river shoreline includes emergent water milfoil, water smartweed, pondweed, sedge, reed canarygrass, and bulbous bluegrass. Other riparian vegetation occurs in association with perennial springs, seeps, and artificial ponds and ditches on the Hanford Site. The artificial habitats are ephemeral but have contributed to the establishment of cattail, reed canarygrass, willow, cottonwood, and Russian olive in areas otherwise devoid of riparian species. Wetland habitat that occurs in association with the Columbia River includes riffles, gravel bars, oxbow ponds, backwater sloughs, and cobble shorelines. These habitats occur infrequently along the Hanford Reach and have acquired ecological significance because of the net loss of wetland habitat elsewhere within the region. Emergent species include reed canarygrass, common witchgrass, and large barnyard grass. Rushes and sedges occur along the shorelines of several sloughs along the Hanford Reach at White Bluffs, below the 100-H Area, downstream of the 100-F Area, and at the Hanford Slough.

Unique habitats on the Hanford Site include rock outcrops, bluffs, dunes, and islands. Island habitats account for approximately 474 hectares (1,170 acres) and approximately 64 kilometers (40 miles) of river shoreline within the main channel of the Hanford Reach (Hanson and Browning 1959). Islands vary in types of soil and vegetation and range from narrow cobble benches to extensive dune habitats. The islands accommodate many of the same species that occur in mainland habitats. Operation of Priest Rapids Dam upstream of the Hanford Reach creates daily and seasonal fluctuations in river water levels, which may limit the development of plant communities and continued use by terrestrial animals and birds. Shoreline riparian vegetation that characterizes the islands includes willow, poplar, Russian olive, and mulberry. Species occurring on the island interior include sagebrush, buckwheat, lupine, mugwort, thickspike wheatgrass, giant wildrye, yarrow, and cheatgrass (Warren 1980). Management of these islands is a shared responsibility of the DOE, the U.S. Fish and Wildlife Service, and the U.S. Bureau of Land Management. Parts of some islands are under private ownership.

To clean up the Hanford Site's approximately 1,100 individual inactive waste sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 USC 9601 et seq), waste sites were grouped into 62 operable units. Several operable units are located near the Columbia River in the 100 Areas and the 300 Area. The 100 Area operable units with the exception of 100-HR-3 are characterized by a narrow band of riparian vegetation along the shoreline of the Columbia River with much of the area inland consisting of old agricultural fields dominated by cheatgrass and tumble mustard. The 100-HR-3 operable unit includes a wide riparian band along the northernmost tip of the Hanford Site between 100-D and 100-H Areas. Scattered big sagebrush and gray rabbitbrush also occur throughout the 100 Areas. Washington State threatened, endangered, or sensitive species of vegetation that have been reported for the 100 Area operable units include Columbia yellowcress, southern mudwort, false pimpernel, shining flatsedge, gray cryptantha, and possibly dense sedge (Landein et al. 1993). Most of these species are located near the 100-B/C Area wetland. The results of a vegetation

survey conducted at an operable unit in the 300 Area showed that the shrubsteppe vegetation consisted of an overstory of antelope bitterbrush and big sagebrush with an understory of cheatgrass and Sandberg's bluegrass (Brandt et al. 1993). Dominant riparian vegetation included white mulberry, shrub willow, reed canarygrass, bulbous bluegrass, sedges, and horsetail. Columbia yellowcress, a Washington State species of concern, was identified at 18 locations near the 300 Area operable unit (Brandt et al. 1993).

Wildlife

All terrestrial habitats, including riparian areas along the Columbia River, are important to terrestrial species of wildlife. Insects are abundant in emergent grasses and provide forage for fish, waterfowl, and shorebirds. Riparian areas provide nesting and foraging habitat and escape cover for many species of birds and mammals. These areas also are seasonally important to a variety of migratory species. For example, willow plants trap food for waterfowl (such as Canada geese) and other birds (such as Forster's tern) and provide nesting habitat for passerine birds (such as mourning doves). Western toads and frogs are the most common amphibian species occurring near artificial bodies of water and along the Hanford Reach.

Mammals that occur primarily in riparian areas include rodents, bats, furbearers (for example, beaver and mink), porcupine, raccoon, skunk, and mule deer. During the summer months, mule deer rely on riparian vegetation for foraging and periodically cross the Columbia River to access islands or the eastern shorelines. The Columbia River also provides foraging habitat for most species of insectivorous bats (Becker 1993).

Common bird species that occur in riparian habitats include American robin, black-billed magpie, song sparrow, and dark-eyed junco (Cadwell 1994). Predatory birds include common barn owl and great horned owl. Species known or expected to nest in riparian habitat include Brewer's blackbird, mourning dove, black-billed magpie, and the northern oriole. Bald eagles, which have wintered on the Hanford Site since 1960, use trees along the Hanford Reach for daytime perching and communal night roosts. Great blue herons and black crowned night herons are also associated with trees along the Columbia River and use groves or individual trees for perching, nesting, or rookeries.

The Hanford Site is located in the Pacific Flyway, and the Hanford Reach serves as a resting area for migrating waterfowl, shorebirds, and other birds. During the fall and winter months, when ducks and geese are resting along shorelines and on islands, the area between the old Hanford townsite and the Vernita Bridge is closed to recreational hunting.

The White Bluffs, across from 100-F Area and along the eastern side of the Columbia River, provides perching, nesting, and escape habitat for several species on the Hanford Site. The bluffs provide nesting habitat for prairie falcons, red-tailed hawks, and several species of swallows. Bluff areas provide habitat for sensitive wildlife and vegetation species (such as Hoover's desert parsley and the peregrine falcon) that otherwise may be impacted from frequent disturbance.

Columbia River islands afford a unique arrangement of upland and shoreline habitat and provide resting, nesting, and escape habitat for waterfowl and shorebirds. Nesting by Canada geese has been monitored on the islands since 1950. The islands provide suitable habitat for nesting Canada geese

because humans are restricted from using the islands during the nesting season and there is suitable substrate, adequate forage, and cover for broods (Eberhardt et al. 1989). The nesting population fluctuates yearly, and in recent years coyote predation has decreased the population (Cadwell 1994). The islands also accommodate large nesting colonies of California gulls and ring-billed gulls. Island areas ranging from 12-20 hectares (30-50 acres) may accommodate colonies of nesting gulls numbering more than 2,000.

Insects, reptiles, amphibians, birds, and mammals that occur in CERCLA operable units in general are typical of species that occur across the Hanford Site. During 1991-1993, surveys for birds, mammals, insects, and vegetation were conducted at several of the 100 and 300 Area operable units (Brandt et al. 1993; Landeen et al. 1993). Surveys conducted in 1991 and 1992 at the 100 Area operable units noted the presence of 107 species of birds and 11 of the 29 species of mammals known to occur in the area (Landeen et al. 1993). Species of concern that use the operable units include the American white pelican, bald eagle, and peregrine falcon (Landeen et al. 1993).

Brandt et al. (1993) recorded the results of surveys conducted in 1992 to determine the presence of reptile, bird, and mammal species in the 300 Area operable unit. Reptiles and amphibians present included the western yellow-bellied racer, gopher snake, side-blotched lizard, sagebrush lizard, and several toads and frogs. Fifty-three species of birds, including fourteen riverain and nineteen riparian species were also recorded. Seven species listed as candidates for protection under state or federal regulations included the burrowing owl, common loon, Forster's tern, great blue heron, loggerhead shrike, osprey, and sage sparrow. Fifteen species of mammals were also observed. The most frequently encountered small mammals were house mouse and Great Basin pocket mouse. Although not observed during the 1992 surveys, Townsend's ground squirrel, black-tailed jackrabbit, Nuttall's cottontail, beaver, mule deer, badger, and coyote are known to use the 300 Area operable unit.

Aquatic Ecology

There are two types of natural aquatic habitats on the Hanford Site: the Columbia River and small spring-streams and seeps located mainly in the Rattlesnake Hills. The following discussion was summarized from Cushing (1995) with additional references as noted.

The Columbia River and its Hanford Reach is the dominant aquatic ecosystem on the Hanford Site. The river is a very important resource to the local region. Public Law 100-65, passed by Congress in 1988, authorized the study of the Hanford Reach for possible designation as a wild and scenic river. In 1994, based on the results of this study, the National Park Service (NPS 1994) recommended creation of a 41,310-hectare (102,000-acre) national wildlife refuge. Lands on the Hanford Site currently designated as a wildlife refuge and a game reserve are only administered by the National Fish and Wildlife Service and Washington State Department of Game, respectively. The National Park Service further recommended that the Hanford Reach and its corridor be designated as a recreational river in the national wild and scenic rivers system. The refuge and river would be administered by the U.S. Fish and Wildlife Service. Before such a plan can become law, it must be endorsed by the Secretary of the Interior and enacted by Congress. If enacted, the designation would not preclude existing land use and recreational use of the river for boating, hunting, and fishing, but it would preclude expansion of agriculture and other noncompatible development within the refuge and river corridor. Establishing the lands adjacent to the river as a national

wildlife refuge would increase protection to all habitat types within and along the reach, protect both terrestrial and aquatic resources, and benefit the entire Hanford Reach ecosystem.

The Columbia River is a complex ecosystem because of its size, number of alterations (for example, dams), biotic diversity, and size and diversity of its drainage basin. With its series of large reservoirs, the Columbia River contains significant populations of primary energy producers (algae and plants) that provide for the basic energy requirements of insects, fish, birds, and mammals. Phytoplankton (free-floating algae) and periphyton (attached algae) are abundant in the Columbia River and provide food for herbivores such as immature insects, which in turn are consumed by carnivorous species. Plankton populations in the Hanford Reach are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids Reservoir, and by manipulation of water levels in downstream reservoirs. Phytoplankton and zooplankton populations at the Hanford Site are largely transient, flowing downstream from one reservoir to another.

Phytoplankton species identified from the Hanford Reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae, and dinoflagellates. Diatoms are the dominant algae in Columbia River phytoplankton, usually representing more than 90 percent of the populations (Neitzel et al. 1982a). The peak concentration of phytoplankton is observed in April and May with a secondary peak in late summer and early autumn. Minimum numbers are present in December and January (Cushing 1967a). Periphyton consists of small plants (benthic microflora) attached mostly to river rocks. However, communities of periphyton will develop on any suitable solid substrate wherever there is sufficient light for photosynthesis. Peaks of production occur in spring and late summer (Cushing 1967b). The dominant genera of periphyton communities are diatoms.

Macrophytes are large plants rooted in areas where the ground is consistently wet or areas are covered with shallow water. They are sparse in the Hanford Reach because of strong currents, a rocky bottom, and frequently fluctuating water levels. Macrophytes are more common downstream in the reservoir behind McNary Dam and where rushes and sedges occur along shorelines of slack-water areas such as White Bluffs Slough below the 100-H Area, the slough area downstream of the 100-F Area, and Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels (below Coyote Rapids and the 100-D Area). Large areas of macrophytes occur at the confluence of the Yakima and Columbia rivers. Macrophytes have considerable ecological value because they provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. However, they encourage increased sedimentation of fine particulate matter, which can have a significant impact on the ecology of the Columbia River.

Populations of zooplankton, which consist of minute animals, are generally sparse in the Hanford Reach. In areas of open water, crustacean zooplankters are dominant. Population densities are lowest in winter and highest in the summer, with summer peak densities ranging up to 4,500 organisms/m³ (130 organisms/ft³). Winter densities are generally fewer than 50 organisms/m³ (fewer than 2 organisms/ft³) (Neitzel et al. 1982b).

Benthic organisms (as opposed to benthic microflora) are small animals found either attached to or closely associated with river rocks or other substrata. All major fresh water benthic taxa are represented in

the Columbia River. Insect larvae such as caddisflies, midge flies, and black flies are dominant. Other benthic organisms include limpets, snails, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer (Wolf 1976). The stomach contents of fish collected in the Hanford Reach from June through March revealed that benthic invertebrates are important food items for nearly all juvenile and adult fish.

At least 43 species of fish were recorded in the Hanford Reach of the Columbia River by Gray and Dauble (1977). The brown bullhead has been collected since that study, bringing the current total to at least 44. Of these species, chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the Columbia River as a migration route to and from spawning areas and have the greatest economic importance. Both 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 percent of the total in the early 1980s to 50-60 percent of the total by 1988 (Dauble and Watson 1990). The destruction of other Columbia River spawning grounds by dams has increased the relative importance of the Hanford Reach as a spawning area (Watson 1970, 1973). Other fish of importance to sport anglers are mountain whitefish, white sturgeon, smallmouth bass, crappie, catfish, walleye, and yellow perch. Large populations of rough fish are also present, including carp, redbreast shiner, suckers, and northern squawfish.

Shad, another 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 of the Hanford Site, has risen to many thousands each year, and current year juveniles have been collected in the Hanford Reach. The shad is not dependent on the specific current and bottom conditions that the salmonids require for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

Studies were initiated in the spring of 1993 to evaluate the potential for using retired 100-K Area water basins for fish production (Dauble et al. 1994). Pilot studies indicated that juvenile fall chinook salmon could be transported to the facility and successfully held before being released in the Columbia River. Other studies were conducted by the Yakama Indian Nation as part of their expansion of fall chinook salmon rearing. In 1994, 500,000 young salmon were successfully reared in 14 net pens and released directly to the Columbia River via a pipeline. Another study involved rearing approximately 75,000 larval walleye and 27,000 juvenile channel catfish in other basins. In the spring of 1995, the Yakama Indian Nation reared up to 1 million fall chinook salmon at the 100-K facility using two of the basins and up to 28 net pens. The Nez Perce Tribe transferred some young sturgeon from the 100-K facility to a hatchery upstream of Lower Granite Reservoir on the Snake River to be used as brood stock for future supplementation of depleted Snake River stocks.

Wetlands

Several habitats on the Hanford Site could be considered wetlands, but the largest and most important is the riparian zone bordering the Columbia River. The extent of this zone in the Hanford Reach varies but includes extensive stands of willows, grasses, various aquatic macrophytes, and other plants. The riparian

zone is extensively impacted by both seasonal water-level fluctuations and daily variations related to power generation at Priest Rapids Dam immediately upstream of the Hanford Site. Other extensive areas of wetlands occur at the confluence of the Yakima and Columbia rivers and in slack-water areas farther downstream in the reservoir behind McNary Dam.

Threatened and Endangered Species

No plants or mammals on the federal list of threatened and endangered wildlife and plant species are known to occur on the Hanford Site. However, three bird species on the federal list have been recorded on the Hanford Site. Table 1 shows threatened and endangered species on federal and state lists that have been recorded on the Hanford Site and, thereby, occur within that portion of the study area.

Table 1. Threatened (T) and Endangered (E) Species Occurring or Possibly Occurring within the Hanford Site

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

The bald eagle is the only threatened or endangered animal that uses the Columbia River. It is a regular winter resident and forages on dead salmon and waterfowl but has not yet been observed to nest successfully on the Hanford Reach. Access controls are in place along the river at certain times of the year to prevent the disturbance of eagles. The Washington State Bald Eagle Protection Rules were issued in 1986, and DOE prepared a site management plan to mitigate eagle disturbance (Fitzner and Weiss 1994).

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

Hazardous Waste Materials

Historical operations at the Hanford Site produced considerable quantities of hazardous waste that contained radioactive as well as chemical contaminants. These wastes continue to impact the Columbia River, mainly from contaminated groundwater entering the river. Current operations continue to produce hazardous wastes but in much smaller quantities. Below is a brief summary of historical waste management practices that continue to impact the Columbia River and where current wastes are generated. Additional detail can be found in ERDA (1975), Cushing (1995), Dirkes and Hanf (1996), Schmidt et al. (1996), and other references as noted.

100 Areas

The 100 Areas collectively housed eight plutonium production reactors that operated from 1944 through 1971 and used the Columbia River as a direct source of cooling water. The cooling water became contaminated with radioactive materials that leaked from the nuclear fuel as well as from neutron activation of elements in reactor construction materials and natural elements (mostly uranium) present in Columbia River water. The water was also treated with chemicals (frequently solutions containing chromium) to inhibit fouling and corrosion. After passing through the reactors, the heated and contaminated water was returned to the Columbia River. The composition of the radionuclides and activity level in the discharged cooling water varied considerably (Walters et al. 1992). Important factors were

- ◆ number of reactors operating and their power levels
- ◆ seasonal changes in the natural elements found in raw river water
- ◆ chemicals used in water treatment
- ◆ corrosion rates of piping and fuel-element cladding
- ◆ occasional purging of radioactive film from reactor components
- ◆ length of time effluent was retained in basins before discharge
- ◆ episodic fuel-element failures

The ninth operating reactor, N Reactor, began operations in 1963 and was shut down in January 1987. N Reactor used a closed-loop cooling system, and heated cooling water was not returned directly to the Columbia River. However, various waste materials were discharged into cribs and ditches at each of the six reactor areas, and groundwater in the unconfined aquifer was subsequently contaminated. Full-scale remediation at 37 former liquid disposal sites in the 100 Areas began in 1996.

As a result of historical water disposal practices, groundwater mounds were created, and water soluble contaminants gradually flowed into the Columbia River at springs and seeps. At the 100-N Area, contaminated water that was discharged into two large cribs located near the shoreline soon created artificial springs along a short stretch of riverbank, which are collectively referred to as N Springs. The 1301-N crib was permanently retired from service in September 1985 and currently does not receive liquid wastes. The 1325-N crib continues to receive small amounts of cooling water, steam condensate, and low-level radioactive liquid wastes from N Reactor facilities. Continued ground disposal and the groundwater mound created during historical operations are responsible for continued water flow at N Springs.

Historical operations at the 100-D and 100-H Areas contaminated the groundwater with non-radioactive chromium. In 1994, a groundwater pump-and-treatment system began operation to remove chromium from the contaminated groundwater. The system was shut down in the fall of 1996. Through 1995 it had removed about 40 kilograms (87 pounds) of chromium. Current plans call for a new, expanded system to begin operations during the summer of 1997.

Current operations at the 100-K and 100-N Areas continue to dispose of small quantities of liquid wastes to ground and the Columbia River. Sanitary sewage is currently discharged to the ground at the 100-B, 100-D, 100-H, and 100-K Areas where the disposal systems consist of septic tanks and drainfields. Sanitary sewer waste at the 100-N Area is discharged to a sewage lagoon and five septic tanks. National Pollution Discharge Elimination System (NPDES) permits have been granted for seven discharge points. However, only three discharges (one at 100-K, one at 100-N, and the 100-N springs) are currently active. The discharge at 100-K Area is associated with the operation of the two fuel storage basins currently storing irradiated fuel relocated from N Reactor in December 1989. The Tri-Party Agreement stipulates that the fuel and sludge in the 100-K basins be removed by December 2002. Discharges at the 100-N Area consist of the return of raw cooling water and condensates through a 2.6-meter (102-inch) diameter pipe and the N Springs. Water samples collected from monitoring wells adjacent to N Springs in 1995 occasionally showed traces of oil, grease, iron, and ammonia, but all within the limits of the NPDES permit. A pump-and-treatment system to remove strontium-90 from the groundwater adjacent to N Springs was installed in 1995 and continues to operate.

200 Areas

Many facilities have operated in the 200 Areas since the startup of operations in 1944. The final shutdown of nuclear production reactors occurred in 1987, and the Hanford Site mission shifted from nuclear materials production to waste management, environmental cleanup and restoration, and technology development. As a result, production and support facilities in the 200 Areas were shut down (for example, the Plutonium Finishing Plant in 1989, PUREX Plant in 1990, and Uranium-Oxide Plant in 1993) or converted to support the current Hanford Site mission (examples are T Plant and B Plant). New facilities were constructed to provide for waste storage, treatment, and disposal. Wastes produced currently are products of waste management, cleanup, and Hanford Site restoration activities. Nearly all liquid wastes generated in the past, both radioactive and chemical, were either sent to large underground storage tanks or released to the environment through various drains, cribs, trenches, ditches, or artificial ponds.

In recent years, liquid waste discharges to the ground have been curtailed, and by the end of 1995 only B Pond (Figure 2) in the 200 East Area received effluents containing small amounts of radioactive materials. Current discharges are subject to compliance with a Washington State Department of Ecology Liquid Effluent Consent Order. DOE has agreed to use the best available technology/all known and reasonable treatment methods to eliminate or cleanup liquid discharges and to obtain operating permits. A plan and schedule for compliance of lower priority miscellaneous liquid waste streams throughout the Hanford Site was approved by the Washington State Department of Ecology in 1995. In partial fulfillment of the compliance plan, the annual volume of water discharged to the ground in the 200 Areas was reduced to 4.9 billion liters (1.3 billion gallons) in 1995 from 11 billion liters (3 billion gallons) in 1993. Furthermore, the flow rate at the end of 1995 was equivalent to an annual volume of only 790 million liters

(210 million gallons). Other wastes discharged to ground include various sanitary sewage systems and powerhouse waste water. Sanitary sewer wastes in the 200 Areas are discharged to septic tanks and drainfields. Sludge pumped from the septic tanks is taken to the 100-N Sewage Lagoon for disposal. Waste water from the 200 East Area powerhouse, which contains no radioactive or hazardous materials, is discharged to an open ditch (Figure 2).

The following is a brief description of 200 Area facilities that treat liquid waste streams to avoid ground and groundwater contamination (Dirkes and Hanf 1996):

- ◆ *Liquid Effluent Retention Facility.* The Liquid Effluent Retention Facility was constructed to provide interim storage of 242-A Evaporator process condensate suspected of containing RCRA-listed waste. The 242-A Evaporator is used to reduce the volume of low-level mixed waste contained in tanks. Construction of the Liquid Effluent Retention Facility was completed in 1993, and the facility became operational in 1994. A total of 33 million liters (8.7 million gallons) of process condensate was stored in the facility at the end of 1995.
- ◆ *200 Area Effluent Treatment Facility.* The 242-A Evaporator/ PUREX Plant Process Condensate Treatment Facility (200 Area Effluent Treatment Facility) was constructed to provide effluent treatment and disposal capability required for continued operation of the 242-A Evaporator. The facility provides for effluent collection, treatment, and temporary storage to allow verification of treated effluent characteristics before discharge. It also provides a state-approved land disposal structure for the effluent. The 200 Area Effluent Treatment Facility became operational in 1995 and operated at a treatment rate of 570 liters/minute (150 gallons/minute). Secondary waste generated by the facility is concentrated and packaged to meet state requirements for storage and/or disposal of solid waste.
- ◆ *200 Area Treated Effluent Disposal Facility.* The 200 Area Treated Effluent Disposal Facility began operations in 1995. The facility is a collection and disposal system for 13 non-RCRA-permitted effluent streams from the 200 West and 200 East Areas that already meet discharge requirements. The state operating permit limits the average monthly flow to 2,400 liters/minute (640 gallons/minute). The effluent is discharged to B Pond located east of 200 East Area.

The only meaningful pathway for historical waste materials released into the environment in the 200 Areas to reach the Columbia River is through groundwater transport. Radioactive and chemical constituents of liquid wastes released to the environment during historical operations were either retained in the soil column or washed into the groundwater along with excess water. Studies on the retention properties of Hanford Site soils defined the constituents of radioactive and chemical waste that would be retained within the soil column beneath waste disposal structures. The quantity of waste that could be discharged to a crib or trench without the waste constituents reaching the groundwater, except those soluble in water, was also defined and established the predicted useful life of each waste disposal structure. Monitoring the groundwater for the presence of waste constituents also provided information used to control the disposal of liquid wastes. Under proper waste management practices, materials retained in the

soil column tend to remain there for an extended period of time. However, waste constituents are subject to downward transport through the soil column if a source of water, acting as a driving force, becomes available.

The historical inventory of waste materials in the groundwater beneath the 200 Areas is gradually being transported to the Columbia River even though groundwater mounds built up under the 200 Areas have been dissipating since nuclear production operations ceased. Radionuclides detected in the groundwater beneath the 200 Areas in 1995 included tritium (hydrogen-3), cobalt-60, strontium-90, technetium-99, iodine-129, plutonium, uranium, and americium-241. Current discharges do not add significant amounts of waste materials to the existing inventory: in 1995, less than 0.02 curie of tritium (hydrogen-3) and less than 0.5 curie for all other radionuclides (Gleckler 1996). Non-radioactive materials detected in the groundwater included carbon tetrachloride, chloroform, chromium, cyanide, fluoride, and nitrate. Groundwater in the 200 West Area has been pumped and treated for the removal of technetium-99, uranium, carbon tetrachloride, and chloroform. Groundwater in the 200 East Area has been pumped and treated for the removal of cobalt-60, technetium-99, cesium-137, and plutonium.

300 Area

Historical nuclear fuel fabrication and research laboratory operations in the 300 Area resulted in the disposal of contaminated process waste waters to two ponds, a sanitary sewer leaching trench, and various cribs. Beginning in the early 1980s, process liquid wastes containing uranium, copper, and other heavy metal contaminants were transported to the 183-H Solar Evaporation Basins (100-H Area) for solidification. Other process wastes were sent to the 300 Area Process Trenches and were allowed to leach into the soil. The 183-H Basins were subsequently decommissioned when fuel manufacturing operations in the 300 Area were curtailed. Waste sludges were removed from the basins in 1990, and demolition began in 1995. Contaminated sediments were removed from the 300 Area Process Trenches in 1991, and the trenches were retired in 1994. Construction of a new 300 Area Treated Effluent Disposal Facility to receive process wastes was also completed in 1994. An NPDES permit was issued to allow the facility to discharge treated effluents to the Columbia River via a subsurface river diffuser near Johnson Island. Sludge generated from operation of the facility is packaged in drums and disposed of in an onsite landfill. Current sanitary sewer wastes are discharged to a septic tank and trench system. In 1994, two new NPDES permit applications were prepared for the discharge of 300 Area powerhouse ash waste water and water intake filter backwash to the Columbia River.

400 Area

No radioactive or hazardous liquid wastes are discharged to the ground in the 400 Area. Process sewer wastes are drained to a process pond for disposal (Figure 2), and sanitary sewer wastes are discharged to a septic system and pond.

Environmental Monitoring

Environmental monitoring of the Hanford Site consists of effluent monitoring and environmental surveillance. Effluent monitoring is performed at the facility or at the point of release into the environment. It includes Near Facility Environmental Monitoring conducted in the environment near facilities that currently discharge effluents or have discharged them in the past. Environmental surveillance, including groundwater monitoring, consists of sampling and analyzing environmental media from on and off the Hanford Site to detect and quantify potential contaminants and to assess their significance to the environment and human health. Details are provided in an environmental monitoring plan for the Hanford Site (DOE 1994).

Effluent Monitoring

Effluent monitoring includes facility effluent monitoring (monitoring effluent at the point of release to the environment) and near-facility environmental monitoring (monitoring the environment near operating facilities).

Liquid effluent that may contain radioactive or hazardous constituents is monitored at facilities before release to the Hanford Site environment. Effluent monitoring data are evaluated to determine the degree of regulatory compliance for each facility or the entire Hanford Site as appropriate. The evaluations are also useful in assessing the effectiveness of effluent treatment and control systems and management practices. Radioactive, nonradioactive, and chemical liquid effluents released to the Hanford Site environment are documented and reported each year (Gleckler 1996). In addition, monitoring results for liquid discharges to the Columbia River that are regulated by an NPDES permit are reported monthly to EPA. The following discussion is limited to liquid effluent discharges and is derived from Gleckler (1996) and Dirkes and Hanf (1996), where more detailed information may be found. Additional references are noted below.

Liquid effluents have been discharged from facilities in all areas of the Hanford Site. However, as a result of the changing Hanford Site mission and facility upgrades, the quantity of liquid waste generated has been greatly reduced, and the number of discharge points continues to decrease. The amounts of radioactive materials in liquid effluents discharged at the Hanford Site are approaching levels indistinguishable from background concentrations. Currently, radioactive liquid effluents are discharged only to B Pond in the 200 East Area and to the Columbia River. The waste-water streams feeding these discharges are sampled and analyzed for total alpha activity, total beta activity, and selected radionuclides. The total amount of all radionuclides discharged to the ground in the 200 Areas during 1995 was about 0.41 curies and consisted mostly of strontium-90, ruthenium-106, and tin-113 with lesser amounts of tritium (hydrogen-3), cesium-137, and isotopes of europium. The total amount of radioactive releases to the Columbia River in 1995 from operations at the 100-K and 100-N facilities was about 0.36 curies consisting mostly of tritium (hydrogen-3) and strontium-90 (Gleckler 1996). Discharges to the Columbia River from 100-N facilities include a 2.6-meter (102-inch) diameter discharge pipe and N Springs. Releases from N Springs are calculated from results for samples collected from an adjacent groundwater monitoring well and from groundwater flow as predicted by a computer model (Gilmore et al. 1992). The amount of strontium-90 entering the Columbia River from N Springs has fallen dramatically, from approximately 2 Ci/year in 1991 to about 0.2 Ci/year in 1995 (Gleckler 1996).

Nonradioactive hazardous materials are also monitored in liquid effluent streams. Discharges to B Pond or N Springs did not contain reportable quantities of nonradioactive hazardous materials in 1995 (Gleckler 1996). Discharges to the Columbia River from the 300 Area Treated Effluent Disposal Facility exceeded the NPDES allowable concentrations for total suspended solids, copper, or bis(2-ethylhexyl)phthalate on five occasions in 1995 (Dirkes and Hanf 1996). No other NPDES violations were recorded in 1995.

Chemical releases to the environment consist of hazardous chemicals that are discharged directly rather than through a liquid effluent stream. These releases consist almost entirely of accidental spills. Releases of hazardous substances that exceed specified quantities and are continuous and stable in quantity and rate must be reported as required by CERCLA. A synopsis of CERCLA reportable spills is published each year (Dirkes and Hanf 1996).

The Near Facility Environmental Monitoring Program monitors the release of radioactive materials into the environment from new and existing facilities, from surplus facilities awaiting decontamination and decommissioning, and fugitive emissions from uncontained contaminated areas. Environmental samples are collected from near release points and analyzed for radiological and hazardous chemical contaminants. Near facility monitoring results are published each year. Additional current information can be found in Schmidt et al. (1996).

Although B Pond is currently the only surface water disposal facility operating, all surface water disposal sites are monitored regularly. Radiological analyses of liquid samples from these sites included total alpha, total beta, tritium (hydrogen-3), gamma-emitting radionuclides, and plutonium-239, 240. Radiological analyses of sediment and aquatic vegetation included strontium-90, gamma-emitting radionuclides, plutonium-239, 240, and uranium. Non-radiological analyses and measurements included nitrate, pH (acidity/alkalinity), and temperature. Thirteen groundwater springs and seeps along the 100-N Area shoreline were sampled in 1995 to verify that the reported amount of radionuclides released to the Columbia River, as calculated from groundwater data and computer model predictions, were not underestimated. All results were published in Schmidt et al. (1996).

Environmental Surveillance

Environmental surveillance activities, including groundwater monitoring, are conducted routinely both on and off the Hanford Site and consist of detecting and quantifying radiological and non-radiological contaminants in air, soil, vegetation, food, Columbia River water, groundwater, drinking water, sediment, fish, and other freshwater and marine aquatic life. Two projects, Surface Environmental Surveillance and Groundwater Monitoring, conduct the majority of environmental surveillance activities at the Hanford Site. Activities are also conducted to demonstrate compliance with environmental regulations, confirm adherence to DOE environmental protection policies, support DOE environmental management decisions, and provide information to the public. Emphasis is placed on surveillance of exposure pathways and chemical constituents that present the greatest potential risk to humans and the environment. Samples to be collected, sampling frequency, and the analyses required are identified each year in a master sampling schedule (Bisping 1996).

Environmental surveillance is conducted as an independent program under DOE Order 5400.1, "General Environmental Protection Program"; DOE Order 5400.5, "Radiation Protection of the Public and Environment"; and the guidance in *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE 1991).

Environmental surveillance results were recorded in quarterly reports from 1946 to 1958. Since 1958, results have been available as annual reports. Current surveillance results for the offsite and onsite environs and a summary of groundwater monitoring results are given in the annual *Hanford Site 1995 Environmental Report* (Dirkes and Hanf 1996). Full details and results for the groundwater monitoring program are given in annual groundwater monitoring reports (for example, Dresel et al. 1996). Additional reports are published when special studies are completed.

Surface Environmental Surveillance

The following discussion is limited to environmental surveillance activities associated with the Columbia River and groundwater flowing into the Columbia River from springs and seeps. The surveillance of springs and seeps is in addition to effluent monitoring at N Springs. River water quality monitoring is currently conducted by PNNL and by the U.S. Geological Survey. More detailed information can be found in Dirkes and Hanf (1995) and Dirkes (1993).

Columbia River Surface Water. The Columbia River has been monitored at the Hanford Site since 1945, shortly after the startup of the original plutonium production reactors. Historically, radiological analyses were the primary focus of river monitoring activities with non-radiological analyses gaining importance in recent years. Samples have been collected routinely from several locations including stations upstream of the Hanford Site, along the Hanford Reach, downstream of the Hanford Site, and along the coast of the Pacific Ocean at Willapa Bay, Washington. Following the shutdown of the last single-pass cooling reactor in 1971, the quantity of radionuclides released to the Columbia River decreased significantly. As expected, the amounts of radioactive materials detected in Columbia River water, sediments, and biota decreased accordingly (Robertson et al. 1973; Robertson and Fix 1977; Cushing et al. 1981). Surveillance activities at the Hanford Site were greatly streamlined following the dramatic change in operations in 1971. Emphasis was placed on evaluating the contribution of Hanford Site effluents to radiation doses received by persons living in the vicinity of the Hanford Site and using the Columbia River and its water. The development of computerized data bases and computer models to predict environmental concentrations and calculate estimated radiation doses have greatly enhanced the surveillance program.

The main focus on surveillance of the Columbia River is to detect environmental impacts and establish compliance with public health standards, and environmental standards or protection guides, rather than to detail a radiological and chemical characterization. Media from the Columbia River that are collected and analyzed for radionuclides include river water, sediment, vegetation, fish, and other freshwater and marine aquatic life. Current radionuclide analyses include gross alpha, gross beta, gamma scan, tritium (hydrogen-3), strontium-90, technetium-99, iodine-129, plutonium, and uranium. Non-radioactive analyses include metals, anions, and volatile organic compounds.

The map illustrates the Hanford Site, a large industrial and nuclear complex. Key features include the Columbia River to the north, the Yakima River to the south, and the Hanford Site Boundary. Sampling locations are marked with various symbols: circles for river or pond samples, squares with cross-hatching for offsite irrigation samples, squares with horizontal lines for sediment samples, triangles for spring water samples, and triangles with cross-hatching for spring water and sediment samples. Specific locations labeled include Vernita Bridge, Priest Rapids Dam, West Lake, B Pond, 100 Areas, 200 Areas, 300 Area, 400 Area, Fast Flux Test Facility Pond, Richland, Richland Pump House, Riverview Irrigation Canal, Pasco, Kennewick, and McNary Dam (approximately 80 kilometers downstream). The map also shows the flow direction of the rivers and a north arrow.

Flow Direction

Vernita Bridge

Priest Rapids Dam

Hanford Site Boundary

Columbia River

White Bluffs Slough

100 Areas

100-F Slough

West Lake

B Pond

200 Areas

Fast Flux Test Facility Pond

400 Area

300 Area

300 Area Springs

300 Area Water Intake

Richland

Richland Pump House

Riverview Irrigation Canal

Pasco

Kennewick

McNary Dam (approximately 80 kilometers downstream)

Flow Direction

Yakima River

0 4 8 kilometers

0 2 4 6 8 miles

Legend:

- River or Pond Sample
- Offsite Irrigation Sample
- ▨ Sediment Sample
- △ Spring Water Sample Only
- ▤ Spring Water and Sediment Sample

Figure 4. Water and Sediment Sampling Locations, 1995

Questions about how representative shoreline river sampling locations were, with respect to the overall Columbia River, were addressed very early in the monitoring program. In addition to the routine sample locations, cross-river sampling at numerous transect locations was conducted during the years of peak liquid effluent discharges to observe the channeling of reactor effluent within the river, to better understand the dispersion characteristics of the river, and to accurately interpret single-point monitoring stations located on the river (Backman 1962, Haney 1957, Honstead 1954, Honstead 1957, Honstead et al. 1951, Norton 1957, Soldat 1962, Sonnichsen et al. 1970). Soldat (1962) published data relating to dispersion studies and measurements of radioactivity made on the Columbia River in the vicinity of the Hanford Site from 1946 through early 1961. Results of these studies indicated that contaminant plumes entering the river along the shoreline tended to remain near the shore for several miles downstream of the discharge point. Backman (1962) concluded that effluents discharged from the 300 Area were nearly completely mixed by the time they reached the Pasco water treatment pumping station, approximately 26 kilometers (16 miles) downstream.

Cross-sectional surveys, which were all but eliminated following the shutdown of the single-pass cooling reactors, were reinstated in 1991 as a result of findings of a special study conducted during 1987 and 1988 (Dirkes 1993). The study concluded that under certain flow conditions, tritium (hydrogen-3) entering the river near the old Hanford townsite from the 200 Area groundwater plume was not completely mixed by the time it reached the Richland Pump house, located approximately 10 kilometers (6 miles) downstream of the most southerly discharge point of the plume. Renewed interest in cross-sectional sampling was in response to the change in how the primary source of radioactive materials entered the river—from direct effluent discharges to the seepage of contaminated groundwater resulting from past discharges to the ground.

Separately since 1986, under the National Stream Quality Accounting Network program, the U.S. Geological Survey has collected water samples along transects of the Columbia River at Vernita Bridge and the Richland Pump house. Physical measurements and chemical analyses are performed on the samples. Results are reported annually by the U.S. Geological Survey (for example, Wiggins et al. 1996).

Columbia River Sediment. Sediment in the Columbia River contains low levels of radionuclides and non-radioactive metals of Hanford Site origin as well as radionuclides from worldwide fallout (Beasley et al. 1981, Robertson and Fix 1977, Woodruff et al. 1992). Public exposure to these contaminants is well below the level at which routine surveillance is required. However, periodic sampling is conducted to confirm the low levels and to ensure that no significant changes have occurred. The locations where sediment samples were collected in 1995 are shown in Figure 4. Results for sediment samples collected in 1995 are summarized in Dirkes and Hanf (1996). To understand the distribution of radioactive materials in Columbia River sediments, a special study was conducted in 1995 on the difference in grain-size composition and the total organic carbon content of sediment samples (Blanton et al. 1995).

Columbia River Seeps and Springs. As noted previously, the Columbia River is the primary discharge area for the unconfined aquifer underlying the Hanford Site. Contaminated groundwater enters the river through surface and subsurface discharges. Discharge zones located above river water level are usually called springs. When the flow rate is very low the discharge is called a seep. Usually, only springs are sampled because of their readily available water. Because of the influence of river water level on

spring and seep flow rate, the amount of water discharged to the Columbia River is unknown but believed to be on the order of 0.02 percent of the total flow of the river. The locations of spring sampling for 1995 are noted in Figure 4. Routine monitoring of select riverbank springs was initiated in 1988 at the 100-N Area, the old Hanford townsite, and the 300 Area (Dirkes 1990). Monitoring was expanded in 1993 to include the 100-B, 100-K, 100-D, and 100-H Areas, and a spring at 100-F Area was added in 1994. Results for radiological and non-radiological analyses on spring and seep samples collected in 1995 are summarized in Dirkes and Hanf (1996).

Groundwater Monitoring

Groundwater monitoring (surveillance) is an integral part of the groundwater protection plan for the Hanford Site (DOE 1995). The plan integrates monitoring at active waste disposal facilities to comply with RCRA, operational monitoring in and adjacent to reactor and chemical processing facilities, and sitewide groundwater monitoring. Monitoring is also carried out during cleanup investigations under CERCLA programs (DOE 1992). The RCRA and operational monitoring programs are managed by the Hanford Site operating contractor. The CERCLA program is managed by the environmental restoration contractor. The sitewide monitoring program is conducted by PNNL as part of the Hanford Groundwater Surveillance Project. This Project uses data from all groundwater monitoring programs to provide as complete an interpretation of present conditions as possible. More detailed information on sitewide monitoring can be found in Dresel et al. (1996) and Dirkes and Hanf (1995). Results for operational monitoring were summarized by Johnson (1993).

Figure 5 shows the locations of groundwater wells monitored by the various programs in 1995. Groundwater samples are collected from wells completed in the unconfined and upper-confined aquifers. The unconfined aquifer is monitored because it provides a pathway for contaminants to reach onsite water supply wells and the Columbia River. The upper-confined aquifer is monitored less extensively because it provides only a potential pathway for contaminants to migrate off the Hanford Site.

Wells located within known contaminant plumes are monitored to characterize and define trends in the concentrations of the associated radiological or chemical constituents. Wells located along the Hanford Site perimeter are monitored to assess the potential for contaminants to migrate offsite through the groundwater pathway. Background concentrations of naturally occurring chemical and radiological constituents in groundwater are measured in samples from wells located in areas unaffected by Hanford Site operations, including upgradient locations, and provide the best estimate of pre-Hanford Site groundwater quality.

The selection of analyses for samples at a particular well is based on the waste materials previously disposed of to the ground in the area, ongoing waste disposal activities, and chemical contaminants observed in the past at that location. Samples are collected at various frequencies depending on the historical trends of constituent data, regulatory or compliance requirements, and characterization requirements. Sampling frequencies range from monthly to annually with some constituents monitored less frequently than annually in some wells. The annual sampling schedule for 1996 lists the wells to be sampled, analyses to be performed, and frequency of sample collection (Bisping 1996a). Current radionuclide analyses include gross alpha, gross beta, gamma scan, tritium (hydrogen-3), carbon-14,

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Figure 5. Hanford Site Unconfined Aquifer Monitoring Well Locations, 1995

strontium-90, technetium-99, iodine-129, americium-241, plutonium, and uranium. Analyses for chemical constituents include total carbon, total organic carbon, total organic halogens, metals, anions (nitrate), cyanide, ammonium ion, volatile organic compounds, semi-volatile organic compounds, polychlorinated biphenyls (PCBs), dioxins/furans, and pesticides/herbicides. Various physical and chemical properties are also measured.

Certain soluble contaminants, especially tritium (hydrogen-3) and nitrate, move freely with the flow of groundwater. Tritium (hydrogen-3) has been a component of many waste streams discharged to the ground from Hanford Site operations. As a result, the extent of contamination in the groundwater from historical operations, and to some degree current operations, is generally reflected by the distribution of tritium (hydrogen-3) plumes. Figure 6 shows the current distributions of several tritium (hydrogen-3) plumes in the groundwater beneath the Hanford Site. The half-life of tritium (hydrogen-3) is about 12 years, so the plumes gradually change shape as radioactive decay, addition, transport, and dilution take place. Because the amounts of contaminants and volume of process water discharged to the ground has been sharply reduced, radioactive decay becomes the most important factor influencing reduced concentrations of tritium (hydrogen-3) in groundwater. Figure 7 shows the current plume distribution of nitrate, another soluble groundwater contaminant. Nitrate differs from tritium (hydrogen-3) in that it is a chemical contaminant and does not decay away. The shape of nitrate plumes change primarily in response to addition, transport, and dilution. Contaminants originating from the 200 Areas eventually enter the Columbia River from the vicinity of the old Hanford townsite to the 300 Area. Contaminants detected in groundwater at concentrations greater than the radionuclides in Columbia River water at the first downstream point of withdrawal (Richland Pumphouse), respective Drinking Water Standard and known or suspected of flowing into the Columbia River are listed in Table 2.

Table 2. Groundwater Contaminants Entering the Columbia River from Historical Hanford Site Operations^(a)

Location	Contaminant
Near the old Hanford townsite to north of the 300 Area	Tritium (Hydrogen-3), Iodine-129
100-B Area	Strontium-90
100-D Area	Tritium (Hydrogen-3), Chromium
100-F Area	Tritium (Hydrogen-3), Strontium-90, Nitrate
100-H Area	Strontium-90, Chromium
100-K Area	Tritium (Hydrogen-3), Strontium-90, Chromium
100-N Area	Tritium (Hydrogen-3), Strontium-90
300 Area	Uranium
(a) At concentrations greater than the respective Drinking Water Standard as reported in Dirkes and Hanf (1996) and Dresel et al. (1996).

Figure 6. Distribution of Tritium (Hydrogen-3) in the Unconfined Aquifer, 1995

Figure 7. Distribution of Nitrate in the Unconfined Aquifer, 1995

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Part I

Screening Assessment

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1.0 Introduction

Current ecological and human risk from contaminants in the Columbia River have been evaluated in the screening assessment component of the Columbia River Comprehensive Impact Assessment (CRCIA) Project. The risk studied was that attributable to past and present activities at the Hanford Site. These activities resulted in radioactive and hazardous materials that can affect the environment and human health. As a result, ecological risk was evaluated relative to the health of the current river ecosystem. Human risk was evaluated for a range of river use options.

For the screening assessment, we attempted to answer the following questions:

- ◆ What contaminants need to be studied?
- ◆ What information already exists about contamination to the river from activities at Hanford?
- ◆ What species should be studied to identify the possible effects of contamination on the environment?
- ◆ What exposures (Scenarios) do humans have to river contamination?
- ◆ What levels of contamination exist in the study area?

1.1 Purpose and Objective

The purpose of the CRCIA screening assessment is to support decisions on Interim Remedial Measures and to focus a subsequent and more comprehensive risk assessment. The objective of the screening assessment was to identify areas where the greatest potential exists for adverse effects on humans or the environment. The Hanford Reach of the Columbia River was evaluated in the screening assessment in a way that will be useful in the CERCLA process but not necessarily in strict accordance with CERCLA procedures (for example, risk assessment methodology and remedial decision making).

The purpose of Part I of this report is to provide the results of the screening assessment conducted by the Pacific Northwest National Laboratory in consultation with the Columbia River Comprehensive Impact Assessment Management Team (CRCIA Team). The requirements for the remaining work to be done have been written by the CRCIA Team and are included as Part II of this report.

1.2 Scope of Work

The scope of the CRCIA screening assessment was to evaluate potential risk to the environment and human health resulting from current levels of Hanford-derived contaminants. The screening assessment has the primary components of:

- ◆ Determining study domain and spatial scale
- ◆ Identifying contaminants to be assessed
- ◆ Identifying a variety of species to evaluate ecological exposure to the contaminants
- ◆ Identifying a variety of exposure scenarios to evaluate human exposure to the contaminants
- ◆ Identifying, collecting, and preparing monitoring data available for the contaminants
- ◆ Assessing risk to human health and the environment posed by exposure to the contaminants

A screening assessment by its very nature is a limited assessment. Such limited assessments are used to indicate whether the issues under study warrant a full investigation. Screening assessments often express risk in relative terms rather than absolute because of the number and type of assumptions required to drive risk models, the degree of uncertainty inherent in model input, and the limitations in available environmental data. The value of conducting a screening assessment is that the assumptions, uncertainties, and limitations are applied consistently across the study area resulting in useful information relative to the areas thought to be of greatest concern. The limitations of the CRCIA screening assessment were that it was restricted to 1) current conditions, 2) the area between the vicinity of Priest Rapids Dam and McNary Dam, 3) a limited number of contaminants, 4) a limited amount of monitoring data, 5) a limited number of species, and 6) a limited number of scenarios.

The study area for the screening assessment (see Figure 1 in the Site Characterization section) extends from upstream of the Hanford Site in areas unaffected by Hanford Site operations down to McNary Dam, which is the first dam downstream of the Hanford Site. Historical data indicate that the concentrations of contaminants in this reach of the Columbia River are as high as or higher than those in areas downstream of McNary Dam (see the environmental monitoring reports for the Hanford Site published since 1958, the most recent of which is Dirkes and Hanf 1996). Other factors determining the study area include the availability of appropriate environmental data to conduct the screening assessment, the lack of such data downstream of McNary Dam, the known discharge of contaminants into the river (primarily via groundwater seepage) along the Hanford Site, and the resource constraints (time and dollars) originally imposed on the screening assessment. The specific parameters of the scope are:

Area	Columbia River (vicinity of Priest Rapids Dam to McNary Dam), groundwater (up to 0.8 kilometer/0.5 mile in from the river), and adjacent riparian zone		
Time	January 1990 - June 1996 (most recent date of data used in the screening assessment) with data gaps filled by earlier data where available		
Contaminants	<u>Radionuclides</u>		
	• tritium (hydrogen-3)	• technetium-99	• europium-154,
	• carbon-14	• iodine-129	• uranium-234
	• cobalt-60	• cesium-137	• uranium-238
	• strontium-90	• europium-152	• neptunium-237
	<u>Carcinogenic Chemicals</u>		
	• benzene	• chromium	
	<u>Toxic Chemicals</u>		
	• ammonia	• lead	• nitrites
	• chromium	• mercury	• phosphates
• copper	• nickel	• sulfates	
• cyanide	• nitrates	• zinc	
	• diesel constituents (diesel oil, kerosene, xylenes)		
	See Section 2.0 and Appendix I-A		
Data Sources	City of Pasco, City of Richland, Environmental Restoration Contractors, Hanford Environmental Information System, Oregon State Department of Energy, Pacific Northwest National Laboratory, U.S. Army Corps of Engineers, U.S. Geological

Survey, Washington Public Power Supply System, Washington State Department of Ecology, Washington State Department of Health, Westinghouse Hanford Company

See Section 3.0 and Appendix I-B

Measured Media Groundwater, sediment, seeps, surface water, external radiation, riparian soil, biota

Species

Algae

- periphyton
- phytoplankton

Amphibians

- Woodhouse's toad

Aquatic Invertebrates

- clams/mussels/snails
- crayfish
- fresh water shrimp
- mayfly
- water flea

Birds

- American coot
- American kestrel
- American white pelican
- bald eagle
- California quail
- Canada goose/mallard
- cliff swallow
- common snipe
- diving ducks
- Forster's tern
- great blue heron
- northern harrier

Emergent Vegetation

- tule

Fish

- channel catfish
- common carp
- largescale sucker
- mountain sucker
- mountain whitefish
- Pacific lamprey
- salmon
- small mouth bass
- trout
- white sturgeon

Fungi as a taxon

Macrophytes

- Columbia yellowcress
- water milfoil

Mammals

- beaver
- coyote
- mule deer
- muskrat
- raccoon
- weasel
- western harvest mouse

Reptiles

- side-blotched lizard
- western garter snake

Terrestrial Vegetation

- black cottonwood
- dense sedge
- ferns
- reed canary grass
- rushes
- white mulberry

See Section 4.1 and Appendix I-C

Human
Exposure
Scenarios

Industrial/Commercial Scenarios

- industrial worker
- fish hatchery worker

Wildlife Refuge/Wild and Scenic River Scenarios

- ranger
- avid recreational visitor
- casual recreational visitor

Native American Scenarios

- subsistence resident
- upland hunter
- river-focused hunter and fisher
- gatherer of plant materials
- Columbia River island user

General Population Scenarios

- resident
- agricultural resident

See Section 5.1

1.3 Approach

To best represent the current environmental conditions and state of knowledge relative to contaminant concentrations in the Columbia River, the study area was divided into 27 segments along the river. The segmentation also provides meaningful information associated directly with the site operable units that will be useful in evaluating future remedial actions. The screening assessment estimated consistently for each segment by using the 1) data showing the current level of each contaminant, 2) data for each species, and 3) parameters developed for each human scenario.

The approach to estimating risk to the environment and humans began by determining which contaminants should be evaluated in the screening assessment. Contaminants were selected prior to gathering the source term data so as to focus the data gathering efforts on the specific contaminants to be screened in the assessment.

The contaminants that could possibly be associated with past Hanford operations were evaluated. This contaminant identification process, described in Section 2.2, was based on a preliminary review of easily available records, environmental measurements, and process knowledge. The initial list contained nearly 100 possible environmental contaminants. Although a considerable effort was expended to compile this list, its use was to focus the remaining data gathering on only those contaminants of greatest interest. Therefore, not all possible available measurements are included. Refinements are described below.

The initial list of potential contaminants was screened (using a multi-stage screening process described in Section 2.3) to a manageable number of contaminants likely to produce the greatest environmental or human health risks. This process was based on a set of simple exposure equations for people and biota. The final list was established to provide reasonable assurance that the preponderance of the risk addressed for humans was either acute toxicity or long-term carcinogenicity and for other species either acute toxicity or long-term survival. Additional considerations were given to known sources of radiation and radioactive materials.

The contaminants assessed fall into one of three categories: carcinogenic chemicals, toxic chemicals, and radionuclides. Carcinogenic chemicals are those with a cancer causing or promoting agent. Toxic chemicals are those with a poisonous agent. Radionuclides are radioactive isotopes of an element. The selection of contaminants is described in Section 2.0.

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

Although the primary focus was on the Columbia River and its associated riparian zone, the potential for influx of contaminants via groundwater through seeps and springs was addressed by relying on additional measurements of the potential contaminants in groundwater some distance inland from the river shoreline. Depending on the availability of groundwater measurements, this distance varied up to 0.8 kilometer (0.5 mile) in from the river with the larger distance corresponding to areas with fewer measurements.

A detailed search for environmental measurements was made. Hanford and non-Hanford sources were queried, including Hanford contractors, local municipalities, the States of Washington and Oregon, and federal agencies. Data were collected for measurements in the surface water of the Columbia River itself, river sediment, seeps and springs within the Hanford Reach, and Hanford Site groundwater. Only relatively current data were used, defined as being within the period from 1990 to present, to avoid evaluating problems that no longer exist. A large database was prepared. However, for many of the contaminants of interest in many locations, measurements have not been made. For these cases, a series of surrogation and extrapolation rules were devised to allow approximation of the local contamination levels. (Where use of these approximations has identified a contaminant of potential hazard, the use of the substitute values is highlighted to indicate the need for further confirmatory measurements.) The final database is much larger and better substantiated than that used in the initial selection of contaminants to consider, but it is limited to those that were selected for evaluation.

Concurrently with the data gathering, the CRCIA Team established the indicators that would be used to judge the degree of hazard. For the ecological risk assessment, this consisted of defining a set of indicator species for which comparisons against toxicological benchmarks would be made. The selection of these indicator species is defined in Section 4.1. For the human risk assessment, a suite of 12 human exposure scenarios was prepared. These are described in Section 5.1. Individual calculations for each of these scenarios are compared with both toxicity and carcinogenicity indices.

Computational models were developed for all of the ecological species and human scenarios. A computational model is the tool used to produce quantitative results. It includes the algorithms and input data implemented on a computer to produce a solution. The computerized models and their parameters are described in Sections 4.2 and 5.2 and in the appendices. The models were tested and verified prior to their use.

At the direction of the CRCIA Team, we calculated the equations using two methods: deterministic and stochastic.

- ◆ A deterministic analysis is a single calculation performed with a single value selected for each parameter. A deterministic analysis means a single (conservatively high) data value is used to represent the existing condition. For example, for a deterministic analysis of someone who works in the 100-D Area and ingests soil contaminated with lead, we would narrow the various levels of lead measured in the soil at the 100-D Area (Segment 7) down to one representative value and then apply that value to the ingestion rate near the upper bound for a worker. The ingestion rate of soil has several parameters: rate of intake, the frequency of exposure, and the duration of exposure. In a deterministic calculation, PNNL in conjunction with the CRCIA Team selected each of these parameters to help establish a reasonable maximum exposure.
- ◆ A stochastic analysis is a set of calculations performed over the range of parameters. A stochastic analysis means the entire range of data values is used. Using the worker in the 100-D Area again as an example, for a stochastic analysis, we would use all the various levels of lead measured in the soil at the 100-D Area (Segment 7) and apply them simultaneously across the range of parameters for ingesting soil. This is a repetitive process because the values for each parameter are paired randomly with values for each of the other parameters. The entire set of resulting answers defines the possible results.

The data gathered about environmental levels of contaminants showed variability among and within environmental media and among and within individual river segments. In addition, there is uncertainty about almost all of the many parameters used in the ecological and human exposure and risk calculations. This implies that there is also considerable variability and uncertainty about any of the calculated results. Therefore, the calculation of results was done in a manner that incorporates these uncertainties. First, the calculations were performed with single conservative values for the parameters (tending to give larger exposures) that gave conservative results. This portion of the analysis is called deterministic. Then, a stochastic analysis in which all possible combinations of the parameter values were evaluated and an output distribution rather than a single value was performed. For the human risk calculations, both deterministic and stochastic calculations are available for all contaminants in all river segments. For the ecological risk analysis, the deterministic calculations were performed for all species/contaminant/segment combinations, but the stochastic calculations were only performed for those combinations for which it appeared that any risk was possible.

A benefit of the use of the stochastic calculations was that it enabled the results to be subjected to statistical comparisons. In these comparisons, the concentrations and resulting risk of the contaminants in each Hanford-influenced river segment could be compared to those in a river segment upstream, one supposedly uninfluenced by Hanford releases. These comparisons gave insight into the nature and magnitude of the incremental risks posed by Hanford releases.

The initial reports on the selection of contaminants, data, species, and scenarios for use in the screening assessment were published as drafts and submitted for review by external technical peer reviewers, the CRCIA Team, and the public. The comments received on those draft reports were taken into consideration in the final selection of contaminants, data, species, and scenarios to be used in the screening assessment. The following sections on contaminants (Section 2.0), data (Section 3.0), species (Section 4.1), and scenarios (Section 5.1) now reflect the changes that resulted from the comments (see Appendix I-F in Part I for the comments and how they were resolved).

In addition to this revised information, Part I also contains new information. This new information provides the results of the screening assessment of potential risk posed by exposure of species (Section 4.2 and Appendix I-D) and humans (Section 5.2 and Appendix I-E) to the contaminants selected for study. A synthesis of the results is in Section 6.0, and references for Part I are found in Section 7.0.

Supporting information relative to the respective sections and appendixes has been published on diskettes, which are being issued with limited distribution. In addition, because numerous changes have occurred in Volume II of the draft data report since its initial publication, a revised Volume II is being issued also with limited distribution. This report, including the diskettes and updated version of Volume II, are available on the Internet at <http://www.hanford.gov/crcia/crcia.htm>. Both the diskettes and hard copies of Volume II are also available from S.D. Cannon (509-372-6210).

When numbers are very large or very small, we present them using scientific notation. Scientific notation is a type of shorthand for numbers. For example, we could write the number 1 billion as 1,000,000,000 or using scientific notation as 1E+09 or 1×10^9 . To translate from scientific notation to a traditional number, move the decimal point either left or right from the number. For example, if the value given is 2E+03 (2.0×10^3), move the decimal point three numbers (insert zeros if no numbers are given) to the right of its present location. The number would then read 2,000. If the value given is 2E-05 (2.0×10^{-5}), move the decimal point five numbers to the left of its present location. The result would become 0.00002.

2.0 Contaminants for the Screening Assessment

To select the contaminants to be analyzed in the screening assessment, an abundance of historical data concerning contamination of the Columbia River were reviewed. The data that fit within the scope of the screening assessment were then subjected to a multi-stage screening process. The references used as data sources for selecting the contaminants are annotated in Section 2.1. These data sources were not always the same as the ones ultimately used for the source term of the screening assessment of potential risk. Contaminants were selected prior to gathering the source term data so as to focus the data gathering efforts on the specific contaminants to be screened in the assessment. The data sources used for the source term of the screening assessment of potential risk are described in Section 3.0.

To assess possible risk to humans and the environment, we first needed to determine what potential contaminants are in the Columbia River and which ones fit within the scope of the screening assessment. In this section we describe our initial review of contaminants and selection of a limited set of contaminants for study. For the initial review, we compiled easily available information and used generalized human and ecological assessments. The data and parameters we used in the selection of contaminants for study are NOT the ones we used in the remainder of the screening assessment because the data and parameters used for the risk assessment could only be determined once the contaminants were selected. The reader interested in the results of the risk assessment and not the details of how the contaminants for study were selected may skip most of this section. However, the reader should review at least Section 2.8 to know which contaminants were selected for study.

Before any specific screens were applied to the data to select the contaminants for the screening assessment, the data were first filtered to ensure they were within the scope. The scope for selecting the contaminants was slightly different from the scope of the screening assessment itself. The scope of the screening assessment is to evaluate the current conditions of the Columbia River (vicinity of Priest Rapids Dam to McNary Dam), groundwater (0.8 kilometer/0.5 mile in from the river), and adjacent riparian zone. The scope used for selecting the contaminants was the same except groundwater data were only reviewed if they were within 150 meters (500 feet) of the Columbia River or within one of the operating areas. This resulted in a spatial focus mostly on the Hanford 100, 300, and 1100 Areas and a limited focus in other areas with known groundwater contaminants.

A multi-stage screening process was developed to prioritize the contaminants in terms of human health potential risk and ecosystem potential risk. The screens were for radionuclides, carcinogenic chemicals, toxic chemicals, ambient water quality criteria, aquatic biota threshold toxicity, aquatic biota LC₅₀, embryonic/juvenile fish toxicity, and radiation dose to fish. Each stage of the process identified contaminants of interest. The combined results of the total screening then composed the total list of contaminants to be evaluated in the screening assessment. The potential was also addressed for radiation doses arising from discrete radioactive particles in the river sediment or from direct irradiation from near-river Hanford facilities. Although the primary concern is the current status of the Columbia River, additional consideration was given to the potential for future impact by contaminants currently in the Hanford Site groundwater. Consideration was not given to the potential impact of contaminants that may be in soils or facilities away from the Columbia River but that are not in the groundwater.

The references used as data sources are annotated in Section 2.1. A composite list of radionuclides and chemicals identified as being present in environmental samples is presented in Section 2.2. The numerical approach to screening the several hundred analytes into those evaluated in the assessment is presented in Section 2.3. The results of the screening process are listed in Section 2.4. A discussion of discrete radioactive particles in the sediment of the Columbia River shoreline and islands is given in Section 2.5. Section 2.6 addresses special effects from Hanford facilities located adjacent to the river. Section 2.7 addresses existing and potential future contaminants from groundwater sources distant from the river. The overall conclusions, listed as the contaminants to be evaluated in the screening assessment, are given in Section 2.8. Section 2.9 provides a perspective on the selected contaminants in relation to potential risk. Supporting material is made available in Appendix I-A. The references for this section are found in Section 7.0 of Part I.

2.1 Data Sources

To find which materials might have harmful effects on humans or the environment, we looked at recent information gathered by monitoring the Columbia River and groundwater, river sediment, and soil in the 100, 300, and 1100 Areas of the Hanford Site. Those are the areas next to the river most affected by hazardous materials. We only looked at groundwater information gathered from within 500 feet of the Columbia River because the screening assessment is primarily looking at current conditions. Any contaminants in the groundwater further than 500 feet away from the river would not currently be reaching the river. In this section, we have listed all the documents we used to find information on what contaminants are in or near the river today. Knowing the documents we used, helps other scientists to follow our footsteps and verify our results.

An annotated bibliography of the sources used to identify the analytes sampled in environmental media are provided in this section. No single document or electronic database was available that covered the entire scope of contaminants for this research. Baseline efforts similar to the scope of our task were done in a project by Fowler et al. (1993). However, because that project covered all exposure pathways, numerous DOE sites, and identified only the presence of contaminants and not their concentrations, it is not directly applicable or as comprehensive as required for this task.

The CRCIA Project developed a compendium of existing data on Columbia River contamination (Eslinger et al. 1994). The compendium is a large bibliography of Hanford and non-Hanford sources

that potentially contain relevant environmental monitoring information. This compendium was used as a starting point for data information.

The screening assessment is primarily concerned with the potential risk from current levels of contaminants of Hanford origin. Therefore, the most recent sampling data were used in the selection of the contaminants. Because the potential for future contamination of the river from Hanford facilities away from the river is a concern (albeit beyond the scope of the screening assessment), summary information related to existing groundwater plumes that are outside the 100 Areas or farther than 150 meters (500 feet) from the Columbia River on the Hanford Site was also reviewed.

To understand some of the key terms in the bibliography, it is necessary to know that the radioactive, hazardous chemical, and mixed wastes are found in various individual waste sites, referred to as waste management units, located throughout the Hanford Site. These individual waste management units include past practice sites; surplus facilities; and treatment, storage, and disposal (TSD) facilities. Past practice sites and TSD facilities may take the form of spills, cribs, ditches, ponds, tanks, trenches, landfills, burial

grounds, pits, French drains, and other means of intentional or unintentional disposal. Surplus facilities include contaminated buildings, exhaust stacks, and underground transfer lines. The individual waste management units are organized into "operable units" based on geographic proximity or similarity of waste disposal history.

The following annotated bibliography summarizes the sampling data sources and primary references used in the selection of the contaminants. The complete reference, sampling purpose, sampling time frame, media sampled as well as supplementary comments are provided. Documents of specific types are listed together in alphabetical order. Tables A.1 and A.2 in Appendix I-A present a complete list of radionuclides and chemicals evaluated at the Hanford Site. These data sources are not always the same as the ones ultimately used as the source term for the screening assessment of potential risk. The data sources used as the source term for the screening assessment of potential risk are described in Section 3.0.

2.1.1 General References

Blanton, M. L., W. W. Gardiner, and R. L. Dirkes. 1995. *Environmental Monitoring of Columbia River Sediments: Grain-Size Distribution and Contaminant Association*, PNL-10535, Pacific Northwest Laboratory, Richland, Washington.

This document reports an evaluation of the characteristics associated with contaminant absorption that 1) documents the differences in sediment grain size and organic content, and 2) provides associations between grain size, organic matter, and contaminants in sediments occurring at six established monitoring sites. Sediments at the six sites (upstream of, within, and downstream of Hanford) were analyzed for grain size, organic carbon content, radionuclides, metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides.

Dirkes, R. L. 1993. *Columbia River Monitoring: Distribution of Tritium in Columbia River Water at the Richland Pump House*. PNL-8531, Pacific Northwest Laboratory, Richland, Washington.

This document reports the results of a special investigation conducted by the PNNL Surface Environmental Surveillance Project. Supplemental monitoring of tritium (hydrogen-3) in the Columbia River was conducted in the summers of 1987 and 1988. The purpose of the monitoring was to provide information related to the dispersion and distribution of Hanford-originating contaminants entering the river through the seepage of groundwater along the Hanford Site.

Dirkes, R. L. 1994. *Summary of Radiological Monitoring of Columbia River Water along the Hanford Reach, 1980 through 1989*. PNL-9223, Pacific Northwest Laboratory, Richland, Washington.

A portion of PNNL's Surface Environmental Surveillance Project is involved with monitoring the Columbia River. This document summarizes the river water monitoring activities of the Columbia River monitoring program during the 1980s. Routine and special monitoring projects and radiological and chemical constituents are reviewed. This report summarizes the information presented in the annual environmental reports.

Dirkes, R. L., G. W. Patton, and B. L. Tiller. 1993. *Columbia River Monitoring: Summary of Chemical Monitoring Along Cross Sections at Vernita Bridge and Richland*. PNL-8654, Pacific Northwest Laboratory, Richland, Washington.

Chemical monitoring was performed by PNNL's Surface Environmental Surveillance Project at the Vernita Bridge and the Richland Pump House. Potential Hanford-originating chemicals of interest were selected for sampling; these included volatile organic compounds (VOCs), metals, and anions. Monthly samples were taken from August 1991 to December 1991. The sample frequency was reduced to quarterly during calendar year 1992. The monitoring results were benchmarked with those of the United States Geological Survey monitoring program, and no variants were found.

DOE - U.S. Department of Energy. 1992a. *Sampling and Analysis of 100 Area Springs*. DOE/RL-92-12, Rev. 1, U.S. Department of Energy, Richland, Washington.

This document provides validated monitoring data from the sampling of the Columbia River, seeps, springs, and sediment adjacent to the Hanford 100 Areas National Priorities List Site. The data were published as part of a Tri-Party Agreement milestone to evaluate how the contaminated seeps and springs impact the Columbia River. An assessment of the data is included. Samples were collected in September and October 1991 during the normal low-flow period of the Columbia River. Twenty-six locations were sampled along a 37-kilometer (22-mile) stretch of the river, ranging from just upstream of the 100-B/C Area water intake to the old Hanford townsite.

DOE - U.S. Department of Energy. 1992b. *Hanford Site Groundwater Background*. DOE/RL-92-23, U.S. Department of Energy, Richland, Washington.

This report is a preliminary evaluation of data and information related to the natural composition of groundwater in the unconfined aquifer system beneath the Hanford Site. This information is to be used as a baseline for distinguishing the presence and significance of contamination in the groundwater. The relevant part of the aquifer evaluated extended from the surface waters that potentially recharge the aquifer to the uppermost portion of the underlying confined aquifer. Surface waters were found, in general, to have lower concentrations of constituents than the springs, unconfined groundwater, and confined groundwater. The provisional background threshold levels of background constituent concentrations in groundwater presented in this report are described as "likely to be conservatively low" (p. iv).

DOE - U.S. Department of Energy. 1994a. *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*. DOE/RL-92-24, Rev. 2, Vol. 1 of 2, U.S. Department of Energy, Richland, Washington.

This document was written to support environmental restoration, waste management, and facilities operations activities at Hanford. The background composition of Hanford Site soil is characterized for the purposes of identifying soil contamination and as a baseline in risk assessment processes used to determine soil cleanup and treatment levels. The compositions of naturally occurring soil in the zone above the groundwater level have been determined for non-radioactive inorganic and organic analytes and related physical properties. The range of inorganic and organic analytes that can be expected in Hanford Site background soil is evaluated. The highest measured background concentrations occur in three volumetrically minor soil types (the most important of which is topsoil adjacent to the Columbia River) which are rich in organic carbon. The chemical composition of more than 170 soil samples from 22 places on the Hanford Site and 3 places adjoining the Hanford Site was determined for inorganic analytes in accordance with

EPA protocols. Twelve of the samples were analyzed for volatile and semivolatile organic chemicals, as well as for pesticides and polychlorinated biphenyls (PCB). Samples were collected from September through November 1991.

DOE - U.S. Department of Energy. 1994b. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities*. DOE/RL-93-88, Rev. 0, U.S. Department of Energy, Richland, Washington.

This report is an annual hydrologic evaluation of 20 RCRA groundwater monitoring projects and one non-hazardous waste facility at the Hanford Site. The interpretation of groundwater data collected at 30 waste management units between October 1992 and September 1993 is included. Also, recent groundwater quality evaluations for the 100 and 300 Areas and the entire Hanford Site are described. Widespread contaminants include nitrate, chromium, carbon tetrachloride, tritium (hydrogen-3), and other radionuclides.

DOE - U.S. Department of Energy. 1996a. *Hanford Site Background: Part 2, Soil Background for Radionuclides*. DOE/RL-96-12, U.S. Department of Energy, Richland, Washington.

This document was written to support environmental restoration, waste management, and facilities operations activities at Hanford. The background composition of Hanford Site soil is characterized for the purposes of identifying soil contamination and as a baseline in risk assessment processes used to determine soil cleanup and treatment levels. Radionuclides are differentiated as being either natural or anthropogenic, and a very limited suite are provided.

Dunkes, K. L. 1996. *100 Area River Effluent Pipelines Characterization Report*. BHI-00538, Bechtel Hanford, Inc., Richland, Washington.

In the summer of 1995, the river effluent pipelines at the 100-B and 100-D Reactor sites were radiologically, chemically, and physically characterized using a robotic transporter for the sampling and characterization equipment. The inspections documented each pipeline's interior condition via video recording of the interior, radiation monitoring instruments, ultrasonic testing to determine the pipe's thickness, and collection of interior scale and sediment samples. The samples were evaluated for 12 radionuclides and 19 metals.

Eslinger, P. W., L. R. Huesties, A. D. Maughan, T. B. Miley, and W. H. Walters. 1994. *Data Compendium for the Columbia River Impact Assessment*. PNL-9785, Pacific Northwest Laboratory, Richland, Washington.

This document provides a bibliography of sources of existing data on Columbia River contamination. Approximately 4,500 documents and 13 major databases are listed that potentially contain information about contaminants in the Columbia River due to Hanford activities. The bibliography was further refined to highlight 60 key documents that contain data or describe analyses important in evaluating the health of the Columbia River. The work was performed to meet the Tri-Party Agreement milestone number M-13-80.

Ford, B. H. 1993. *Groundwater Field Characterization Report for the 200 Aggregate Area Management Study*. WHC-SD-EN-TI-020, Westinghouse Hanford Company, Richland, Washington.

This report provides contaminant plume maps for the unconfined aquifer of the 200 East and 200 West groundwater aggregate areas. Data deficiencies are identified with recommendations for additional

sampling and well drilling. Individual plumes are identified for arsenic, chromium, cyanide, fluoride, nitrate, carbon tetrachloride, chloroform, trichloroethylene, tritium (hydrogen-3), gross beta, cobalt-60, strontium-90, technetium-99, iodine-129, cesium-137, gross alpha, uranium, and plutonium.

Fowler, K. M., K. B. Miller, M. O. Hogan, and J. F. Donaghue. 1993. *Risk-Based Standards Chemicals of Interest Database Documentation*. U.S. Department of Energy, Richland, Washington.

A comprehensive set of risk-based standards are needed by DOE to conduct its waste management, environmental restoration, and decontamination and decommissioning activities. The first step in developing the standards was to gather information on hazardous and radioactive substances that are found as contaminants or that are stored at DOE facilities. Twenty-six DOE sites were surveyed for substances that are generated, used, or present. Sources of information included Superfund Amendments and Reauthorization Act Title III reports (SARA 1986), remedial investigation/feasibility study reports, and other miscellaneous sources. The radionuclide and chemical names and media type in which they were found (air, groundwater, sediment, soil, surface water, tank wastes, and not specified/available) are indicated, but no quantitative sampling results are provided in this document. A total of 326 radionuclides and chemicals were identified for the Hanford Site.

Hartman, M. J., and K. A. Lindsey. 1993. *Hydrogeology of the 100-N Area, Hanford Site, Washington*. WHC-SD-EN-EV-027, Westinghouse Hanford Company, Richland, Washington.

The report primarily describes the hydrologic units beneath the 100-N Area. It includes descriptions of primary contaminants of interest, including strontium-90 and tritium (hydrogen-3) associated with the liquid waste disposal sites, sulfate and sodium, and petroleum products associated with leaks and spills. A total of eight petroleum (diesel oil) spills are documented between 1966 and 1988. Following the 1966 leak, an interceptor trench was built to collect migrating diesel oil where it was periodically burned. A significant amount of free petroleum apparently remains in the zone above groundwater level. As much as 45 centimeters (1.5 feet) of petroleum product has been observed floating on top of the water in some of the monitoring wells. The petroleum seems to appear on the water table following periods of recharge to the aquifer.

Hope, S. J., and R. E. Peterson. 1995. *Chromium Concentrations in 100-H Reactor Area Pore Water within Chinook Salmon Spawning Habitat of the Hanford Reach, Columbia River*. BHI-00345, Bechtel, Hanford, Inc., Richland, Washington.

The report describes the results of a study using a unique method of obtaining pore water samples from salmon spawning habitat within river substrate in proximity to the 100-H Reactor area. Pore water was obtained by divers from a depth of 18 inches in the substrate. Pore water was collected from 31 sample points along 17 transects from a 5000-foot reach of river adjacent to the 100-H area and along three transects containing 6 sample points at Vernita Bar. Of these samples, 3 at the 100-H area exceeded the Ambient Water Quality Criterion of 11 micrograms per liter (EPA 1992).

Law, A. G. 1990. *Status of Groundwater in the 1100 Area*. Correspondence No. 8900604B R4, Westinghouse Hanford Company, Richland, Washington.

This document provides the quarterly results from the Westinghouse Hanford Company operational groundwater monitoring program for five wells installed in the vicinity of the 1100 Area. Results for approximately 380 analytes are presented. All are essentially undetected or at background levels.

Peterson, R. E., and V. G. Johnson. 1992. *Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site*. WHC-EP-0609, Westinghouse Hanford Company, Richland, Washington.

Data were obtained during environmental surveillance activities and remedial investigations to characterize the influence of contaminated groundwater on the Columbia River. Radionuclides and metals in the seepage, sediment associated with the seepage, and near-shore Columbia River water were sampled. Samples collected in September and October of 1991 are compared with data collected in 1984 and 1988 as well as nearby groundwater data.

Rowley, C. A. 1993. *100-N Area Underground Storage Tank Closures*. WHC-SD-EN-TI-136, Westinghouse Hanford Company, Richland, Washington.

This report describes removal/characterization actions concerning underground petroleum storage tanks in the 100-N Area undertaken from 1990 through 1992. Instances of leaks from underground connections are noted. No groundwater contamination was found resulting from these tanks.

Weiss, S. G. 1993. *100 Area Columbia River Sediment Sampling*. WHC-SD-EN-TI-198, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

To determine whether radiological and chemical contaminants are present in the Columbia River, 44 sediment samples were collected from 28 locations in the Hanford Reach in the fall of 1992. The sand-sized and smaller sediment samples collected from the near shore and shoreline were analyzed for metals and radionuclides. Three of the sample locations were upriver from Hanford. Sediment was collected at depths of 0-15 centimeters (0-6 inches) and 30-60 centimeters (12-24 inches) below the surface. Contamination from arsenic, chromium, copper, lead, and zinc was found. The arsenic, lead, and zinc contamination may not be of Hanford origin. Cesium-137 and europium-152 were the most frequently detected radionuclides.

Wells, D. 1994. *Radioactivity in Columbia River Sediments and Their Health Effects*. Special Report, Washington State Department of Health, Olympia, Washington.

This document addresses the current human health effects of artificial radioactivity in the Columbia River sediment. The Columbia River sediment data from the early 1960s to the present were provided by state agencies, federal agencies, and academic researchers. The sediment samples were collected from the Hanford area to the estuaries and coastlines of Oregon and Washington. Samples include surface sediment and deeper sediment behind the dams of the lower Columbia River. Ecological risks were not evaluated nor were the human health risks from sediment contaminated with radioactive materials entering the Columbia River at riverbank seeps and springs.

2.1.2 Hanford Environmental Information System

DOE - U.S. Department of Energy. 1994c. *HEIS - Hanford Environmental Information System*. For documentation supporting the HEIS database, see DOE/RL-93-24, 9 volumes, U.S. Department of Energy, Richland, Washington. Queried: August 24, 1994.

The Hanford Environmental Information System (HEIS) is an electronic database that consolidates the data gathered during environmental monitoring and restoration of the Hanford Site. Data stored in HEIS are collected under several regulatory programs. The basis of HEIS is individual sample data for air, biota,

groundwater, soil, sediment, surface water, and miscellaneous materials. HEIS was queried for information about maximum contaminant concentrations in groundwater within 150 meters (500 feet) of the Columbia River.

2.1.3 Remedial Investigation/Feasibility Studies

EPA is the lead regulatory agency for the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). Under CERCLA, a specific process has been established to identify potentially hazardous sites, characterize site contamination, assess treatment technologies, and then design and construct the appropriate treatment facilities. The remedial investigation/feasibility study (RI/FS) portion of the process defined in CERCLA requires determining the nature and extent of the threat posed by a release of hazardous substances to the environment and evaluating proposed remedies. The following RI/FS studies contributed information to the CRCIA Project.

DOE - U.S. Department of Energy. 1990a. *Remedial Investigation/Feasibility Study Work Plan for the 300-FF-5 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL 89-14, U.S. Department of Energy, Richland, Washington.

The 300-FF-5 operable unit consists of the groundwater aquifer beneath the 300-FF-1, 300-FF-2, and 300-FF-3 source operable units and adjacent areas defined by the extent of the groundwater contamination. The scope of the 300-FF-5 operable unit RI/FS focuses on groundwater, soil, surface water/sediment and aquatic biota and considers all contaminant sources in the 300 Area that contribute to the existing groundwater contamination beneath the 300 Area and the surrounding environment. The sample data upon which the RI/FS is based appear to have been taken in the mid-1980s. Groundwater monitoring for metals began in 1985.

DOE - U.S. Department of Energy. 1990b. *Remedial Investigation/Feasibility Study Work Plan for the 300-FF-1 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL 88-31, U.S. Department of Energy, Richland, Washington.

The purpose of the 300-FF-1 operable unit remedial investigation was to provide sufficient information to conduct the feasibility study by determining the nature and extent of the threat to public health and the environment posed by releases of hazardous substances from 300-FF-1, a process liquid operable unit that contains all the liquid waste disposal facilities within the 300 Area. Hazardous and radioactive materials from this operable unit contribute to groundwater contamination. Soil sampling data are provided for radionuclides, inorganics, and an extensive list of organics. Monitoring of groundwater analytes was more limited.

2.1.4 Hanford Site Environmental Reports

Every year, beginning in 1957, a report is prepared that summarizes environmental data, which characterize the Hanford Site environmental management performance and demonstrate compliance status. These reports summarize the activities and results of monitoring by the Surface Environmental Surveillance Project. In recent years, data have been provided in separate volumes. The following annual reports were used in the selection of the contaminants for the screening assessment.

Bisping, L. E. 1994. *Hanford Site Environmental Data for Calendar Year 1993 - Surface and Columbia River*. PNL-9824, Pacific Northwest Laboratory, Richland, Washington.

Bisping, L. E., and R. K. Woodruff. 1993. *Hanford Site Environmental Data for Calendar Year 1992 - Surface and Columbia River*. PNL-8683, Pacific Northwest Laboratory, Richland, Washington.

Bisping, L. E. 1992. *Hanford Site Environmental Data 1991 - Surface and Columbia River*. PNL-8149, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., and R. W. Hanf. 1995. *Hanford Site Environmental Report for Calendar Year 1994*. PNL-10574, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., R. W. Hanf, R. K. Woodruff, and R. E. Lundgren. 1994. *Hanford Site Environmental Report for Calendar Year 1993*. PNL-9823, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren. 1993. *Hanford Site Environmental Report for Calendar Year 1992*. PNL-8682, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren. 1992. *Hanford Site Environmental Report for Calendar Year 1991*. PNL-8148, Pacific Northwest Laboratory, Richland, Washington.

2.1.5 Limited Field Investigations

Limited Field Investigations (LFIs) are abbreviated versions of Remedial Investigations conducted as part of Tri-Party Agreement activities to identify those Hanford waste sites that are recommended to remain as candidates for interim remedial measures. The assessments include consideration of whether contaminant concentrations pose an unacceptable risk that warrants action through interim remedial measures.

Each LFI is conducted on a single Hanford operable unit (for example, operable unit 100-HR-3). Operable unit is the term used to identify specific areas designated for cleanup. The number and first letter in the operable unit name indicate the location of the operable unit; operable unit 100-HR-3 is in the 100-H Area. Many of the column headings in Tables A.1 and A.2 of Appendix I-A correspond to the operable unit name. The LFI reports annotated in this section are available to the public. Since the completion of this work, additional LFIs have become available. These newer LFIs are not listed here because they were not used in developing the list of contaminants.

DOE - U.S. Department of Energy. 1994d. *Limited Field Investigation Report for the 100-BC-1 Operable Unit*. DOE/RL-93-06, U.S. Department of Energy, Richland, Washington.

This study was initiated to characterize the liquid and sludge at disposal sites associated with the B Reactor in the 100-BC Area. Groundwater sampling data are contained in the LFI, 100-BC-5 (see below). Surface water and sediment sampling are not applicable to the 100-BC-1 area. Media were sampled for VOCs, semivolatiles, inorganics, metals, PCBs, pesticides, radionuclides, and physical properties. Sampling data were collected from April 1992 through July 1992.

DOE - U.S. Department of Energy. 1993a. *Limited Field Investigation Report for the 100-BC-5 Operable Unit*. DOE/RL-93-37, Draft A, U.S. Department of Energy, Richland, Washington.

This study was initiated to further characterize the groundwater contamination in the 100-BC Area. Groundwater, surface water, sediment, and soil sampling data are provided. Volatile constituent concentrations were of primary interest, but the media were also sampled for radionuclides, organics, inorganics, and physical properties. The LFI groundwater sampling data are reported for July 1992, October 1992, and January 1993.

DOE - U.S. Department of Energy. 1993b. *Limited Field Investigation Report for the 100-DR-1 Operable Unit*. DOE/RL-93-29, Draft A, U.S. Department of Energy, Richland, Washington.

The purpose of this study was to characterize the waste facility sites associated with the D Reactor and the water retention basin systems for both the D and DR Reactors and in the 100-DR Area. Soil sampling results are reported. Groundwater sampling data for this same region are contained in the LFI, 100-HR-3 (see below). Media were sampled for VOCs, semivolatiles, inorganics, metals, PCBs, pesticides, radionuclides, specific anions, hexavalent chromium, and physical properties. Samples were collected in March 1993.

DOE - U.S. Department of Energy. 1993c. *Limited Field Investigation Report for the 100-HR-1 Operable Unit*. DOE/RL-93-51, Draft A, U.S. Department of Energy, Richland, Washington.

This study was initiated to characterize the waste units associated with facility sites supporting the H Reactor in the 100-H Area. This document provides sludge, sediment, and soil sampling data. Groundwater sampling data are contained in the LFI, 100-HR-3 (see below). Media were sampled for VOCs, semivolatiles, inorganics, metals, PCBs, pesticides, radionuclides, and physical properties. The media were sampled from December 1991 through August 1992.

DOE - U.S. Department of Energy. 1993d. *Limited Field Investigation Report for the 100-HR-3 Operable Unit*. DOE/RL-93-43, Draft A, U.S. Department of Energy, Richland, Washington.

This study was initiated to further characterize the groundwater contamination in the 100-HR-3 operable unit, which is inclusive of three sub-areas: 100-D, 100-H, and the 600 Area between the D and H Reactor areas. This document provides groundwater, sediment and soil sampling data for radionuclides, volatile and semivolatile organic compounds, inorganics, and pesticides. Media were sampled from May 1992 through March 1993.

DOE - U.S. Department of Energy. 1994e. *Limited Field Investigation Report for the 100-KR-1 Operable Unit*. DOE/RL-93-78, Draft A, U.S. Department of Energy, Richland, Washington.

This document provides soil sampling data. Groundwater sampling data are contained in the LFI, 100-KR-4 (see below). Surface water and sediment sampling are not applicable to the 100-KR-1 operable unit. Media were sampled for VOCs, inorganics, metals, radionuclides, hexavalent chromium, and physical properties. Samples were taken from October 1992 through March 1993.

DOE - U.S. Department of Energy. 1994f. *Limited Field Investigation Report for the 100-KR-4 Operable Unit*. DOE/RL-93-79, U.S. Department of Energy, Richland, Washington.

This LFI was initiated to further characterize the groundwater contamination in the 100-KR area operable units: 100-KR-1, 100-KR-2, and 100-KR-3. In addition to the groundwater samples, other sampling data include surface water, sediment, soil, and aquatic biotic impacted by the KE and KW reactors. The media were sampled for VOCs, semivolatiles, inorganics, metals, pesticides, and radionuclides. Samples were collected in October 1991, September 1992, December 1992, March 1993, and June 1993.

2.1.6 Discrete Radioactive Particles and Other Direct Exposure Sources

In addition to the routine environmental monitoring documented in the Hanford Site annual reports, occasional special studies are performed to evaluate particular conditions. Key studies are described here.

Cooper, A. T., and R. K. Woodruff. 1993. *Investigation of Exposure Rates and Radionuclide and Trace Metal Distributions Along the Hanford Reach of the Columbia River*. PNL-8789, Pacific Northwest Laboratory, Richland, Washington.

This report documents the first major field study to investigate exposure rates along the Columbia River shoreline since the Sula (1980) investigation of 1979. Radionuclides and trace metals were surveyed between Priest Rapids Dam and north Richland. A smaller number of discrete radioactive particles were also noted.

EG&G Energy Measurements. 1990. *An Aerial Radiological Survey of the Hanford Site and Surrounding Area, Richland, Washington*. EGG-10617-1062, EG&G Energy Measurements, The Remote Sensing Laboratory, Las Vegas, Nevada.

EG&G used a radiation detection system in a helicopter to conduct a radiological survey of the Hanford area. The detection system was calibrated to suppress natural background radiation and therefore only detected sources of anthropomorphic gamma-emitting radioactivity. The aerial data are presented as isopleths overlaid onto maps of the Hanford Site. The aerial survey is an aid in locating areas with elevated exposure rates but does not stringently define contaminated areas.

Sula, M. J. 1980. *Radiological Survey of Exposed Shorelines and Islands of the Columbia River Between Vernita and the Snake River Confluence*. PNL-3127, Pacific Northwest Laboratory, Richland, Washington.

This report describes a radiological survey performed to evaluate the magnitude and distribution of radioactive contamination on the exposed shorelines of the Columbia River. External exposure rate measurements were made at nearly 30,000 locations. In addition, discrete particles of radioactive material were discovered. Discrete metallic flakes containing cobalt-60 were found. The highest areal density of particles was found on an island near D Reactor, although the presence of particles was indicated as far downriver as the survey extended.

Thatcher, A.H. 1995. *100N Area Shoreline Radiation Survey and Dose Evaluation*, Washington State Department of Health, Olympia, Washington.

Washington State Department of Health staff performed a radiation survey along the 100-N area shoreline in July of 1994, and one of the opposite shoreline in February of 1995. The goal of the surveys was to measure "skyshine" (caused by Compton scattering of gamma rays) as a result of sources of cobalt-60 and cesium-137 in the 100-N Area. Results indicated two areas of elevated exposure near the Emergency Dump Tank and the Liquid Waste Disposal Facilities. In both areas, the net maximum exposure rate is 19 microrentgen per hour, occurring along approximately 800 feet of shoreline. Analysis of the results for the opposite shoreline identified no observable increases over background.

Wade, C. D., and M. A. Wendling. 1994. *100-D Island USRADS Radiological Surveys Preliminary Report Phase II*. BHI-00-134, Bechtel Hanford, Inc., Richland, Washington.

This report describes the results of radiological surveys made in April 1994 over the upstream third of the island adjacent to the 100-D Reactor Area. The survey used the Ultrasonic Ranging and Data System. A significant note is that "with a few exceptions, every area which was determined to be gamma elevated was sampled and the sampling removed the entire contamination present. In these locations, extremely small 'hot particles' were removed from the silt layer beneath the river rock." Analyses of these particles showed them to contain almost entirely cobalt-60 activity, between 0.4 and 22 microcuries each. A total of 103 particles were recovered from an area of about 5 hectares (12.5 acres).

2.1.7 National Environmental Policy Act (NEPA) Documents

Quantifying the potential for future releases of contaminants to the Columbia River from surplus facilities or waste sites requires a significant investigation, one which is defined in Part II of this report, but is beyond the scope of the screening assessment.

DOE - U.S. Department of Energy. 1987. *Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes, Hanford Site, Richland, Washington*. DOE/EIS-0113, U.S. Department of Energy, Washington, D.C.

This EIS addressed the selection and implementation of final disposal actions for high-level, transuranic, and tank wastes at Hanford. Although a decision on the existing single-shell tanks was ultimately deferred, this EIS provides descriptions of the potential releases of radionuclides to the groundwater, and ultimately the Columbia River, for each of the major waste categories at Hanford.

DOE - U.S. Department of Energy. 1989. *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington, Draft Environmental Impact Statement*. DOE/EIS-0119D, U.S. Department of Energy, Washington, D.C.

and

DOE - U.S. Department of Energy. 1992c. *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington, (Final Environmental Impact Statement)*. DOE/EIS-0119F, U.S. Department of Energy, Washington, D.C.

This EIS, together with its addendum which constitutes the final EIS, describes the potential future releases of radionuclides to groundwater, and ultimately the Columbia River, from decommissioning the

eight original Hanford reactors (excluding N Reactor) and the associated fuel storage basins. The preferred alternative for disposal was selected to be one-piece removal of the reactors from the riverside and burial in the 200 Areas.

DOE - U.S. Department of Energy. 1990c. *Low-Level Burial Grounds Dangerous Waste Permit Application: Request for Exemption from Lined Trench Requirements for Submarine Reactor Compartments*. DOE/RL-88-20, Supplement 1, U.S. Department of Energy, Richland, Washington.

and

DOE - U.S. Department of Energy. 1992d. *Low-Level Burial Grounds Dangerous Waste Permit Application: Request for Exemption from Lined Trench Requirements and from Land Disposal Restrictions for Residual Liquid at 218-E-12B Burial Ground Trench 94*. DOE/RL-88-20, Supplement 1, Revision 1, U.S. Department of Energy, Richland, Washington.

These two reports discuss decommissioned, defueled naval submarine reactor compartments containing radioactivity caused by exposure of structural components to neutrons during normal operation of the submarines. After all the alternatives were evaluated in the U.S. Department of the Navy 1984 environmental impact statement (Navy 1984), land burial of the submarine reactor compartments was selected as the preferred disposal option. The reactor compartments currently are sent to Trench 94 of the Hanford 218-E-12B Burial Ground. In addition to radioactivity, the reactor compartments disposed contain lead and PCBs as hazardous constituents. Modeling results indicate that release of contaminants to the groundwater or surface water will not occur until after long periods of time and that even after reaching the groundwater, contaminants will not be in excess of current regulatory limits, such as drinking water standards.

DOE - U.S. Department of Energy. 1994g. *Hanford Remedial Action Draft Environmental Impact Statement*. DOE/DEIS-0222. U.S. Department of Energy, Washington, D.C.

This EIS provides estimates of long-term risk resulting from the current groundwater plumes existing beneath the Site, as well as projections of future risks from non-tank, non-operating-facility waste management units.

Navy - U.S. Department of the Navy. 1984. *Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants*. U.S. Department of the Navy, Washington, D.C.

This EIS discusses various alternatives for disposal of the radioactive portions of decommissioned nuclear submarines, leading to the selection of the Hanford Site as the location for permanent disposal. Estimates are presented for potential future radiation doses resulting from these activities.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel, K. J. Cantrell, R. J. Serne, J. L. Smoot, C. T. Kincaid, and S. K. Wurster. 1992. *Estimation of the Release and Migration of Lead Through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground*. PNL-8356 Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

This report evaluates the potential for radioactive and non-radioactive lead to migrate from buried submarine reactor compartments to the Columbia River. The estimated time of arrival of the contaminant plume ranges from 60,000 years to 4 million years.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel, K. J. Cantrell, R. J. Serne, L. H. Sawyer, J. L. Smoot, J. E. Szecsody, M. S. Wigmosta, and S. K. Wurstner. 1994. *Estimation of the Release and Migration of Nickel Through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground*. PNL-9791, Pacific Northwest Laboratory, Richland, Washington.

This report evaluates the potential for radioactive and non-radioactive nickel to migrate from buried submarine reactor compartments to the Columbia River. The estimated time of arrival of the contaminant plume ranges from 60,000 years to 4 million years.

2.2 Composite List of Identified Radionuclides and Chemicals

Using the documents listed in the previous section, we compiled a list of all contaminants that were tested for between 1980-1994 (current conditions). Tables A.1 and A.2 in Appendix I-A show the list, even those contaminants that were tested for but not found. A total of 568 analytes are listed as having been tested for in the Columbia River and groundwater, and a total of 560 analytes as having been tested for in soil and sediment. An analyte is any substance that has been tested for. Of the analytes tested, 73 were detected in the Columbia River or groundwater, and 86 were detected in soil and sediment. These contaminants are listed in Table 2.1 for Columbia River and groundwater and Table 2.2 for soil and sediment.

A data matrix (Tables A.1 and A.2 in Appendix I-A) was developed using the information found in the documents listed in Section 2.1. All radionuclides and chemicals analyzed in surface water (the Columbia River, springs, and seeps), sediment, groundwater, and soil samples in the 100, 300, 1100 Areas as well as other areas within 150 meters of the Columbia River are included. The data matrix is a composite list of all detected and not detected (in other words, analyzed for but not detected) radionuclides and chemicals from the reviewed literature. Sampling data from 1980 through 1994 were considered.

2.2.1 Risk-Based Standards Database

The development of the data matrix began with all chemicals identified in the Risk-Based Standards Database (Fowler et al. 1993). The Risk-Based Standards Database is a list of hazardous and radioactive substances reportedly found as contaminants or that are stored at DOE facilities nationwide. The Risk-Based Standards Database contains a total of 326 radionuclide and chemical entries for the Hanford Site. The radionuclides and chemicals in the database are sorted by their presence in the following media: Columbia River water, groundwater, soil, air, tank waste, and sediment. A total of 120 organic compounds, 133 inorganics, and 73 radionuclides are identified. These data formed the early basis for the data matrix.

Duplicate entries were removed from the database. Three mixtures (diesel fuel, hydrocarbons, and kerosene) contained in the database were included in the data matrix. The primary database references were consulted for the concentration detected for each media. However, it was not possible to confirm the presence of the organics from the primary references cited in the database. Additional sources were reviewed to obtain information on the organic constituents.

2.2.2 Environmental Sampling Data Reports

The chemical analytical and radioanalytical data collected and presented in published environmental sampling reports were compiled and are presented in the data matrix. These reports include LFI reports, qualitative risk assessments, RI/FS reports, RCRA groundwater monitoring, and special studies reports.

The titles and summaries of these documents are contained in Section 2.1. The scope was limited to the 100, 300, and 1100 Areas and monitoring of the Columbia River and its riparian zone because they are most likely to have current impact.

The names of all radionuclides and chemicals examined (including those reported as non-detected) were added to the data matrix. The reported maximum concentration or activity is noted by media along with the background value, its reference, and the operable unit or geographical area where the sampling occurred. A total of 568 and 560 analytes (Tables A.1 and A.2 in Appendix, I-A) were reported to be tested for in groundwater/Columbia River and soil/sediment, respectively, in the reviewed literature.

Of the analytes tested, 73 were detected in groundwater or Columbia River water, and 86 were detected in soil and sediment. The concentrations detected were compared, where possible, to the background concentrations existing in other, uncontaminated locations. Impacts from contaminants present in concentrations near background (within a factor of two or less of reported background levels) were not calculated.

A separate data matrix incorporates data related to existing groundwater plumes in areas outside the area of primary interest (the 200 Areas and 600 Area groundwater plumes) as well as 100 Area plumes outside the boundaries of the operating areas. These data are designated as "contaminants away from the Columbia River" and are presented in Table A.5 in Appendix I-A. Table A.5 presents both the maximum concentrations and the parameters used to screen for contaminants.

2.2.3 Detected Analytes

Table 2.1 lists the 73 radionuclides and chemicals detected and their maximum concentration or activity in groundwater and Columbia River water. These maximum values were used in the screening process described in Section 2.3. Table 2.2 lists the 86 radionuclides and chemicals detected and their maximum concentration or activity in sediment and soil. Table 2.3 lists the maximum concentration or activity reported in existing Hanford groundwater plumes away from the river. The data in Tables 2.1, 2.2, and 2.3 were used in the screening criteria described in Section 2.3.

2.3 Screening Approach

The review of the available data indicated that concentrations of various radionuclides, carcinogenic chemicals, and toxic chemicals had been measured in Columbia River water (Columbia River, springs, and seeps), groundwater, river sediment, and near-river soil. A multi-stage screening process was developed to prioritize these various contaminants in terms of risk to human health and the ecosystem. Each stage of the process identified contaminants of interest. The combined results of the entire screening process then compose the total list of contaminants to be evaluated in the screening assessment of potential risk.

To determine which of the contaminants should be included in the screening assessment, we created a series of theoretical screens. A screen is a test used to identify potentially critical materials, such as contaminants. Each contaminant that had been detected was subjected to each of the screens. We used three screens to measure relative risk to humans from radionuclides, carcinogenic chemicals, and toxic chemicals. We used five screens to measure relative risk to the environment based on water quality, threshold toxicity of animals and plants, LC_{50} (chemical concentration reported to be lethal to 50 percent of the exposed organisms after some period of exposure, usually a few hours to a few days), toxicity to fish, and radiation dose to fish.

Table 2.1. Maximum Detected Concentrations in the Columbia River and Groundwater in the Hanford Site 100, 300, and 1100 Areas Near the Columbia River, 1980-1994

Name of Anylte	Background	Background Reference	Maximum Concentration in		
			Surface Water	Groundwater	
Radionuclides					
AMERICIUM 241					0.021 pCi/L
ANTIMONY 125					20 pCi/L
CARBON 14					23000 pCi/L
CESIUM 134	ND (SW)	Dirkes 1994	0.012 pCi/L		
CESIUM 137	ND (SW)	Dirkes et al. 1994	0.13 pCi/L		0.5 pCi/L
COBALT 60	ND (SW)	Dirkes et al. 1994	0.011 pCi/L		140 pCi/L
EUROPIUM 154					2 pCi/L
IODINE 129	5 aCi/L (SW)	Dirkes et al. 1994	0.16 pCi/L		
PLUTONIUM 238	ND (SW)	Dirkes et al. 1994			0.01 pCi/L
PLUTONIUM 239/240					0.03 pCi/L
RADIUM 226	0.23 pCi/L	DOE 1992b			0.3 pCi/L
RUTHENIUM 106+D	ND (SW)	Dirkes et al. 1994			34.4 pCi/L
STRONTIUM 90	0.09pCi/L(SW)	Dirkes et al. 1995	0.16 pCi/L		80000 pCi/L
TECHNETIUM 99	0.02 pCi/L (SW)	Dirkes et al. 1995			2270 pCi/L
THORIUM 228					3 pCi/L
THORIUM 232					44.5 pCi/L
TRITIUM (HYDROGEN 3)	40 pCi/L (SW)	Dirkes et al. 1994	175 pCi/L		1900000 pCi/L
URANIUM 233					3.3 pCi/L
URANIUM 234	0.24 pCi/L (SW)	Dirkes 1994	18 pCi/L		120 pCi/L
URANIUM 235	0.009 pCi/L (SW)	Dirkes 1994	0.01 pCi/L		17 pCi/L
URANIUM 238	0.19 pCi/L(SW)	Dirkes 1994	19 pCi/L		93 pCi/L
Chemicals					
ACETONE	ND (SW)	Dirkes et al. 1993	11 µg/L		30 µg/L
ALUMINUM	< 200 ppb	DOE 1992b			7000 µg/L
AMMONIA	20 ppb	Dirkes et al. 1995			70 µg/L
AMMONIUM	120 PPB	DOE 1992b			1630 µg/L
ANTIMONY	ND (SW)	Dirkes et al. 1993			60 µg/L
ARSENIC	10 ppb	DOE 1992b	3.4 µg/L		37 µg/L
BARIUM	68.5 ppb28(SW)	DOE 1992b, Dirkes 1994	48.2 µg/L		719 µg/L
BERYLLIUM	< 5 ppb	DOE 1992b			6 µg/L
BIS(2-ETHYLHEXYL) PHTHALATE					50 µg/L
BORON	< 100 ppb	DOE 1992b			64 µg/L
CADMIUM	< 10 ppb	DOE 1992b			31 µg/L
CALCIUM	63600,18000(SW) ppb	DOE 1992b, Dirkes 1993	35900 µg/L		302000 µg/L
CHLORIDE	8690, 860(SW) ppb	DOE 1992b, Dirkes 1993	870 µg/L		122000 µg/L
CHLOROFORM	ND (SW)	Dirkes et al. 1993			42 µg/L
CHROMIUM	< 30, <20(SW)ppb	DOE 1992b, Dirkes 1993	22 µg/L		1950 µg/L
COBALT	ND (SW)	Dirkes et al. 1993			9 µg/L
COPPER	< 30, <20(SW) ppb	DOE 1992b, Dirkes 1993	22 µg/L		940 µg/L
CYANIDE					21.1 µg/L
DICHLOROETHYLENE, 1,2-	ND (SW)	Dirkes et al. 1993			200 ug/L
DICHLOROETHYLENE, 1,2-trans-					72 µg/L
FLUORIDE	775, 160(SW) ppb	DOE 1992b, Dirkes 1993	150 µg/L		2080 µg/L
HYDRAZINE					7 µg/L
IRON	86, 72(SW) ppb	DOE 1992b, Dirkes 1993	463 µg/L		640000 µg/L
LEAD	< 5 ppb	DOE 1992b			900 µg/L
LITHIUM					10 µg/L
MAGNESIUM	16480, 4600(SW) ppb	DOE 1992b, Dirkes 1993	9860 µg/L		55000 µg/L
MANGANESE	24.5 ppb (b),ND(SW)	DOE 1992b, Dirkes 1993	22.8 µg/L		1090 µg/L
MERCURY	< 0.1 ppb	DOE 1992b			16 µg/L
METHYL ETHYL KETONE	ND (SW)	Dirkes et al. 1993			18 µg/L
METHYLENE CHLORIDE					3040 µg/L
MOLYBDENUM					25 µg/L
NICKEL	< 30 ppb	DOE 1992b, Dirkes 1993	31 µg/L		479 µg/L

Table 2.1. (Cont'd)

Name of Analyte	Background	Background Reference	Maximum Concentration in	
			Surface Water	Groundwater
NITRATE	12400, 310(SW) ppb	DOE 1992b, Dirkes 1993	480 µg/L	90000 µg/L
NITRITE	ND (SW)	Dirkes et al. 1993		60000 µg/L
PHOSPHATE	<1000 ppb	DOE 1992b	3240 µg/L	200 µg/L
PHOSPHORUS	70 ppb	Dirkes et al. 1995		1200 µg/L
POTASSIUM	7975, 1000(SW) ppb	DOE 1992b, Dirkes 1993	2430 µg/L	11300 µg/L
SELENIUM	< 5 ppb	DOE 1992b		17.2 µg/L
SILICON	26500 ppb	DOE 1992b		17000 µg/L
SILVER	< 10 ppb	DOE 1992b	19 µg/L	10 µg/L
SODIUM	33500, 2000(SW) ppb	DOE 1992b, Dirkes 1993	13800 µg/L	350000 µg/L
STRONTIUM	264.1 ppb	DOE 1992b		349 µg/L
SULFATE	90500, 8800(SW) ppb	DOE 1992b, Dirkes 1993	8600 µg/L	600000 µg/L
SULFIDE				3000 µg/L
TETRACHLOROETHYLENE	ND (SW)	Dirkes et al. 1993		39 µg/L
THALLIUM				4 µg/L
TITANIUM				380 µg/L
TOLUENE	ND (SW)	Dirkes et al. 1993	4.7 µg/L	2.9 µg/L
TRICHLOROETHYLENE	ND (SW)	Dirkes et al. 1993		24.1 µg/L
VANADIUM	15 ppb	DOE 1992b		40 µg/L
XYLENE	ND	Dirkes 1993	4 µg/L	
ZINC	< 50, 12(SW) ppb (b)	DOE 1992b, Dirkes 1993	11 µg/L	8800 µg/L

Table 2.2. Maximum Detected Concentrations in Soil and Sediment in the Hanford Site 100, 300, and 1100 Areas, 1980-1994

Name of Analyte	Soil	Background	Maximum Concentration in			
	Background	Reference	Soil		Sediment	
Radionuclides						
AMERICIUM 241			34	pCi/g		
ANTIMONY 124					1.2	pCi/g
CARBON 14			34	pCi/g		
CESIUM 134	0.002 pCi/g Sed	Blanton 1995	0.04	pCi/g	0.29	pCi/g
CESIUM 137	1.16 pCi/g, 0.57 Sed	DOE 1996, Blanton 1995	2900	pCi/g	6	pCi/g
COBALT 60	ND, 0.03 pCi/g Sed	DOE 1990a, Blanton 1995	18000	pCi/g	4.9	pCi/g
EUROPIUM 152			59000	pCi/g	2.41	pCi/g
EUROPIUM 154	0.039 pCi/g Sed	Blanton 1995	20000	pCi/g	0.24	pCi/g
EUROPIUM 155	0.085 pCi/g Sed	Blanton 1995	6200	pCi/g	0.32	pCi/g
HYDROGEN 3			1600	pCi/g		
NEPTUNIUM 237					0.606	pCi/g
NICKEL 63			20000	pCi/g		
PLUTONIUM 238	0.0003 pCi/g Sed	Blanton 1995	11	pCi/g	0.00115	pCi/g
PLUTONIUM 239/240	0.0095 pCi/g Sed	Blanton 1995	230	pCi/g	0.071	pCi/g
POTASSIUM 40	17.9 pCi/g, 17.1 Sed	DOE 1996, Blanton 1995	16	pCi/g	23	pCi/g
RADIUM 226	0.92 pCi/g	DOE 1996	3.09	pCi/g	1.7	pCi/g
STRONTIUM 90	0.21 pCi/g, 0.021 Sed	DOE 1996, Blanton 1995	950	pCi/g	207	pCi/g
TECHNETIUM 99			0.67	pCi/g	0.5	pCi/g
THORIUM 228			1.61	pCi/g	3	pCi/g
THORIUM 232	1.46 pCi/g	DOE 1996	1.1	pCi/g	3.2	pCi/g
THORIUM 234					0.812	pCi/g
URANIUM 233			3.9	pCi/g	2.3	pCi/g
URANIUM 234	1.22 pCi/g	DOE 1996			3.9	pCi/g
URANIUM 235	0.15 pCi/g, 0.16 Sed	DOE 1996, Blanton 1995	0.23	pCi/g	0.1	pCi/g
URANIUM 238	1.18 pCi/g, 1.36 Sed	DOE 1996, Blanton 1995	4.7	pCi/g	3.2	pCi/g
ZINC 65	ND Sed	Blanton 1995			0.24	pCi/g
ZIRCONIUM 95	ND Sed	Blanton 1995	0.56	pCi/g		
Chemicals						
ACENAPHTHENE	ND	DOE 1994a	210	µg/kg		
ALUMINUM	13621 mg/kg	DOE 1994a	26700000	µg/kg	9350000	µg/kg

2.0 Contaminants for the Screening Assessment

Table 2.2. (Cont'd)

Name of Analyte	Soil	Background	Maximum Concentration in	
	Background	Reference	Soil	Sediment
AMMONIA	16.0 mg/kg	DOE 1994a	12800 µg/kg	12000 µg/kg
ANTHRACENE	ND, 5.09 µg/kg Sed	DOE 1994a, Blanton 1995	430 µg/kg	
AROCOR 1248 (PCB)	ND, ND Sed	DOE 1994a, Blanton 1995	9900 µg/kg	
ARSENIC	7.6 mg/kg, 9.3 Sed	DOE 1994a, Blanton 1995	47000 µg/kg	11000 µg/kg
BARIUM	155.9 mg/kg, 775 Sed	DOE 1994a, Blanton 1995	672000 µg/kg	825,000 µg/kg
BENZENE	ND	DOE 1994a	4500 µg/kg	
BENZO(G,H,I)PERYLENE	ND, 14.6 µg/kg Sed	DOE 1994a, Blanton 1995	410 µg/kg	6.96 µg/kg
BENZO[a]ANTHRACENE	ND, 19.6 µg/kg Sed	DOE 1994a, Blanton 1995	940 µg/kg	7.06 µg/kg
BENZO[a]PYRENE	ND, 15.0 µg/kg Sed	DOE 1994a, Blanton 1995	810 µg/kg	7.77 µg/kg
BENZO[b]FLUORANTHENE	ND, 40.7 µg/kg Sed	DOE 1994a, Blanton 1995	890 µg/kg	11.23 µg/kg
BENZO[k]FLUORANTHENE	ND, 12.6 µg/kg Sed	DOE 1994a, Blanton 1995	760 µg/kg	
BENZOIC ACID	ND	DOE 1994a	1700 µg/kg	
BERYLLIUM	1.6 mg/kg, 1.4 Sed	DOE 1994a, Blanton 1995	8000 µg/kg	1380 µg/kg
BIS(2-ETHYLHEXYL) PHTHALATE	ND	DOE 1994a	68000 µg/kg	
CADMIUM	ND, 6 mg/kg Sed	DOE 1994a, Blanton 1995	1800 µg/kg	2700 µg/kg
CALCIUM	21012 mg/kg	DOE 1994a	40800000 µg/kg	9000000 µg/kg
CHLORDANE	ND	DOE 1990a	4500 µg/kg	
CHLORIDE			1100 µg/kg	
CHROMIUM	24.1 mg/kg, 60 Sed	DOE 1994a, Blanton 1995	259000 µg/kg	122000 µg/kg
CHRYSENE	ND, 42.8 µg/kg Sed	DOE 1994a, Blanton 1995	920 µg/kg	9.69 µg/kg
COBALT	17.6 mg/Kg	DOE 1994a	34100 µg/kg	11500 µg/kg
COPPER	25.9 mg/Kg, 38 Sed	DOE 1994a, Blanton 1995	14000000 µg/kg	40000 µg/kg
CYANIDE	ND	DOE 1990a	1050 µg/kg	
DIBENZOFURAN	ND	DOE 1994a	130 µg/kg	
DIESEL FUEL			2800000 µg/kg	
ENDRIN ALDEHYDE	ND, ND Sed	DOE 1994a, Blanton 1995	3.3 µg/kg	
ETHYL BENZENE	ND	DOE 1994a	32000 µg/kg	
FLUORANTHENE	ND, 21.7 µg/kg Sed	DOE 1994a, Blanton 1995	1800 µg/kg	13 µg/kg
FLUORENE	ND	DOE 1994a	190 µg/kg	
FLUORIDE			4700 µg/kg	
INDENO(1,2,3-CD)PYRENE	ND, 11.5 µg/kg Sed	DOE 1994a, Blanton 1995	520 µg/kg	5.82 µg/kg
IRON	35746 mg/Kg	DOE 1994a	33500000 µg/kg	1.71E+08 µg/kg
KEROSENE	ND	DOE 1994a	3085000 µg/kg	
LEAD	12.6 mg/kg, 50 Sed	DOE 1994a, Blanton 1995	540000 µg/kg	76000 µg/kg
MAGNESIUM	8169 mg/kg	DOE 1994a	11600000 µg/kg	7600000 µg/kg
MANGANESE	548 mg/kg, 900 Sed	DOE 1994a, Blanton 1995	839000 µg/kg	578000 µg/kg
MERCURY	0.61 mg/kg, 0.1 Sed	DOE 1994a, Blanton 1995	4300 µg/kg	0.073 µg/kg
METHYL-2-PENTANONE, 4-	ND	DOE 1994a	22000 µg/kg	
METHYLENE CHLORIDE	ND	DOE 1994a	120 µg/kg	
METHYLNAPHTHALENE, 2-	ND	DOE 1994a	42 µg/kg	
NICKEL	22.2 mg/kg, 35 Sed	DOE 1994a, Blanton 1995	221000 µg/kg	28300 µg/kg
NITRATE			30400 µg/kg	
PHENANTHRENE	ND, 9.7 µg/kg Sed	DOE 1994a, Blanton 1995	1500 µg/kg	9.22 µg/kg
POTASSIUM	2676 mg/kg	DOE 1994a	4980000 µg/kg	1900000 µg/kg
PYRENE	ND, 17.6 µg/kg Sed	DOE 1994a, Blanton 1995	1200 µg/kg	14.33 µg/kg
SELENIUM	ND	DOE 1994a	4200 µg/kg	
SILVER	1.48 mg/kg	DOE 1994a	18000 µg/kg	2500 µg/kg
SILVER CHLORIDE			17300000 µg/kg	
SODIUM	969 mg/kg	DOE 1994a	1770000 µg/kg	920000 µg/kg
STRONTIUM			67000 µg/kg	
STRONTIUM CHLORIDE			1 µg/kg	
SULFATE (SULFUR)			131000 µg/kg	
TOLUENE	ND	DOE 1994a	350000 µg/kg	
TOTAL PETROLEUM HYDROCARBONS			1.26E+08 µg/kg	
VANADIUM	96.7 mg/kg	DOE 1994a	389000 µg/kg	82200 µg/kg
XYLENE	ND	DOE 1994a	1800000 µg/kg	
ZINC	74.7 mg/kg, 620 Sed	DOE 1994a, Blanton 1995	520000 µg/kg	533000 µg/kg

Table 2.3. Maximum Detected Concentrations in Groundwater in the Hanford Site 100, 200, and 600 Areas Away from the Columbia River, 1980-1994

Contaminant	Number of Plumes	Max. Conc.	Units
100 Areas			
Tritium (Hydrogen-3)	4	80,000	pCi/L
Strontium-90	8	1,800	pCi/L
Nitrate	10	130,000	ppb
Chromium (+6)	3	1,570	ppb
200 West Area			
Arsenic	4	24	ppb
Chromium	5	323	ppb
Fluoride	3	10,067	ppb
Nitrate	5	1,322,000	ppb
Carbon Tetrachloride	1	6,559	ppb
Chloroform	2	1,595	ppb
Trichloroethylene	3	32	ppb
Tritium	3	6,193,000	pCi/L
Technetium-99	5	26,602	pCi/L
Iodine-129	2	30	pCi/L
Uranium	4	1,616	pCi/L
200 East Area			
Arsenic	4	24	ppb
Chromium	4	288	ppb
Cyanide	2	893	ppb
Nitrate	7	397,000	ppb
Chloroform	1	7	ppb
Tritium	5	4,126,000	pCi/L
Cobalt-60	2	440	pCi/L
Strontium-90	5	5,149	pCi/L
Technetium-99	2	22,163	pCi/L
Iodine-129	3	20	pCi/L
Cesium-137	1	1,326	pCi/L
Uranium	1	27	pCi/L
Plutonium-239/240	1	69	pCi/L
600 Area (Solid Waste Landfill Site)			
1,1,1-trichloroethane	1	50	ppb
trichloroethylene	1	7	ppb
tetrachloroethene	1	12	ppb
1,1-dichloroethane	1	7	ppb
chloroform	1	0.5	ppb

Because the conceptual model for human health risk is associated with a scenario of a dedicated river user, such a scenario was used to screen for the contaminants of interest. The scenario used is an adaptation and expansion of the Hanford Site Risk Assessment Methodology (DOE 1995). Once the contaminants of interest were determined, a suite of scenarios (Section 5.1) was developed for use in assessing potential risk. Although similar to the scenarios for the risk assessment, the scenario for the contaminant assessment has slightly different factors.

The reference screening exposure scenario for the contaminant assessment involves a person who frequents the shores of the river, drinks 2 liters/day of untreated river water, consumes about 0.27 kilograms/day (100 kilograms/year) (CRITFC 1994) of freshwater fish, ingests 200 milligrams/day of incidental sediment (DOE 1995), inhales 100 $\mu\text{grams}/\text{m}^3$ of resuspended material at a breathing rate of 20 m^3/day (DOE 1995), and eats 45 kilograms/year of irrigated fruits and vegetables (DOE 1995).

The conceptual models for ecosystem risk used to identify the contaminants of interest are simpler. They rely on the EPA Ambient Water Quality Criteria (EPA 1992) (threshold concentrations of contaminants in water at which effects begin to be seen), on the concentrations that result in mortality for fish or other aquatic species if data were available, and on the concentrations that have adverse consequences for developing fish eggs, embryos, or juveniles. In addition, potential radiation doses to fish were evaluated.

All analytes found in the reviewed literature (which related to the 100, 300, and 1100 Areas, regions along the banks of the Columbia River, or inland contaminant plumes) were compiled (see Section 2.2). Initial screening eliminated the contaminants on the list that showed no detectable levels of activity or concentration. In addition, analytes which were present only in tank wastes and not in environmental media were eliminated from the study.

The screening process operated on one portion of the available data at a time. Separate screenings were used for contaminants measured in Columbia River water, groundwater near the river, river sediment, near-river soil, and groundwater distant from the river. For each of these media, further subdivisions addressed radionuclides, human carcinogens, and human toxins, and a range of ecological benchmarks including multiple measures of toxicity to adult and developing fish and radiation dose to fish. Procedures for determining the screening rankings are described in the following sections.

2.3.1 Screening Based on Columbia River Measurements

The screening process was based on relative measures of risk for three screens related to human risk (radionuclides, carcinogenic and toxic chemicals) and five screens related to ecological risk (water quality, threshold toxicity, LC_{50} , toxicity to fish, radiation dose to fish).

2.3.1.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake.

Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate.

A relationship between the concentration of the contaminant in the water and the concentration in the sediment was required. For the screening, this relationship was assumed to be described by the sorption parameter, K_d . The sorption parameter is a measure of the ratio of contaminant concentration in sediment to that in water.

A second relationship was required between the concentration in river water and that in fish consumed by the individual. For the screening, this was defined using a bioconcentration factor (BCF), which is a ratio between the contaminant concentration in fish and the water in which the fish lives. These are linear relationships that can be expressed as a simple multiple of the water concentration times the appropriate factor.

A third relationship was that between the contaminant concentration in irrigation water and the resulting concentration in irrigated crops. This relationship has two terms, addressing both the deposition of the irrigation water on the leaves of the plants and the uptake of the contaminant through the roots of the plants. Irrigation was assumed to be 5 liters per m^2 /day over 6 months (a total of 36 inches). For foliar deposition (deposition on leaves), an initial retention of 25 percent was assumed, with a long-term weathering half-time of 14 days and an assumed translocation of 100 percent of the retained deposition to the edible portions of the plant. These are standard assumptions that tend to maximize the overall exposure (see, for example, Napier et al. 1988). The contaminants mixed in the rooting zone soil were assumed to be 15 centimeters deep (6 inches). Uptake via the roots was parameterized with a plant-to-soil concentration ratio (CR). Using equilibrium assumptions (the plants have reached a steady state with regard to the incoming concentration), the concentration in the plants was estimated as

$$C_{leaf} = \frac{C_w I}{Y \ln(2)/T_w} = 12.6 C_w \quad (1)$$

$$C_{root} = C_w CR I T / D = 4.02 C_w CR \quad (2)$$

$$C_{plant} = C_{leaf} + C_{root} = C_w (12.6 + 4.02 CR) \quad (3)$$

where

- C_{leaf} = estimated concentration in plants via foliar deposition, pCi/kg
- C_w = measured concentration in Columbia River water, pCi/L
- I = irrigation rate, 5 L/ m^2 /day for 6 months/year (36 inches/year)
- $\ln(2)/T_w$ = weathering removal constant, where T_w is the weathering half-time of 14 days
- Y = above ground plant yield available for interception, taken to be 2 kg/ m^2
- C_{root} = estimated concentration in plants via root uptake, pCi/kg
- CR = plant-to-soil concentration ratio
- T = translocation factor from leaves to edible parts of the plant, assumed to be 1.0
- D = soil surface density, 224 kg/ m^2
- C_{plant} = estimated concentration in edible plants, pCi/kg

For an individual contaminant, the screening score for human risk resulting from radionuclides in Columbia River water was derived from the following equation:

$$\text{Score} = \text{River water concentration} * [(\text{External exposure} * \text{External Slope Factor}) + (\text{Drinking} + \text{Fish consumption} + \text{Sediment ingestion/inhalation} + \text{Crop ingestion}) * \text{Internal slope factor}]$$

Using the terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = C_w \left[\frac{K_d * SS}{1000} + (730 + 100 * BCF + K_d * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * CR) * IS) \right] \quad (4)$$

where

- Score = individual screening score for a single contaminant
- Kd = sediment/water ratio, L/kg
- SS = radionuclide slope factor for external exposure, risk/year per pCi/g
- 1000 = unit conversion, g/kg
- 730 = water consumption of 2 L/day for 365 days/year giving 730 L/year
- 100 = fish consumption of 100 kg/year
- BCF = bioconcentration factor for fish, L/kg
- 0.072 = sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
- 0.0007 = sediment inhalation based on 100 $\mu\text{grams}/\text{m}^3$ and breathing rate of 20 m^3/day giving 0.0007 kg/year
- 45 = irrigated fruit and vegetable consumption, kg/year
- CR = plant-to-soil concentration ratio
- IS = radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.1.2 Screening for Human Carcinogens

The second human risk screen was for carcinogenic chemicals. The conceptual exposure patterns for carcinogens in river water are the same as those for radionuclides. However, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms are put in daily, rather than annual, units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\text{Score} = C_w \left[2 + 0.27 * BCF + K_d * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR) \right] (0.001) \frac{\text{CPF}}{70} \quad (5)$$

where C_w = measured Columbia River water concentration, g/L
 2 = water consumption of 2 L/day
 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
 BCF = bioconcentration factor for fish, L/kg
 Kd = sediment/water ratio, L/kg
 2×10^{-4} = sediment consumption of 200 mg/day, kg
 2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m³ and a breathing rate of 20 m³/day, kg
 0.12 = irrigated fruit and vegetable consumption, kg/day
 CR = plant-to-soil concentration ratio
 0.001 = conversion factor, micrograms to milligrams
 CPF = cancer potency factor, (mg/kg/day)⁻¹
 70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.1.3 Screening for Toxic Chemicals

The third human risk screen was for toxic (hazardous but noncarcinogenic) chemicals. For toxic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario is the same as for radionuclides or carcinogens. The individual contaminant scoring was

$$\text{Score} = C_w [2 + 0.27 * \text{BCF} + \text{Kd} * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * \text{CR})] \frac{(0.001)}{70 * \text{RfD}} \quad (6)$$

where C_w = measured concentration in Columbia River water, g/L
 2 = water consumption of 2 L/day
 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
 BCF = bioconcentration factor for fish, L/kg
 Kd = sediment/water ratio, L/kg
 2×10^{-4} = sediment consumption of 200 mg/day, kg
 2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m³ and a breathing rate of 20 m³/day, kg
 0.12 = irrigated fruit and vegetable consumption per day, kg
 CR = plant-to-soil concentration ratio
 0.001 = conversion factor, micrograms to milligrams
 70 = assumed weight of an adult, kg
 RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.1.4 Screening for Ambient Water Quality Criteria

The first ecological risk screen was for ambient water quality criteria. For aquatic biota, the measured concentration of the contaminant in Columbia River water was compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. The screening equation was

$$\text{Score} = \frac{C_w}{\text{AWQC}} \quad (7)$$

where

$$\begin{aligned} C_w &= \text{measured Columbia River water concentration, g/L} \\ \text{AWQC} &= \text{ambient water quality criterion, g/L} \end{aligned}$$

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.1.5 Screening for Aquatic Biota Threshold Toxicity

The second ecological risk screen was for aquatic biota threshold toxicity. Some data are available that identify the concentrations of certain chemicals that result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. The equation to generate ranking scores for individual contaminants was

$$\text{Score} = \frac{C_w}{\text{TLM}} \quad (8)$$

where

$$\begin{aligned} C_w &= \text{measured Columbia River water concentration, g/L} \\ \text{TLM} &= \text{threshold limit for fresh water (the concentration at which effects are first observed), g/L} \end{aligned}$$

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.1.6 Screening for Aquatic Biota LC₅₀

The third ecological risk screen used aquatic biota LC₅₀ (lowest concentration lethal to 50 percent of the test species). Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of the small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar. The equation was

$$\text{Score} = \frac{C_w}{LC_{50}} \quad (9)$$

where

C_w = measured Columbia River water concentration, g/L
 LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.1.7 Screening for Embryonic/Juvenile Fish Toxicity

The fourth ecological risk screen was for embryonic/juvenile fish toxicity. A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravel and developing young fish, without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant concentrations were found, but a screen identical in structure to that for the adult fish LC₅₀ screen was constructed and used. The equations and parameters are identical to those in Equation (9) above, but the toxicity is directly related to developmental effects rather than adult mortality.

2.3.1.8 Screening for Radiation Dose to Fish

The fifth ecological risk screen was for radiation dose to fish. The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical not radiological contaminants. In order to rank potentially hazardous radionuclides, a screen

involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8} C_w \text{ BCF EE} \quad (10)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV

C_w = measured concentration of contaminant in Columbia River water, pCi/L

BCF = bioconcentration factor for fish, L/kg

EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.2 Screening Based on Near-River Groundwater Measurements

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for Columbia River water.

Groundwater adjacent to the Columbia River can flow into the river, and Columbia River water can flow into the groundwater, depending on the stage of the river. Therefore, concentrations of contaminants in groundwater near the river are difficult to predict, and concentrations measured near the shore differ from those measured further inland. Flow rates from groundwater to the Columbia vary from location to location. Individual springs may have very low flow rates. An average groundwater discharge to the Columbia River of 3 cubic feet per second (cfs) was modeled by Kipp et al. (1976) for a 8.3-kilometer (5-mile) length of the river near the old Hanford townsite. Raymond et al. (1976) and Cline et al. (1985) report an estimated discharge of 100 cfs over the entire Hanford Reach. More recent research (Wuerstner and Devary 1993) indicates that an annual average of 100 cfs is an upper bound.

2.3.2.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake. Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate (EPA 1994a). The same

relationships used above for estimating contaminant concentrations in sediment, fish, and irrigated crops were used in these screens. The only difference was the use of groundwater instead of river water as the source of contaminants.

Conceptually, a relationship is needed between the concentration of the contaminant in the groundwater and the concentration in the water the individual is exposed to. This can be thought of as an effective dilution factor. Depending on the location of the individual (for instance, at the site of a groundwater seep or miles downstream), this dilution factor may vary over a large range. However, for the purposes of screening on relative importance, it turned out that the dilution factor was immaterial because it applied equally to all contaminants and to the sum of scores for all contaminants and disappeared from the final equations. This is demonstrated below.

For an individual contaminant, the screening score for human risk resulting from radionuclides in groundwater was derived from the following equation:

$$\text{Score} = \text{Groundwater concentration} * \text{Dilution factor} * \\ [(\text{External exposure} * \text{External slope factor}) + \\ (\text{Drinking} + \text{Fish consumption} + \text{Sediment ingestion/inhalation} + \\ \text{Crop ingestion}) * \text{Internal slope factor}]$$

Using the various terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = C_{\text{gw}} \text{ DIL} \left[\frac{K_d * SS}{1000} + (730 + 100 * \text{BCF} \right. \\ \left. + K_d * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * \text{CR})) * \text{IS} \right] \quad (11)$$

where

- Score = individual screening score for a single contaminant
- C_{gw} = measured concentration of contaminant in groundwater, pCi/L
- DIL = dilution factor (dimensionless)
- K_d = sediment/water ratio, L/kg
- SS = radionuclide slope factor for external exposure, risk/year per pCi/g
- 1000 = unit conversion, g/kg
- 730 = water consumption of 2 L/day for 365 days/year giving 730 L/year
- 100 = fish consumption of 100 kg/year
- BCF = bioconcentration factor for fish, L/kg
- 0.072 = sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
- 0.0007 = sediment inhalation based on 100 $\mu\text{grams}/\text{m}^3$ and breathing rate of 20 m^3/day giving 0.0007 kg/year
- 45 = irrigated fruit and vegetable consumption, kg/year
- CR = plant-to-soil concentration ratio
- IS = radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores (each containing DIL)} * 100\%$$

Notice that both the numerator and denominator of this final ranking equation contain the factor DIL. This factor can be removed from the assessment without disrupting the relative positions of the rankings. In effect, this makes knowledge of the location of the exposure unnecessary. The relative impact of each contaminant is the same whether the individual is exposed to a riverbank spring or to contaminants fully mixed in the flow of the river downstream.

2.3.2.2 Screening for Human Carcinogens

The conceptual exposure patterns for carcinogens in groundwater are the same as those for radionuclides. However, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms are put in daily rather than annual units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\begin{aligned} \text{Score} = C_{gw} [2 + 0.27 * \text{BCF} + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) \\ + 0.12 * (12.6 + 4.02 * \text{CR})] (0.001) \frac{\text{CPF}}{70} \end{aligned} \quad (12)$$

where

- C_{gw} = measured concentration of contaminant in groundwater, g/L
- 2 = water consumption of 2 L/day
- 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
- BCF = bioconcentration factor for fish, L/kg
- Kd = sediment/water ratio, L/kg
- 2×10^{-4} = sediment consumption of 200 mg/day, kg
- 2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m³ and a breathing rate of 20 m³/day, kg
- 0.12 = irrigated fruit and vegetable consumption, kg/day
- CR = plant-to-soil concentration ratio
- 0.001 = conversion factor, micrograms to milligrams
- CPF = cancer potency factor, (mg/kg/day)⁻¹
- 70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

The effective dilution factor was neglected in these equations because it canceled out.

2.3.2.3 Screening for Toxic Chemicals

For hazardous but non-carcinogenic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario is the same as for the radionuclides or carcinogens. The individual contaminant scoring was

$$\text{Score} = C_{gw} [2 + 0.27 * \text{BCF} + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * \text{CR})] \frac{(0.001)}{70 * \text{RfD}} \quad (13)$$

where

- C_{gw} = measured concentration of contaminant in groundwater, g/L
- 2 = water consumption of 2 L/day
- 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
- BCF = bioconcentration factor for fish, L/kg
- Kd = sediment/water ratio, L/kg
- 2×10^{-4} = sediment consumption of 200 mg/day, kg
- 2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m³ and a breathing rate of 20 m³/day, kg
- 0.12 = irrigated fruit and vegetable consumption, kg/day
- CR = plant-to-soil concentration ratio
- 0.001 = conversion factor, micrograms to milligrams
- 70 = assumed weight of an adult, kg
- RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

Again, the effective dilution factor was neglected in these formulations.

2.3.2.4 Screening for Ambient Water Quality Criteria

For aquatic biota, the measured concentration of the contaminant in groundwater was compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. While some effective dilution factor was required to find the actual risk, in finding relative risk this term may be neglected as shown above. The screening equation was

$$\text{Score} = \frac{C_{gw}}{AWQC} \quad (14)$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
AWQC = ambient water quality criterion, g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.2.5 Screening for Aquatic Biota Threshold Toxicity

Some data are available that identify the concentrations of certain chemicals which result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. While some effective dilution factor is required to find the actual risk, in finding relative risk this term may be neglected as shown above. The equation to generate ranking scores for individual contaminants in groundwater was

$$\text{Score} = \frac{C_{gw}}{TLM} \quad (15)$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
TLM = threshold limit for fresh water (TLM), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.2.6 Screening for Aquatic Biota LC₅₀

Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar.

The equation was

$$\text{Score} = \frac{C_{gw}}{LC_{50}} \quad (16)$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
 LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.2.7 Screening for Embryonic/Juvenile Fish Toxicity

A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravels and developing young fish without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (16), above, but the toxicity is directly related to developmental effects rather than adult mortality.

2.3.2.8 Screening for Radiation Dose to Fish

The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical, not radiological, contaminants. In order to rank potentially hazardous radionuclides, a screen involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. For screening of groundwater, some dilution is to be expected before sufficient free surface water could exist to support life. This additional dilution was neglected in the screen. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8} C_{gw} \text{ BCF EE} \quad (17)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV
 C_{gw} = measured concentration of contaminant in groundwater, pCi/L

BCF = bioconcentration factor for fish, L/kg

EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.3 Screening Based on Columbia River Sediment Measurements

Sediment within the river is both a reservoir of contaminants and a source of contamination of the river water as the material desorbs or resuspends into the water column. Accurate representation of this process requires detailed knowledge of the chemical interactions of the contaminant and the water. Information at this level of detail is not available for most of the contaminants considered.

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for Columbia River water and groundwater.

2.3.3.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake. Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate (EPA 1994a). The same relationships used above for estimating contaminant concentrations in sediment, fish, and irrigated crops were used in these screens. Sediment was used instead of river water as the source of contaminants.

Conceptually, a relationship is needed between the concentration of the contaminant in the sediments and the concentration in the water the individual is exposed to. This can be thought of as a combination of sorption and an effective dilution factor. However, for the purposes of screening on relative importance, it turned out that the dilution factor was immaterial because it applied equally to all contaminants and to the sum of scores for all contaminants and disappeared from the final equations, as demonstrated in Section 2.3.2. All that remained was the sorption correction.

For an individual contaminant, the screening score for human risk resulting from radionuclides in sediment was derived from the following equation:

$$\begin{aligned} \text{Score} = & \text{Sediment concentration} / \text{Sorption} \times \text{Dilution factor} * \\ & [(\text{External exposure} * \text{External slope factor}) + \\ & (\text{Drinking} + \text{Fish consumption} + \text{Sediment ingestion/inhalation} + \\ & \text{Crop ingestion}) * \text{Internal slope factor}] \end{aligned}$$

Using the various terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = \frac{C_{\text{sed}} \text{ DIL}}{Kd} \left[\frac{Kd * SS}{1000} + (730 + 100 * BCF + Kd \right. \quad (18)$$

$$\left. * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * CR)) * IS \right]$$

where

- Score = individual screening score for a single contaminant
- C_{sed} = measured concentration of contaminant in sediment, pCi/kg
- DIL = dilution factor (dimensionless)
- Kd = sediment/water ratio, L/kg
- SS = radionuclide slope factor for external exposure, risk/year per pCi/g
- 1000 = unit conversion, g/kg
- 730 = water consumption of 2 L/day for 365 days/year giving 730 L/year
- 100 = fish consumption of 100 kg/year
- BCF = bioconcentration factor for fish, L/kg
- 0.072 = sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
- 0.0007 = sediment inhalation based on 100 $\mu\text{grams}/\text{m}^3$ and breathing rate of 20 m^3/day giving 0.0007 kg/year
- 45 = irrigated fruit and vegetable consumption, kg/year
- CR = plant-to-soil concentration ratio
- IS = radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores (each containing DIL)} * 100\%$$

Notice that both the numerator and denominator of this final ranking equation contain the factor DIL. This factor can be removed from the assessment without disrupting the relative positions of the rankings.

2.3.3.2 Screening for Human Carcinogens

The conceptual exposure patterns for carcinogens in sediment are the same as those for radionuclides. However, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms were put in daily rather than annual units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\text{Score} = \frac{C_{\text{sed}}}{Kd} [2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) \quad (19)$$

$$+ 0.12 * (12.6 + 4.02 * CR)] (0.001) \frac{\text{CPF}}{70}$$

where

- C_{sed} = measured sediment concentration, g/kg
- 2 = water consumption of 2 L/day
- 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
- BCF = bioconcentration factor for fish, L/kg
- Kd = sediment/water ratio, L/kg
- 2×10^{-4} = sediment consumption of 200 mg/day, kg
- 2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m³ and a breathing rate of 20 m³/day, kg
- 0.12 = irrigated fruit and vegetable consumption, kg/day
- CR = plant-to-soil concentration ratio
- 0.001 = conversion factor, micrograms to milligrams
- CPF = cancer potency factor, (mg/kg/day)⁻¹
- 70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

The effective dilution factor was neglected in these equations because it canceled out.

2.3.3.3 Screening for Toxic Chemicals

For hazardous but non-carcinogenic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario was the same as for the radionuclides or carcinogens. The individual contaminant scoring was

$$\text{Score} = \frac{C_{sed}}{Kd} [2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR)] \frac{(0.001)}{70 * RfD} \quad (20)$$

where

- C_{sed} = measured sediment concentration, g/kg
- 2 = water consumption of 2 L/day
- 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
- BCF = bioconcentration factor for fish, L/kg
- Kd = sediment/water ratio, L/kg
- 2×10^{-4} = sediment consumption of 200 mg/day, kg
- 2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m³ and a breathing rate of 20 m³/day, kg
- 0.12 = irrigated fruit and vegetable consumption, kg/day
- CR = plant-to-soil concentration ratio

- 0.001 = conversion factor, micrograms to milligrams
70 = assumed weight of an adult, kg
RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants are then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

Again, the effective dilution factor was neglected in these formulations.

2.3.3.4 Screening for Ambient Water Quality Criteria

For aquatic biota, the measured concentration of the contaminant in sediment was used to generate an equivalent concentration in surface water, which was then compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. The screening equation was

$$\text{Score} = \frac{C_{\text{sed}}}{K_d \text{ AWQC}} \quad (21)$$

where

- C_{sed} = measured sediment concentration, g/kg
 K_d = sediment/water ratio, L
AWQC = ambient water quality criterion, g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.3.5 Screening for Aquatic Biota Threshold Toxicity

Some data are available that identify the concentrations of certain chemicals that result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. The equation to generate ranking scores for individual contaminants measured in sediment is

$$\text{Score} = \frac{C_{\text{sed}}}{K_d \text{ TLM}} \quad (22)$$

where

- C_{sed} = measured sediment concentration, g/kg
 K_d = sediment/water ratio, L/kg
TLM = threshold limit for fresh water (TLM), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.3.6 Screening for Aquatic Biota LC_{50}

Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar. The equation was

$$\text{Score} = \frac{C_{sed}}{K_d LC_{50}} \quad (23)$$

where

- C_{sed} = measured sediment concentration, g/L
 K_d = sediment/water ratio, L/kg
 LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.3.7 Screening for Embryonic/Juvenile Fish Toxicity

A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravels and developing young fish without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant

concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (23), above, but the toxicity is directly related to developmental effects, rather than adult mortality.

2.3.3.8 Screening for Radiation Dose to Fish

The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical not radiological contaminants. In order to rank potentially hazardous radionuclides, a screen involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8} \frac{C_{\text{sed}} \text{ BCF } EE}{K_d} \quad (24)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV

C_{sed} = measured sediment concentration, pCi/kg

BCF = bioconcentration factor for fish, L/kg

EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration

K_d = sediment/water ratio, L/kg

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.4 Screening Based on Near-River Soil Measurements

Contaminants in waste sites or other sites adjacent to the Columbia River may not pose a current hazard to down-river users of the river, but they may pose a threat of future contamination of the river. The possibility also exists that such sources may be contributing as yet undetected contamination to the river. One of the goals of the Columbia River Comprehensive Impact Assessment is to tie Hanford cleanup activities to the potential for river contamination. In this spirit, contaminated soil near the river is included as a possible source of contaminants. Adequate consideration of these contaminants must include site-specific details about how they could be transported from their current locations into the groundwater and hence into the Columbia River. For the purpose of screening to determine which contaminants require attention, all contaminants are assumed to be potentially environmentally mobile and potentially available for transport in groundwater. Based on this assumption, the potential groundwater contamination is treated in a manner parallel to the actual measured groundwater in Section 2.3.2.

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for Columbia River water and groundwater.

2.3.4.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake. Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate (EPA 1994a). The same relationships used above for estimating contaminant concentrations in sediment, fish, and irrigated crops were used in these screens. Soil was used instead of river water as the source of contaminants.

Conceptually, a relationship is needed between the concentration of the contaminant in the soil and the concentration in the water the individual is exposed to. This can be thought of as a combination of sorption and an effective dilution factor. However, for the purposes of screening on relative importance, it turned out that the dilution factor was immaterial because it applied equally to all contaminants and to the sum of scores for all contaminants and disappeared from the final equations, as demonstrated in Sections 2.3.2 and 2.3.3. All that remained was the sorption correction.

For an individual contaminant, the screening score for human risk resulting from radionuclides in soil was derived from the following equation:

$$\begin{aligned} \text{Score} = & \text{Soil concentration/Sorption} \times \text{Dilution factor} * \\ & [(\text{External exposure} * \text{External slope factor}) + \\ & (\text{Drinking} + \text{Fish consumption} + \text{Sediment ingestion/inhalation} + \\ & \text{Crop ingestion}) * \text{Internal slope factor}] \end{aligned}$$

Using the various terms and parameters described above, the individual contaminant scores can be written as

$$\begin{aligned} \text{Score} = & \frac{C_{\text{soil}} \text{ DIL}}{K_d} \left[\frac{K_d * SS}{1000} + (730 + 100 * BCF + K_d \right. \\ & \left. * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * CR)) * IS \right] \end{aligned} \quad (25)$$

where

- Score = individual screening score for a single contaminant
- C_{soil} = measured concentration of contaminant in soil, pCi/kg
- DIL = dilution factor (dimensionless)
- K_d = sediment/water ratio, L/kg
- SS = radionuclide slope factor for external exposure, risk/year per pCi/g
- 1000 = unit conversion, g/kg
- 730 = water consumption of 2 L/day for 365 days/year giving 730 L/year
- 100 = fish consumption of 100 kg/year

- BCF = bioconcentration factor for fish, L/kg
 0.072 = sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
 0.0007 = sediment inhalation based on 100 $\mu\text{g}/\text{m}^3$ and breathing rate of 20 m^3/day , giving 0.0007 kg/year
 45 = irrigated fruit and vegetable consumption, kg/year
 CR = plant-to-soil concentration ratio
 IS = radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores (each containing DIL)} * 100\%$$

Notice that both the numerator and denominator of this final ranking equation contain the factor DIL. This factor can be removed from the assessment without disrupting the relative positions of the rankings.

2.3.4.2 Screening for Human Carcinogens

The conceptual exposure patterns for carcinogens in sediment are the same as those for radionuclides; however, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms were put in daily rather than annual units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\text{Score} = \frac{C_{\text{soil}}}{K_d} [2 + 0.27 * \text{BCF} + K_d * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * \text{CR})] (0.001) \frac{\text{CPF}}{70} \quad (26)$$

where

- C_{soil} = measured soil concentration, $\mu\text{g}/\text{kg}$
 2 = water consumption of 2 L/day
 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
 BCF = bioconcentration factor for fish, L/kg
 K_d = sediment/water ratio, L/kg
 2×10^{-4} = sediment consumption of 200 mg/day, kg
 2×10^{-6} = sediment inhalation based on a mass loading of 100 $\mu\text{g}/\text{m}^3$ and a breathing rate of 20 m^3/day , kg
 0.12 = irrigated fruit and vegetable consumption, kg/day
 CR = plant-to-soil concentration ratio
 0.001 = conversion factor, micrograms to milligrams
 CPF = cancer potency factor, $(\text{mg}/\text{kg}/\text{day})^{-1}$
 70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

The effective dilution factor has been neglected in these equations because it cancels out.

2.3.4.3 Screening for Toxic Chemicals

For hazardous but non-carcinogenic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario was the same as for the radionuclides or carcinogens. The individual contaminant scoring is

$$\text{Score} = \frac{C_{\text{soil}}}{Kd} [2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR)] \frac{(0.001)}{70 * RfD} \quad (27)$$

where

- C_{soil} = measured soil concentration, $\mu\text{g/kg}$
- Kd = sediment/water ratio, L/kg
- 2 = water consumption of 2 L/day
- 0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
- BCF = bioconcentration factor for fish, L/kg
- 2×10^{-4} = sediment consumption of 200 mg/day, kg
- 2×10^{-6} = sediment inhalation based on a mass loading of $100 \mu\text{g/m}^3$ and a breathing rate of $20 \text{ m}^3/\text{day}$, kg
- 0.12 = irrigated fruit and vegetable consumption, kg/day
- CR = plant-to-soil concentration ratio
- 0.001 = conversion factor, micrograms to milligrams
- 70 = assumed weight of an adult, kg
- RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants are then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

Again, the effective dilution factor was neglected in these formulations.

2.3.4.4 Screening for Ambient Water Quality Criteria

For aquatic biota, the measured concentration of the contaminant in soil was used to generate an equivalent concentration in surface water, which was then compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. The screening equation was

$$\text{Score} = \frac{C_{\text{soil}}}{K_d \text{ AWQC}} \quad (28)$$

where

- C_{soil} = measured soil concentration, $\mu\text{g/kg}$
- K_d = sediment/water ratio, L/kg
- AWQC = ambient water quality criterion, $\mu\text{g/L}$

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.4.5 Screening for Aquatic Biota Threshold Toxicity

Some data are available that identify the concentrations of certain chemicals that result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. The equation to generate ranking scores for individual contaminants measured in sediment is

$$\text{Score} = \frac{C_{\text{soil}}}{K_d \text{ TLM}} \quad (29)$$

where

- C_{soil} = measured soil concentration, $\mu\text{g/kg}$
- K_d = sediment/water ratio, L/kg
- TLM = threshold limit for fresh water (TLM), $\mu\text{g/L}$

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.4.6 Screening for Aquatic Biota LC_{50}

Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for

example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same endpoint, the absolute values of the two cannot be related. However, the relative rankings should be similar. The equation was

$$\text{Score} = \frac{C_{\text{soil}}}{K_d \text{ LC}_{50}} \quad (30)$$

where

- C_{soil} = measured soil concentration, $\mu\text{g/kg}$
- K_d = sediment/water ratio, L/kg
- LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), $\mu\text{g/L}$

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.4.7 Screening for Embryonic/Juvenile Fish Toxicity

A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravels and developing young fish without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (30), above, but the toxicity is directly related to developmental effects, rather than adult mortality.

2.3.4.8 Screening for Radiation Dose to Fish

The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical, not radiological, contaminants. In order to rank potentially hazardous radionuclides, a screen involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8} \frac{C_{\text{soil}} \text{ BCF } EE}{K_d} \quad (31)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV

C_{soil} = measured soil concentration, pCi/kg

BCF = bioconcentration factor for fish, L/kg

EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration

K_d = sediment/water ratio, L/kg

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score} / \text{Sum of all scores} * 100\%$$

2.3.5 Screening Based on Distant Groundwater Measurements

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for near-river groundwater. The equations and parameters are the same as presented in Section 2.3.2.

2.4 Screening Results

Application of the equations and assumptions defined above resulted in a series of complementary but not necessarily intercomparable screening values for each contaminant. The varying numbers of assumptions and associated varying degrees of conservatism required that each of the screenings be evaluated separately. The results of the combined screenings, however, then defined the overall list of contaminants to be used in the screening assessment. The overall results and interpretation of the screening are given here. The radionuclides and chemicals are listed in the tables in the order of the screening results.

In this section (Tables 2.4-2.11), we list those contaminants that the screens showed to be ones we needed to include in our study. Each table depicts the contaminants by the particular medium in which the contaminants were found (Columbia River, groundwater, sediment, and soil) and denotes whether the contaminant affects humans or the environment.

2.4.1 Columbia River Water Sample Screening

A screen was used to account for over 99 percent of the relative risk from contaminants identified directly in the water of the Columbia River. The individual screenings and the identified contaminants related to human risk are listed in Table 2.4, and those related to ecological risk are listed in Table 2.5.

Table 2.4. Contaminants of Potential Interest Related to Human Health Identified via Screening of Columbia River Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemical Screening
Cesium-137 Iodine-129 Uranium-234 Uranium-238	Chromium	Nitrates Phosphates Copper ^(a)
(a) See later discussion in Section 2.4.5 on samples near limit of detection.		

Table 2.5. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Columbia River Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC ₅₀ Screening	Embryonic/Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Chromium ^(a) Copper ^(a) Nickel ^(a) Zinc ^(a)	Nickel ^(a) Phosphate	Copper ^(a) Nitrate Zinc ^(a) Chromium ^(a)	Diesel ^(b) Chromium ^(a)	Uranium-234 Uranium-238
(a) See later discussion in Section 2.4.5 on samples near limit of detection.				
(b) Diesel as xylene. See discussion in Section 2.4.5 on suspect samples.				

The radioisotope cesium-137 is present in worldwide fallout. It is possible that this contaminant may be derived from non-Hanford sources, although background levels of cesium-137 in surface water are generally undetectable. The Hanford Environmental Dose Reconstruction Project did not identify this radionuclide as resulting from significant Hanford releases (Napier 1993).

Several contaminants are highlighted in Tables 2.4 and 2.5 with footnotes. These indicate a potential problem with the screening result on the basis of source information. These difficulties are described in Section 2.4.5.

2.4.2 Groundwater Sample Screening

A very large fraction of available Hanford-related environmental samples are of groundwater. Only those taken within about a kilometer of the river were used in compiling the database for the screening. Even so, many positive samples were noted. Most of the samples were derived from investigations of the Hanford operating areas (100, 300), but many were from wells located near the river but far from the reactor, fuel fabrication, and research sites. Contaminants identified for investigation include several

metals and radionuclides. A screening level was used to account for over 99 percent of the relative risk for each result. The individual screenings and the identified contaminants related to human health are listed in Table 2.6, and those related to ecological risk are listed in Table 2.7.

2.4.3 Columbia River Sediment Sample Screening

Because the Hanford Reach is a relatively fast-flowing portion of the river, there is actually little accumulation of sediment at Hanford. Accordingly, sediment samples represent a very small portion of the historical Hanford data. This is a clear area for future sampling work. Nevertheless, the sediment samples did provide sufficient information to apply the screening technique. The individual screenings and the identified contaminants related to human risk are listed in Table 2.8, and those related to ecological risk are listed in Table 2.9.

Table 2.6. Contaminants of Potential Interest Related to Human Health
Identified via Screening of Groundwater Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemical Screening
Strontium-90 Carbon-14 Cobalt-60 Tritium (Hydrogen-3)	Chromium	Nitrates Nitrites

Table 2.7. Contaminants of Potential Interest Related to Ecological Risk
Identified via Screening of Groundwater Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC₅₀ Screening	Embryonic/Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Mercury Lead Chromium Zinc Copper	Sulfates Lead Nickel Ammonia Fluorides	Phosphates Copper Zinc Lead Mercury Nitrate/nitrite	Lead Ammonia Chromium	Carbon-14 Strontium-90

Table 2.8. Contaminants of Potential Interest Related to Human Health
Identified via Screening of Columbia River Sediment Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemical Screening
Neptunium-237 Strontium-90 Cesium-137 Cobalt-60	Chromium	Chromium

Table 2.9. Contaminants of Potential Interest Related to Ecological Risk
Identified via Screening of Columbia River Sediment Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC₅₀ Screening	Embryonic/ Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Chromium		Chromium	Diesel ^(a)	Strontium-90 Cesium-137
(a) Diesel as xylene.				

2.4.4 Near-River Soil Sample Screening

Contaminants measured in soil upland of the riparian corridor near the Columbia River are generally not an immediate hazard because they are currently in the soil and not subject to mass transport to the river and subsequent human and biotic exposure. However, their existence is the primary reason for continuing cleanup of the Hanford operating areas, and it is useful to have a screening prioritization. It is also useful to direct future sampling efforts to determine if any of the contaminants most likely to cause problems are beginning to reach the river. Because of the nature of the contamination (generally solids in or associated with soil) and the nature of the activities carried out at Hanford over its history, these contaminants differ somewhat from those actually found in more mobile media (river water, groundwater, and sediment). Even so, it is informative to note the similarities in the list generated via the soil screening with those lists generated for the other media. The individual screenings and the identified contaminants related to human risk are listed in Table 2.10, and those related to ecological risk are listed in Table 2.11.

In Tables 2.5, 2.9, and 2.11, the contaminant diesel is identified. In the contaminants analyzed for and found, various components of diesel fuel are individually listed. However, in all cases, these components were found in the same sites — those associated with leaks of diesel fuel from underground storage tanks. Therefore, they have been lumped here as a single dominant contaminant.

Table 2.10. Contaminants of Potential Interest Related to Human Health Identified via Screening of Near-River Soil Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemicals Screening
Europium-152 Cobalt-60 Europium-154 Cesium-137 Carbon-14	Chromium Arochlor 1248	Copper Nitrates Nitrites

Table 2.11. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Near-River Soil Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC ₅₀ Screening	Embryonic/Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Copper Cyanide Chlordane	Diesel ^(a)	Silver Chloride Copper Cyanide	Diesel ^(a)	Carbon-14 Cobalt-60 Cesium-137

(a) Various as kerosene, benzene, xylene, ethylbenzene.

2.4.5 Use of Background and Suspect Measurements

During the screening process, a few radionuclides and chemicals were initially identified as of potential interest but were not evaluated further because measurements showed them to be within their naturally occurring background levels. These radionuclides and chemicals and their background values are identified in Tables A.1, A.2, and A.5 in Appendix I-A. In addition, several chemicals were identified by the screening process to be those that EPA (EPA 1991, EPA 1989) considers non-hazardous to humans under environmental conditions. These non-hazardous chemicals removed from further consideration in the human risk screens included aluminum, calcium, iron, magnesium, potassium, and sodium. These contaminants were still screened with the ecological risk screens.

During the screening process, a few contaminants survived the screening but their measurements were the same or lower than measurements taken of the same material where no known polluting source was in the area. Such measurements are known as background levels. Those contaminants (eliminated because their measurements were within their naturally occurring background levels) are identified in Appendix I-A. Also, some of the results from the screens turned up suspect measurements. Suspect measurements are ones that appear to be measuring mistakes, such as the measurement being totally out of line with any other measurements for that contaminant. Although there were several suspect measurements, we did not eliminate any of those but did note which ones look suspect.

The majority of the measurements taken over the past 15 years were collected in accordance with modern quality assurance procedures (Dirkes et al. 1994). Because the data used in the screening process come from these measurements of the past 15 years, their quality is in accordance with modern quality assurance procedures. All data recorded in the referenced studies were used in the screening process and are traceable.

In the course of the evaluations for this screening assessment, five potential constituents of concern with single, questionable, measured results were encountered with the potential to influence the selection criteria related to Columbia River water.

One of the chemicals labeled with a footnote in Table 2.5 is xylene. This chemical was identified as coming from a single sample which is thought to have been contaminated during sampling or analysis because this and other chemicals identified in that one sample are common laboratory and industrial solvents (Dirkes et al. 1993, p. 4.1). Since the suspect sample was paired with another suspect sample from upstream of the Hanford Site, which also indicated high concentrations of organic contaminants, it is unlikely that this compound has elevated concentrations in river water as a result of releases from the Hanford Site. However, in Tables 2.5, 2.9 and 2.11, xylene and other petroleum derivatives are again identified, associated with diesel fuel leaks. Therefore, the general category of diesel fuel is retained.

Four other chemicals labeled with a footnote in Tables 2.4 and 2.5 are copper, chromium, nickel, and zinc. These four metals and several more identified in Table A.3 in Appendix I-A (see SW-LD notations in the general notes column) were very near the lower limits of detection in a series of samples at the Richland pump house (Dirkes et al. 1993). This reference compared concentrations of 20 volatile organic chemicals, 19 metals, and 7 anions upstream from the Hanford Site at the Vernita Bridge and downstream from the Hanford Site at Richland. No volatile organic chemicals were routinely detected at either location. The concentrations of most metals were also very low. However, copper and nickel were each reported one time (out of nine sampling periods) as being slightly above the limit of detection. The limit of detection for copper for the Dirkes et al. 1993 study was 20 micrograms/liter. The single reported positive sample was 22 micrograms/liter. The limit of detection for nickel was 30 micrograms/liter. The single reported positive sample was 31 micrograms/liter. These values probably do not represent the actual level of river contamination. However, because these metals are identified as being of potential concern in other sources (for example, groundwater and/or sediments and/or soils), they are retained on the lists.

2.5 Discrete Radioactive Particles

Discrete radioactive particles are of concern because if you inhaled one of the most radioactive particles and it remained lodged in your nasal passage for up to 48 hours, the resulting dose to a small area of the skin in your nose would be about ten times the working limit. The working limit is 75 microcurie-hours, the limit established to prevent small radiation burns. This section relates that some discrete radioactive particles have been found and removed but assumes the possible existence of others.

The presence of small, discrete particles of radioactive material was discovered by Sula during a shoreline survey in 1978-1979 (Sula 1980). In the 1978-1979 survey, Sula reported finding 188 discrete particles of contaminated material. The majority of the discrete particles were found buried in rocky, flat areas with little or no vegetation. Sula recovered fourteen particles for special study. Laboratory analysis identified

the gamma radiations emitted from the particles to be entirely due to cobalt-60 with activities ranging from 1.7 to 24 microcuries. Sula (1980, p. 36) describes the particles as follows:

When isolated, the particles were barely visible to the naked eye, appearing as small, dark colored chips or flakes of roughly equal size. Microscopic examination of three particles showed them to be metallic appearing flakes with diameters of approximately 0.1 mm. The particles were found to vary in elemental composition, but all contained significant proportions of chromium, iron, and cobalt characteristic of the alloy stellite, used in valve and pump components in all of the production reactors.

Sula declined to predict how many particles exist in the Columbia River but did note that "the number of particles found per square meter of ground surveyed decreases as one travels downstream from the reactor areas" (Sula 1980, p. 36).

The next attempt to measure these particles came in 1993 (Cooper and Woodruff 1993). Although the area surveyed was somewhat less than that surveyed by Sula, the 1993 survey also found eleven particles: ten on one island near the reactors and one farther downstream. Two particles were recovered for further analysis. The activities of these two particles were 1.7 and 16 microcuries of cobalt-60.

Most recently, cleanup efforts on the island closest to and downstream of the 100-D Area (the island noted in both the Sula and Cooper and Woodruff surveys as having the highest concentration of particles) have recovered 103 particles with activities ranging from 0.13 to 22 microcuries of cobalt-60 and minor amounts of other Hanford radionuclides (Wade and Wendling 1994).

Cooper and Woodruff (1993) included an evaluation of the potential for radiation dose from inhalation or ingestion of a discrete particle and from external exposure. It is concluded that, although the possibility of inhalation is remote, the dose-limiting exposure pathway is the inhalation of a particle at the upper end of the range of activity that would remain lodged in the nasal passages for up to 48 hours, resulting in a dose about ten times the recommended limit for occupational exposure of this type (NCRP 1989).

Discrete particles of radioactive material, primarily cobalt-60, are included in the list of contaminants for further evaluation.

2.6 Effects from Hanford Facilities

Some Hanford facilities near the river emit radiation that is detectable on the river shoreline. Others are physically located in the river.

2.6.1 Direct Irradiation

Direct irradiation is of concern because if you boat or fish near certain facilities, the radiation dose rate is higher than in other areas. This section discusses recent measurements of radiation exposure and notes that the dose rates have fallen significantly since the N Reactor was closed in 1988.

For the last several years, the highest direct radiation exposure rates from Hanford operations observed at locations where the public currently has access have been on the Columbia River along about a 2-kilometer stretch of the southern shoreline at the 100-N Area (for example, Dirkes et al. 1994; Thatcher 1995). External radiation measurements have been reported annually in the

Hanford Site annual environmental reports for this location since 1990. The source of the elevated exposure rates is radiation from facilities located along the river in the 100-N Area. Although the public is not currently allowed access to the shoreline, the adjacent river is open to the public for recreational uses.

In 1988, EG&G Energy Measurements performed an aerial survey of direct exposure rates on the Hanford Site, including the Columbia River and adjacent facilities (EG&G 1990). A low-level, generalized increase in exposure rates is indicated for the shorelines of most of the river. The individual facilities are distinctly noticeable. The 100-N Area evidences the highest exposure rates of river locations.

Elevated dose rates at the shoreline are reported in Dirkes et al. (1994, pp. 76, 168). The highest values were measured adjacent to the N Reactor itself and also near the 1301-N Liquid Waste Disposal Facility. The highest readings along the shoreline in 1994 ranged up to about 100 microrentgen/hour in an area where background exposure rates are in the range of 7-10 microrentgen/hour. Dirkes et al. (1994, p. 75) qualify this number to be a probable overestimate. The dose rates have fallen significantly since the closure of the N Reactor in 1988. Dose rates are also elevated near the 100-K Area because of radiologically contaminated materials such as internally contaminated ion-exchange modules used in maintaining water quality in the nearby 105-KE fuel storage basin. A third area of elevated exposure rates is adjacent to the 300 Area.

In 1993, measurements were also made by boat on the Columbia River adjacent to the N Reactor facilities about 75 meters (250 feet) from the Hanford shoreline (Cooper and Woodruff 1993, p. 4.12-4.13). At this distance, the exposure rates, along a 1500-meter (5000-foot) track parallel to the river shoreline near the facility, ranged from essentially background levels (5 microrentgen/hour) to about 20 microrentgen/hour. Exposure rates on the north shore of the river across from N Reactor were all essentially background.

Washington State Department of Health staff performed a radiation survey along the 100-N Area shoreline in July 1994 and one along the opposite shoreline in February 1995. The goal of the surveys was to measure skyshine (caused by Compton scattering of gamma rays) as a result of sources of cobalt-60 and cesium-137 in the 100-N Area. Results indicated two areas of elevated exposure near the Emergency Dump Tank and the Liquid Waste Disposal Facilities. In both areas, the net maximum exposure rate is 19 microrentgen per hour, occurring along approximately 800 feet of shoreline. Analysis of the results for the opposite shoreline identified no significant increases over background.

Elevated levels of direct irradiation are included as "contaminants" to be considered in further evaluations.

2.6.2 Effluent Pipe System

Liquid effluent from the reactors was directly discharged to the main channel of the river primarily via large pipelines buried in the river bottom. At times, liquid effluent was also directly discharged via spillways on the river bank. Because of the potential for the pipelines to contain residual contamination, they were investigated in the summer of 1995. A robot was used to radiologically, chemically, and physically characterize the insides of the 100-B, 100-D, and 100-DR Areas effluent pipelines (Dunks 1995). The inspections documented each pipe's interior condition via video recording of the interior, radiation monitoring measurements, ultrasonic testing to determine the pipes' thickness, and collection of interior scale and sediment samples. Scale and sediment samples were collected with a remote-controlled arm on the robot.

Radiation monitoring in the 100-B pipeline showed no zones with greater than 1 milliroentgen/hour (lower instrument detection level). However, dose rates of 2 to 500 milliroentgen/hour were found in both 100-D and 100-DR Areas pipelines. Samples were taken of scale and sediment and analyzed for carbon-14, potassium-40, cobalt-60, nickel-63, cesium-137, europium-152, europium-154, europium-155, plutonium-238, plutonium-239/240, tritium, and uranium. The concentrations of all radionuclides were lower than the maxima in soil and sediment presented in Table 2.2. The samples were also analysed for aluminum, arsenic, barium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, vanadium, and zinc. Only iron at 100-B and 100-D Areas and chromium and mercury at 100-D Area were found in concentrations greater than soil/sediment samples shown in Table 2.2

Iron is to be expected in steel pipes. Chromium and mercury have been identified in Section 2.4 as contaminants requiring further evaluation. Thus, no additional contaminants were observed in the effluent pipelines that need to be added to the list evaluated in the screening assessment.

2.7 Groundwater Sources Distant from the Columbia River

Certain contaminants now in soil or groundwater distant from the Columbia River at Hanford may some time in the future pose a source of contamination to the river. Some distant contaminants are essentially certain to reach the river, and others are, at this time, only potential, in part because planned remedial actions will either immobilize or remove them. The contaminants that are already in groundwater are quite likely to reach the Columbia River in the future. Those

We are not using measurements of contaminants found in the groundwater farther than 500 feet from the Columbia River to select the contaminants for the screening assessment. But we did pass those contaminants through the screens and give the results in Tables 2.12 and 2.13. Sample portraits of two contaminants, tritium (hydrogen-3) and nitrate, measured in the groundwater as shown in Figures 6 and 7 of the Site Characterization section. While contaminants in groundwater farther than 500 feet from the Columbia River are not yet entering the Columbia River, they have the potential to do so within 10 to 200 years. In this section, we also discuss what actions are being taken to impede the contaminants from reaching the river.

contaminants contained in Hanford tank farms or burial grounds may or may not pose a future hazard. For the screening assessment, only those currently in the groundwater as defined in Section 2.7.1 are considered. Brief reference is given in Section 2.7.2 to documentation of the other categories of materials.

2.7.1 Existing Groundwater Plumes

More than 105 plumes, containing 20 contaminants, are readily observable in groundwater beneath the Hanford Site (Ford 1993; DOE 1994b). A summary of the nature of the existing groundwater contaminant plumes, their general locations, and maximum measured concentrations is given in Table 2.3. Maps of these plumes are provided in Ford (1993), DOE (1994b), and Dirkes et al. (1994). Note that each of the authors of these reports draws the outlines of the plumes somewhat differently, depending on the purpose of the reports. Examples of two of the most widely dispersed contaminants, tritium (hydrogen-3) and nitrate, are shown in Figures 6 and 7 of the Site Characterization section.

Because contaminant plumes distant from the Columbia River are not in direct contact with the river, they do not yet constitute a source of contaminants in the river. The window for future concern varies depending both on the location of the plumes and the material in them. Groundwater travel times from the current location to discharge in the river vary by location. Travel times in the 100 Areas generally are less than 1 year. Travel times for groundwater carrying the plumes in the 200 East Area are generally in the range of 20 to 200 years. Travel times for the contaminants in the 600 Area evolving from the Central Landfill Site are probably about 10 years. Travel times for plumes in the 200 West Area may be as long as 80 to 300 years (Freshley and Graham 1988). All of these estimated times depend on future groundwater conditions and influences such as quantity of water discharged from Hanford operating facilities.

Most of the contaminants listed in Table 2.3 are relatively mobile in groundwater. However, cobalt-60, strontium-90, and cesium-137 interact chemically with the soil and move much more slowly than the groundwater. (They exist in the groundwater in the 200 Areas because they were essentially injected there directly during waste disposal rather than arriving via percolation from a surface source.) The chemical interactions add to the delay that these materials will experience, particularly those in the distant 200 Areas, before the plumes begin to discharge to the Columbia River. Because the half-lives of cobalt-60 (5.3 years), strontium-90 (28.8 years), and cesium-137 (30.2 years) are relatively short compared to the travel time from the 200 Areas to the Columbia River (including sorption effects), they are expected to decay before reaching the river. The strontium-90 in distant plumes in the 100 Areas will likely reach the river or continue to enter the river as is the case at the 100-N Area.

Application of the equations and assumptions defined in Section 2.3.2 to the groundwater plumes resulted in a series of complementary but not necessarily intercomparable screening values for each contaminant.

The overall screening results for existing groundwater plumes away from the river are given in Table 2.12 for those related to human health and Table 2.13 for those related to ecological risk.

Table 2.12. Contaminants of Potential Interest Related to Human Health
Identified via Screening of Existing Groundwater Plumes
Away from the Columbia River

Radionuclide Screening	Carcinogenic Chemical Screening	Hazard Index Screening
Tritium (Hydrogen-3)	Carbon Tetrachloride	Nitrate
Cobalt-60	Chloroform	
Strontium-90	Trichloroethylene	
Technetium-99		
Iodine-129		
Cesium-137		
Uranium-234/238		
Plutonium-239/240		

Table 2.13. Contaminants of Potential Interest Related to Ecological Risk
Identified via Screening of Existing Groundwater Plumes
Away from the Columbia River

Ambient Water Quality Criteria Screening	Aquatic Toxicant Threshold Screening	Aquatic Biota LC₅₀ Screening	Embryonic and Juvenile Fish LC₅₀ Screening	Aquatic Biota Dose Screening
Chromium Cyanide	Fluorides	Nitrates	Chromium	Cesium-137 Uranium-234 Uranium-238

2.7.2 Potential Future Groundwater Sources

The scope of the screening assessment involves the current conditions of the Hanford Reach of the Columbia River. A very large number of radionuclides and chemicals are contained in Hanford facilities, waste management sites, or other contaminated areas. The radionuclides and chemicals are present in varying amounts and with varying potential for release to the environment. The following information is provided for readers interested in possible future releases. This information was not used directly to determine the list of contaminants evaluated in the screening assessment. Remedial actions are planned or

under way by DOE under the provisions of the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1994) to bring the Hanford Site into compliance with the applicable requirements of CERCLA (42 USC 9601), RCRA (42 USC 6901), and the Washington State Hazardous Waste Management Act (RCW 1985). The DOE program responsible for conducting remedial actions at the Hanford Site is referred to as the Richland Environmental Restoration Project. The scope of the Richland Environmental Restoration Project (DOE 1994h) encompasses the following groups of actions:

- ◆ radiation area remedial actions/underground storage tanks (UST)
- ◆ RCRA closures
- ◆ single-shell tank (SST) closures
- ◆ past-practice site operable unit (source and groundwater) remedial actions
- ◆ surplus facilities decontamination and decommissioning
- ◆ storage and disposal facilities

Radiation area remedial actions address the management and control of inactive waste sites to minimize the spread of surface soil contamination. The UST program addresses the management of state-regulated, non-radioactive USTs in accordance with Washington State regulations. RCRA closures address actions at certain waste management units classified under RCRA as treatment, storage, and disposal units (TSD). (At Hanford there are over 50 groups of TSD units.) Units subject to regulation as TSDs must either receive a RCRA operating permit or be closed in accordance with the RCRA closure process.

Single-shell tank closures address the development and implementation of final disposal of the 149 single-shell tanks at Hanford. The tank waste remediation system environmental impact statement addresses the management, treatment, storage, and disposal of waste in the single-shell tanks (DOE 1996b).

Past-practice operable unit remedial actions address the investigation and remediation of units where waste or other substances have been disposed (intentionally or unintentionally) and are not subject to regulation as TSDs. Over 1000 past-practice units have been identified at the Hanford Site (Ecology et al. 1994).

The Surplus Facilities Decontamination and Decommissioning Program addresses the safe management and final disposition of facilities, such as surplus production reactors and chemical processing buildings, that have been retired and declared surplus. Decontamination and decommissioning of the reactors along the Columbia River are addressed in the *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington (Final Environmental Impact Statement)* (DOE 1992c). Storage and disposal facilities address the planning, construction, and operation of facilities required for the success of the Richland Environmental Restoration Project (DOE 1994h). These facilities are being addressed individually through CERCLA (42 USC 9601 et seq.), RCRA (42 USC 6901 et seq.), and NEPA 42 USC 4321 et seq. requirements.

Descriptions of the various potential impacts and releases to the Columbia River from the Richland Environmental Restoration Project (DOE 1994h) are provided in the *Hanford Remedial Action*

Environmental Impact Statement (DOE 1994g). In addition to the Richland Environmental Restoration Project efforts (DOE 1994h), additional documentation on high-level waste and transuranic waste facilities is covered in the *Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes, Hanford Site, Richland, Washington* (DOE 1987).

The future of the many existing waste sites is undergoing review. Very few will remain in their current condition. It is nearly impossible to predict the future impact of these sites until additional planning and activities occur. The reader is directed to the various references for further information on the potential contaminants and their potential future impact on the Columbia River.

2.8 Contaminants Selected for the Screening Assessment

More than 600 different radionuclides or chemicals have been sought in Hanford-related environmental samples. A large number of potential contaminants have never been detected in the Hanford/Columbia River environments. For the roughly 100 compounds that have been detected at some level, screening on the basis of potential impact on human health or the health of Columbia River ecosystems was performed. Eight different types of screens were employed, each designed to support a screening assessment of the current state of the river. (For a comprehensive assessment, other potential sources of contamination would also be evaluated; for example, waste tanks, other facilities, vadose zone sources). The results of the screens were robust in that the same compounds were identified numerous times by the eight screens. Application of the screens for contaminants in the operating areas and other areas within 150 meters (500 feet) of the Columbia River yielded a list (derived from Tables 2.4-2.11) of potential contaminants for analysis in the screening assessment, plus direct irradiation and discrete radioactive particles.

In this section, we list the 23 contaminants (Table 2.14) that passed the screen and so were used in our assessment of potential risk to humans and the environment. When we initially applied the 8 screens, we identified 31 contaminants to evaluate in the screening assessment. However, by applying the limited scope for the screening assessment defined by the CRCIA Team, 8 of the 31 contaminants appeared to be out of scope and so were eliminated.

Existing Hanford groundwater contamination outside the 100 and 300 Areas farther than 150 meters (500 feet) away from the Columbia River was also addressed. Some of the contaminants identified by this portion of the screening process (Tables 2.12 and 2.13) are not yet entering the Columbia River but have the potential to do so within 10 to 200 years (Freshley and Graham 1988). Some contaminants are common with those identified as being already in or near the river, and some (for example, carbon tetrachloride and trichloroethylene) are unique. Of the 14 contaminants identified by the 8 screens for the sources far from the river, 8 are duplicates of those identified from the near-river sources.

When the eight screens were applied to the data sources, 31 contaminants were identified for potential evaluation during the screening assessment. However, by applying the limited scope for the screening assessment defined by the CRCIA Team, 8 of the 31 contaminants appeared to be out of scope. The 8 contaminants identified in the contaminant screening process but which are out of scope are listed below, including the rationale for their elimination. The contaminants eliminated from evaluation in the screening

assessment may well be evaluated in a comprehensive impact assessment. See Part II of this report for a discussion of the requirements for a comprehensive assessment.

Arochlor 1248 - This polychlorinated biphenyl (PCB) and others like it have been identified in a number of contaminated soil sites associated with electrical transformers. The predominant risk to human health and the environment associated with these sites concerns use in upland areas, not risk to the groundwater or the Columbia River. PCBs have not been detected in samples from groundwater wells located in the screening assessment study area (0.8 kilometer/0.5 mile in from the river between Priest Rapids Dam and McNary Dam). Based on historical data from wells, which did not indicate the presence of PCBs, this constituent was not included in the suite of analyses for riverbank seepage samples collected as part of the limited field investigation for the 100 Areas (DOE 1992a). Cleanup of these sites will be driven by the need to protect upland receptors. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Carbon tetrachloride - The process to identify contaminants for the screening assessment included groundwater data from anywhere on site, regardless of distance from the Columbia River. By contrast, the calculations of risk for the screening assessment are limited to data associated with the river corridor. Because carbon tetrachloride is in the groundwater under the 200 Areas at substantial concentrations of up to 6.5 ppm (Ford 1993), it was included in the contaminant screening process. However, carbon tetrachloride has not migrated away from the 200 Areas and is many years away from the river corridor (Dirkes and Hanf 1995). Hence, it is not evaluated in the screening assessment, which focuses on the current state of the river.

Chlordane - This pesticide has been identified as a soil contaminant. The predominant risk to human health and the environment associated with chlordane in soil is for users of upland areas, not risk to the groundwater or the Columbia River. Chlordane has not been detected in samples from groundwater wells located in the screening assessment study area (0.8 kilometer/0.5 mile in from the river between Priest Rapids Dam and McNary Dam). Based on historical data from wells, which did not indicate the presence of pesticides and herbicides, this constituent was not included in the suite of analyses for riverbank seepage samples collected as part of the limited field investigation for the 100 Areas (DOE 1992a). The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Chloroform - This compound was identified as a potential hazard in groundwater away from the river. The much lower concentrations identified as being near the river were not identified as high priority pollutants by the screening process. With the focus of the screening assessment on contaminants of current potential risk and because the more elevated concentrations in the 200 Areas are as yet far from the river (Dirkes and Hanf 1995), this contaminant was eliminated from evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Fluorides - This chemical compound was identified in groundwater both near and away from the river. Near the river, it was identified in concentrations only slightly elevated (less than three times) above

background levels. Because the more elevated concentrations in the 200 Areas are as yet far from the river (Dirkes and Hanf 1995; Ford 1993), this contaminant was eliminated from current evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Plutonium - This contaminant was identified as having very low concentrations in near-river groundwater and soils (undetectable in surface or groundwater, 0.071 pCi/g in sediment, up to 230 pCi/g in soils - see Table A.1 in Appendix I-A). Higher concentrations in limited areas of the 200 Areas groundwater (up to 69 pCi/L) were sufficient to cause the radionuclide to be identified by the screening process. With the focus of the initial phase on contaminants of current potential risk and because the more elevated concentrations in the 200 Areas are as yet far from the river (Dirkes and Hanf 1995; Ford 1993), this contaminant was eliminated from evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Silver chloride - This contaminant was identified as extremely elevated in a single area of soil contamination in the 300 Area. This single area is over 100 times more contaminated with silver than any other area. The predominant risk to human health and the environment associated with silver in soil is for users of upland areas, not risk to the groundwater or the Columbia River. Cleanup of this site will be driven by the need to protect upland receptors. Silver has not been detected in samples from groundwater wells located in the screening assessment study area (0.8 kilometer/0.5 mile in from the river between Priest Rapids Dam and McNary Dam) nor in samples of riverbank seepage and sediment associated with seepage, which were collected as part of the limited field investigation for the 100 Areas (DOE 1992a). The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Trichloroethylene - This compound was identified as a potential hazard in groundwater away from the river. The roughly equivalent concentrations identified as being near the river were not identified as high priority pollutants by the screening process. This is an artifact produced because the screens cannot be directly compared. With the focus of the initial phase on contaminants of current potential risk and because the concentrations in the 200 Areas are essentially the same as those near the river, this contaminant was eliminated from evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Two contaminants listed in Table 2.12, tritium (hydrogen-3) and technetium-99, could possibly also be eliminated using the logic described above for chloroform, fluorides, and plutonium. The groundwater concentrations of these radionuclides are highest in the 200 Areas, as yet far from the Columbia River (Dirkes and Hanf 1995). However, because of public interest and because the 200 Area plumes of these contaminants have been shown to discharge to the Columbia River (Dirkes and Hanf 1995), it is deemed prudent to retain them in the list of contaminants considered.

With the elimination of the above contaminants, the remaining contaminants (see Table 2.14) are those to be evaluated in the screening assessment of potential risk.

Table 2.14. Contaminants Identified for Evaluation in the Screening Assessment^(a)

Radionuclides	Carcinogenic Chemicals	Toxic Chemicals
Tritium (Hydrogen-3) Carbon-14 Cobalt-60 Strontium-90 Technetium-99 Iodine-129 Cesium-137 Europium-152 Europium-154 Uranium 234/238 Neptunium-237	Benzene Chromium	Ammonia Chromium Copper Cyanide Diesel (constituents) Lead Mercury Nickel Nitrates/nitrites Phosphates Sulfates Zinc
(a) Direct irradiation and discrete radioactive particles will also be evaluated.

3.0 Data for the Screening Assessment

This section explains the process of gathering data and provides the data that were used in the ecological (Section 4.2) and human health (Section 5.2) screening assessments.

3.1 Scope

The Columbia River has been the focus of environmental monitoring programs for five decades.

The scope of the data task is to compile data collected by the various monitoring programs for the contaminants of interest. Because the scope of the assessment is the current state of the river, January 1990 was selected as the earliest date for which data would be collected. Data after January 1990 reflect both current conditions and high quality monitoring methods.

The media for which data on contaminant concentrations were needed for the ecological and human health screening assessment calculations are groundwater, sediment, seeps, and surface water. In addition, external radiation data were needed for the human health assessment. Some of the data available but not complete enough for assessment purposes are contaminant concentrations in biota, cobalt-60 particles, drive point groundwater data for chromium, N Springs punch point water data, and pore water data for chromium. These data were used in limited calculations and model validation exercises.

3.2 Approach

All defining decisions for the collection and processing of the data were made with CRCIA Team concurrence. All team decisions relating to the efforts of the data task are presented in Table 3.1.

A Geographic Information System was used to assist in implementing the processing of the data for the screening assessment. The Geographic Information System is a computerized system designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. Many software packages exist that perform basic Geographic Information System functions. Arc/Info Rev. 7.0.2 was used for the data task (ESRI 1994).

For the screening assessment, we needed to find information (monitoring data) about the

- ◆ 26 contaminants (28 when accounting for various constituents of those contaminants for which data were available) potentially in
- ◆ 4 media (groundwater, sediment, seeps, surface water) plus external radiation at
- ◆ 27 segments (areas) along the Hanford Reach of the Columbia River

The data needed to be

- ◆ Found, gathered, and identified according to the segment in which the data originated (see Section 3.3) and
- ◆ Selected for use (See Section 3.4) in the screening assessment

For each of these steps, we consulted and reached consensus with the CRCIA Team on how best to proceed.

Table 3.1. Data Decisions by the CRCIA Team

Date	Decision
1/30/96	Agreement was reached to collect data from January 1, 1990 to present and fill data gaps with older data where it is available for the initial phase of the screening assessment.
1/30/96	The primary geographic focus area for the screening assessment is from the vicinity of Priest Rapids Dam to McNary Dam. A rationale will be provided justifying this area by including in the report a discussion of historical levels/trends in contaminant data over time showing levels typically upstream of McNary, including Hanford data, Oregon data, and Washington data.
2/13/96	All data will be provided on a diskette in the final report.
2/13/96	There will be no soil medium. Soil data will be generated from other media where needed. There are no soil samples associated with the outfall pipe locations, and no other soil data were needed for the screening assessments.
2/13/96	The river (between Priest Rapids Dam and McNary Dam) will be broken into 27 segments. This partially defines the spatial aggregation of the data.
2/13/96	Corridor widths were chosen by segment based on sampling sites available to characterize contamination. Reactor areas 100 B/C, D, F, H, K, N and the 300 Area have 0.4-kilometer (1/4-mile) corridor widths. (N Reactor width was originally 0.8 kilometer but changed to 0.4 kilometer at 3/5/96 CRCIA Team meeting.) The non-trench portion of the 100-K Area has a 0.6-kilometer (3/8-mile) corridor width. All other segments have a 0.8-kilometer (1/2-mile) width. This completes the definition of the spatial aggregation of the data.
2/13/96	A representative value for each groundwater well in each segment will be chosen. A mechanized process needs to be developed to choose the representative value. It is expected that the mechanized process will be adequate for about 80 percent of the values. Remaining values will need to be looked at by hand. A team was formed to develop the algorithm.
2/20/96	Where there is a clear upward or downward trend, a representative value will be chosen from the most recent data.
2/20/96	The maximum representative value for each data set should be an observed data point.
2/20/96	The set of representative data in each segment for each medium will be assumed to be lognormally distributed. The parameters for the lognormal distribution will be estimated from the representative data. Log-probability plots will be provided.
2/20/96	Data for both filtered and unfiltered water will be used in the identification of representative data and in determining the parameters for the lognormal distribution.
2/27/96	Dixon's test will be used to eliminate, at most, a single outlier data point in each data set. In the data section of the final report, every data point that is eliminated will be explained.
2/27/96	For the elimination of outliers, log transformation of the data will be used.
8/12/96	If no groundwater data are available, no other data will be substituted for the missing data. Substitute data would be used for sediment, seep water (groundwater data as a surrogate where available), and surface water. For surface water, if no measured data are available for Segment 1, extrapolate from Segment 2 if available; in Segments 2-27, extrapolate from the nearest upstream segment with measured data.
10/1/96	Proposed system for substituting data when no sediment data are available is not workable so no substitutions will be made.

3.2.1 Segmentation

The ecological and human health screening assessments calculate potential risk based on contributions from multiple pathways affected by contaminant concentrations in multiple media. These contaminant concentrations were not usually measured in a fashion that would allow a complete assessment at every sampling site. To provide data for the assessments, it was necessary to aggregate data to represent concentrations in areas rather than at points. This was done through the technique of river segmentation. Segmentation is a process using knowledge of contaminant sources and physical characteristics to localize risk results.

Staff from DOE, Ecology, and EPA defined 27 segments within the study area from Priest Rapids Dam down to McNary Dam (see Figure 3.1). A segment is a section of the river over which contaminant conditions can be expected to be similar and which captures the major influences to the Columbia River. The main resources used to decide how to most appropriately segment the river were a groundwater well location map (Dresel et al. 1995), the radiological and chemical contaminant plume maps from the 1994 Hanford Site groundwater monitoring report (Dresel et al. 1995), the Surface Environmental Surveillance Project spring monitoring locations information (unpublished information at PNNL), the maps of sampling locations for the special chromium studies being conducted by the Environmental Restoration Contractor at the 100-H Area (Hope and Peterson 1995) and 100-D Area (Hope and Peterson 1996), and Ecology and EPA staff knowledge of the contaminant sources.

Because many contaminant sources are located in the reactor areas, each reactor area was examined to determine if a single segment could be designed around it or whether it should be further divided. When this decision was made, the resources listed above were used to determine the upstream and downstream cutoff points for these segments. This process was continued for other major features of the river, such as the sloughs and the confluence points of the Yakima, Snake, and Walla Walla rivers.

3.2.2 Thiessen Polygon Analysis

A Thiessen polygon analysis was used to define the area of influence of the data from a groundwater well and, thereby, refine the segmentation of the river. Thiessen analyses apportion points into polygonal regions such that each region contains only one point. Each region has the unique property that any location within a region is closer to the region's point than to any other point (Thiessen and Alter 1911). In this study, the points used for the analysis are the groundwater well locations.

Adjustments to segment boundaries were based on the Thiessen analysis for two reasons. First, it was desirable for the polygons within a segment to be of similar size so that each well is used to represent the contaminant concentration over an area of similar size. When polygon sizes became large relative to the other polygons in the segment, then the large polygon was clipped and the space was added to neighboring segments. This phenomenon occurs with the outer most wells in a data dense area when that data dense

Figure 3.1. Segmentation of the Columbia River and Groundwater Corridors

area borders an area with few or no wells. The additional space was then added to a data sparse segment. An example of this type of adjustment can be seen in Figure 3.2 for the upstream boundary of Segment 18.

Second, the original segment boundaries were drawn perpendicular to the river shore. To better reflect the areas of well influence, the polygon lines were used to represent the segment boundaries. Examples of this type of adjustment can be seen in Figure 3.3 for both the upstream and downstream boundaries of Segment 3.

3.2.3 Corridor

Corridors for gathering data were established as a distance from the river shore for all media. This corridor width was used in gathering the data that were relevant to an assessment of the Columbia River. However, these corridors are not indicative of the spatial scope of the screening assessment calculations. The screening assessment applies to the Columbia River and the riparian zone.

Figure 3.2. Example of Segment Boundary Adjustment Using the Thiessen Analysis to Reduce Data Sparse Portions of Segments

Figure 3.3. Example of Segment Boundary Adjustment Using the Thiessen Analysis to Better Reflect Areas of Influence from Wells

Data for all media were initially gathered from a corridor up to 0.8 kilometer (1/2-mile) on either side of the Columbia River. For sediment, seeps, surface water, and external radiation, all data within 0.8 kilometer of the river were used. For the groundwater data, it was necessary to use only the portion of these data that would be relevant to estimating the contaminant concentrations entering the Columbia River from the Hanford Site. This was done by assigning a groundwater corridor width to the Hanford side of Segments 1-21. No groundwater data below the City of Richland would be relevant to estimating Hanford impact on the Columbia River. The corridor width was based on having sufficient groundwater data to characterize the contamination within a segment. These corridor width decisions were made by staff from DOE, Ecology, and EPA with concurrence by the CRCIA Team. The corridor widths for groundwater data are as follows. Segments 2 (100-B/C Area), 5 (116-K-2 trench in 100-K Area), 6 (100-N Area), 7 and 8 (100-D Area), 10 (100-H Area), 13 (100-F Area), and 20 (300 Area) have a 0.4-kilometer (1/4-mile) corridor width. Segment 4 (100-K Area) has a 0.6-kilometer (3/8-mile) corridor width. All other segments have a 0.8-kilometer (1/2-mile) width (Figure 3.1). These groundwater corridor widths are measured from the Columbia River shoreline inland onto the Hanford Site.

3.2.4 Distribution Assumption

All environmental concentration data used in the screening assessment were assumed to be lognormally distributed. Environmental data tend to be positive and are often highly skewed. The assumption of lognormality also forces sampling of the upper tail of the distribution. This assumption tends to represent the observed data well when a lot of concentration measurements with consistent analysis procedures are available. The assumption is not as accurate in cases where analysis techniques vary, detection limits vary, and only a small number of analyses are available.

Some examples of frequency histograms of observed data are given in Figures 3.4 through 3.7. The first two examples are the concentration frequency of occurrence data for chromium in groundwater (Figure 3.4) and surface water (Figure 3.5), respectively, at the 100-N Area (Segment 6). The second two examples are the concentration frequency of occurrence for cobalt-60 in groundwater at the 300 Area.

In the example for chromium in the groundwater, there were 464 measurements, all analyzed with the same analytical technique. In the chromium surface water example, there were only 23 measurements, and 4 of these had contaminated laboratory blanks associated with them. The measurements of 18 $\mu\text{g/liter}$ and 19 $\mu\text{g/liter}$ were all associated with the contaminated laboratory blanks.

The two examples showing frequency distribution for cobalt-60 in the groundwater at the 300 Area demonstrate the problems that occur due to data being collected for different purposes. Figure 3.6 shows all of the observed data in the data set. The bimodal distribution of the data is due to a much higher detection limit for the data at the higher concentrations. These data were all flagged as undetected because the counting procedure was not designed to detect low concentrations of cobalt-60. Figure 3.7 shows the data set with only the data analyzed with the lower detection limit.

3.3 Data Gathering

Many data have been collected that are relevant to the Columbia River environment and CRCIA. The data task gathered the existing data that fell within the scope of the geographical area and time period of the screening assessment.

One exception is the data for the effluent pipe system (see Section 2.6.2). Water used to cool the nuclear reactors was discharged into the central portion of the Columbia River via an effluent pipe system, which had pipelines buried in the river bottom. The liquid effluent passing through these pipelines has resulted in residual radioactive and chemical contamination. Several surveys of selected pipelines have documented chemically and radiologically contaminated scale on the inside of the pipelines and particulate

Both Hanford and non-Hanford organizations had data that met the data selection criteria of the screening assessment:

- ◆ collected between the vicinity of Priest Rapids Dam and McNary Dam
- ◆ collected between January 1990 and August 1996

Data were supplied by the City of Pasco, City of Richland, Hanford Site, Oregon State Department of Energy, U.S. Army Corps of Engineers, U.S. Geological Survey, Washington Public Power Supply System, Washington State Department of Ecology, Washington State Department of Health.

Figure 3.4 Frequency Histogram for Chromium in Groundwater at 100-N Area (Segment 6)

Figure 3.5 Frequency Histogram for Chromium in Surface Water at 100-N Area (Segment 6)

contamination lying along the bottom of the pipelines. A video survey documented the structural integrity. Scrapings of the scale were analyzed for chemicals and radionuclides, and radiological surveys logged the dose within the pipelines (Dunks 1995). The limited data that resulted from the surveys suggest more chemical than radiological contamination exists at potentially biologically significant concentrations if the material were in biologically available form and if exposure pathways exist. However, the higher concentrations of contamination are encrusted in scale on the insides of the pipelines. Currently the pipelines are believed to be relatively intact, resulting in the outlet of the pipe being the only significant access point for aquatic life with perhaps occasional access points at failed joints or other weak points.

Figure 3.6 Frequency Histogram for Cobalt-60 in Groundwater at 300 Area (Segment 20) Depicting Two Detection Limits

Figure 3.7. Frequency Histogram for Cobalt-60 in Groundwater at 300 Area (Segment 20) Depicting One Detection Limit

Because of the suspected limited interaction of river aquatic life with the interior pipeline micro environment and the probable limited bioavailability of the encrusted contamination, Tri-Party managers have not considered the pipelines a near-term high priority. However, the uncertainties associated with the assumptions of limited access and bioavailability are very large. Including the limited data from the effluent pipe system in the screening assessment without an improved understanding of actual exposure would be misleading rather than helpful in the remedial decision process. Therefore, the database for the screening assessment does not contain data from the effluent pipe system. This is an identified data need.

3.3.1 Data Gathering Process

The data gathering process involved identifying sources of environmental data, assimilating that data, and identifying the appropriate river segment to which the data applied.

3.3.1.1 Identification of Data Sources

The first step of the data gathering process was to identify sources of environmental data. A data compendium (Eslinger et al. 1994) was produced for CRCIA and was the initial step to identify existing environmental data sources associated with the Columbia River that may be of potential interest to CRCIA. The data compendium provides a collection of references as well as a discussion of data sources, descriptions of the physical format of the data, and descriptions of the search process used to identify data. Other sources of environmental data were identified by the CRCIA Team. In addition, a meeting was called with data managers and project technical leads at the Hanford Site who are familiar with river sampling activities. The purpose of this meeting was to summarize the data that had been gathered and to identify additional sources of data. This meeting was also used to determine which programs' data were stored in the Hanford Environmental Information System (HEIS).

3.3.1.2 Data Assimilation

Once the sources of environmental data were identified, data were gathered that had mostly been collected between January 1990 to June 1996. These raw data are provided in Volume II (see final publication of Volume II of the original draft data report) and are as received, which means they are sometimes incomplete. The range of sampling dates for the data that were used in the screening assessment are summarized in Table 3.2.

Table 3.2. Sampling Date Ranges

Medium	Earliest Sample Date	Latest Sample Date
Groundwater	01/02/90	06/07/96
Sediment	03/28/90	09/12/95
Seeps	09/17/91	11/19/95
Surface Water	10/24/89	01/03/96
External Radiation	01/25/90	09/29/95

With the help of the project technical leads responsible for the respective sets of data, the data were categorized by media. The data were then cross referenced with the identified contaminants. Once the data of the independent programs had been selected as appropriate for use within the scope of the screening assessment, the various data sets within a medium were combined into a single database.

3.3.1.3 Identification of Sampling Locations and Their Segments

Before the data could be processed by segment into usable input files for the ecological and human health screening assessments, the coordinates of the sampling location had to be identified and examined for accuracy. Many environmental sampling projects on the Hanford Site identify their sampling locations in a Geographic Information System. Other programs document their sampling locations on a map in a report but do not provide coordinates. Data received from HEIS generally had coordinates associated with the data and were easily downloaded into the Geographic Information System. Downloading data into the Geographic

Information System received from other sources that did not have coordinates for sample locations was a two-step process. The first step was to meet with the project technical leads to identify the sample location on a map. The second step was to digitize the sample locations using the Geographic Information System to determine coordinates.

The Geographic Information System was used to identify sampling locations that fell within the study area corridor and to identify the segment numbers of those locations. This was done using a point in polygon intersection selection process in Arc/Info (ESRI 1994). The accuracy of the coordinates assigned to a sample location varied depending on how coordinates were derived. If the coordinates were gathered through use of a global positioning system at the time of sampling, the locations can be accurate down to a meter. If locations were digitized based on a map, the coordinates are representative of the general location only. For the sample locations that were digitized, project technical leads were consulted to confirm that the segment identified was appropriate.

3.3.2 Non-Hanford Data Sources Contacted

The following non-Hanford agencies were contacted for environmental sampling data along the Columbia River for input into the screening assessment. The sources were contacted because they were identified in the data compendium (Eslinger et al. 1994) as data collectors or because they were identified by the CRCIA Team as potentially having pertinent data.

3.3.2.1 City of Richland

The City of Richland conducts most of its water sampling after the water has been treated for human consumption. This sampling is part of a monitoring program which allows the City of Richland to be in compliance with Washington State laws that mandate contaminant levels in drinking water. The City of Richland provided hard copies of the results of water inorganic chemical analyses, but most were not included in the database for the screening assessment because the analysis of the contaminants was conducted after treatment of the water. Water sample information for radiation chemical analyses was also collected from the City of Richland but was not included in the database for the screening assessment because the analysis of the contaminants was conducted after treatment and the surface water samples were taken from wells within Richland not from the Columbia River. For the City of Richland, a single 1990 sample for inorganic chemicals was included in the database for the screening assessment.

3.3.2.2 City of Pasco

The City of Pasco conducts surface water sampling both before and after treating the water for human consumption. This sampling is part of a monitoring program which allows the City of Pasco to be in compliance with Washington State laws that mandate contaminant levels in drinking water. The City of Pasco provided hard copies of the results of water sample analyses for metals from 1990-1994. Only the 1992-1994 metal data were compiled into the database for the screening assessment because the 1990 and 1991 samples were collected and analyzed subsequent to water treatment. The radiological analyses by the City of Pasco measured gross alpha and gross beta only, not any of the radiological contaminants of interest, and so were not included as part of the database for the screening assessment.

3.3.2.3 City of Umatilla

The City of Umatilla does not have an environmental sampling program and relies on the Washington and Oregon departments of health for information. The City of Umatilla takes its municipal water from deep basalt wells not from the Columbia River. No data were collected from the City of Umatilla for input into the screening assessment.

3.3.2.4 City of Hermiston

The City of Hermiston does not have an environmental sampling program and relies on the Washington and Oregon departments of health for information. At this time, the City of Hermiston takes its municipal water from wells not from the Columbia River. No data were collected from the City of Hermiston for input into the screening assessment.

3.3.2.5 Port of Umatilla

The Port of Umatilla does not have an environmental sampling program. No data were collected from the Port of Umatilla for input into the screening assessment.

3.3.2.6 Washington Public Power Supply System

The Washington Public Power Supply System (Supply System) has an environmental monitoring program which consists of the Radiological Environmental Monitoring Program and the Non-Radiological Environmental Monitoring Program. Both of these programs produce annual reports. The data are collected quarterly, and the constituents analyzed for are limited to those of interest to the Supply System. The Radiological Environmental Monitoring Program has data collected from 1990-1994 for radionuclides affecting external radiation, fish, plants/vegetables, sediment, and surface water. These data were included in the database for the screening assessment.

The Supply System is no longer required to monitor for non-radiological contaminants, and the data from previous years when monitoring was required have not been maintained electronically. Hard copies of non-radiological monitoring reports for 1990-1995 were provided by the Supply System for data input into the screening assessment.

3.3.2.7 Oregon State Department of Energy

Data collected from the Oregon State Department of Energy (ORDOE) included data for surface water, sediment, and aquatic vegetation for the McNary Dam area of the Columbia River from 1990-1993. These data were included in the database for the screening assessment. ORDOE provided additional data from McNary Dam down river that were not used because they were not within the scope of the screening assessment (Priest Rapids to McNary Dams and 1990-present). The ORDOE data are published in OHD (1994).

3.3.2.8 U.S. Army Corps of Engineers - Walla Walla and Seattle

The U.S. Army Corps of Engineers (USACE) Seattle District conducted sediment sampling along the Columbia River in the early 1980s to analyze grain size. Because the collection dates were not within the scope of the screening assessment and because contaminant concentrations were not measured, these data were not used in the screening assessment. In 1991, USACE Walla Walla District analyzed metals in sediment samples collected at the Boise Cascade and the Port of Walla Walla locations on the Columbia River. These data (USACE 1991) were included in the database for the screening assessment.

3.3.2.9 U.S. Fish and Wildlife Service

The Moses Lake Field Office of the U.S. Fish and Wildlife Service was contacted for input data. The U.S. Fish and Wildlife Service has collected data in the Saddle Mountain Lake area, but that is outside of the study area for the screening assessment. No U.S. Fish and Wildlife Service data were identified for use in the screening assessment.

3.3.2.10 Washington State Department of Fish and Wildlife

The Washington State Department of Fish and Wildlife in Kennewick was contacted for input data. No Washington State Department of Fish and Wildlife data were identified for use in the screening assessment.

3.3.2.11 Columbia River Inter Tribal Fish Commission

The Columbia River Inter Tribal Fish Commission was contacted several times in August 1996 for input data. Unfortunately, the appropriate staff to assist with identifying data and/or potential data sources were not available.

3.3.2.12 Washington State Department of Health

The Environmental Radiation Program within the Washington State Department of Health (WADOH) collects environmental data and produces annual reports containing that data. Data received from the WADOH included radiological and non-radiological data for external radiation, biota, sediment, seeps, and surface water. These data were included in the database for the screening assessment.

3.3.2.13 Oregon State Department of Environmental Quality - Portland

The Oregon State Department of Environmental Quality is currently coordinating the bi-state estuary study. The Department is only familiar with Oregon sampling along the Columbia River, which has been conducted from the McNary Dam downriver. For information above McNary Dam, the Department refers to the Washington State Department of Health. No data were collected from the Oregon State Department of Environmental Quality for input into the screening assessment.

3.3.2.14 Oregon State University - Corvallis

Two master theses from Oregon State University were reviewed for possible data input. The theses were titled "Determination of Effective Doses from Radionuclides in the Columbia River Sediments" by Renpo Wu completed in August 1994, and "A Radiological Safety Assessment for Disposal of Dredged Material from Lake Wallula" by Donald N. Stewart completed in January 1996. No new data were identified in these two theses. Theses prior to 1990 were also reviewed to see if any data gaps could be filled. No data were collected from the Oregon State University for input into the screening assessment.

3.3.2.15 Boise Cascade Corporation - Wallula

Boise Cascade Corporation currently monitors effluents for acidity/alkalinity and sediment accumulation in the Wallula Lake area of the Columbia River as required for the National Pollutant Discharge Elimination System permits. This information is reported to the Washington State Department of Ecology in Olympia. Few contaminant concentrations are measured in the Boise Cascade samples. However, metals in sediment at Lake Wallula were measured in 1992. These data (Ecology 1993) were included in the database for the screening assessment.

3.3.2.16 Washington State Department of Ecology - Olympia

The Washington State Department of Ecology in Olympia was consulted for other possible sources of data. No additional sources of information were provided and no data other than the Boise Cascade data were collected from Ecology for input into the screening assessment.

3.3.2.17 United States Geological Survey - Pasco and Portland

The United States Geological Survey (USGS) conducts environmental sampling of surface water along the Columbia River at the Vernita Bridge and the City of Richland only. Monitoring reports for 1989-1994 were collected from USGS, and surface water data from these years were included in the database for the screening assessment.

3.3.3 Hanford Data Sources

The following Hanford resources were contacted to obtain environmental sampling data along the Columbia River for input into the screening assessment.

3.3.3.1 Environmental Restoration Contractors

The Environmental Restoration Contractors (ERC - Bechtel Hanford, Inc.; CH2M Hill Hanford, Inc.; IT Hanford, Inc.; Thermo Hanford, Inc.) queried the HEIS database for environmental data relevant to the screening assessment. ERC also provided drive point (aquifer sample tube), pore, seep, and surface water data from a special chromium study along the 100-D (Hope and Peterson 1996) and 100-H (Hope and

Peterson 1995) Areas of the Hanford Site. Because of the uniqueness of the drive point and pore water sampling, these data were used for comparison purposes and were not fully analyzed in the screening assessment.

3.3.3.2 Hanford Environmental Information System

The purpose of HEIS is to provide computer-based access to Hanford Site environmental sample data (Brulotte 1994). Some of the programs that store data in HEIS are the PNNL Groundwater Monitoring Program, the PNNL Surface Environmental Surveillance Program, ERC's CERCLA remedial investigation/feasibility study programs, and the Westinghouse Hanford Company Environmental Monitoring program. Many special studies also place their data in the HEIS system.

The functions of HEIS are the assignment of sample numbers, scheduling and tracking samples, data storage, and database query and report generation. The procedures for computer access to HEIS are found in Schreck (1993), which consists of nine volumes organized by subject and area.

3.3.3.3 Pacific Northwest National Laboratory

Data collected by PNNL through the Ground Water Surveillance Project and the radiological samples for the Surface Environmental Surveillance Project (SESP) were in HEIS and used for the screening assessment. Non-radiological data were gathered from the SESP staff. In addition to the ongoing monitoring data provided by SESP, environmental data from special studies were provided for the screening assessment.

The CRCIA Project conducted sediment sampling of the Columbia River from Priest Rapids down to Bonneville Reservoir in the fall of 1994. This sampling was done in conjunction with SESP. For some locations, the data are reported as SESP monitoring data. All of the CRCIA data for sediment sampled in the study area of the screening assessment were used in the screening assessment.

3.3.3.4 Westinghouse Hanford Company

Environmental monitoring data collected by Westinghouse Hanford Company (WHC) are maintained in the HEIS database and were contained within the HEIS query ERC conducted for the screening assessment. In addition, surface water data collected in support of the National Pollutant Discharge Elimination System permit application for the 300 Area effluent treatment facility were included in the database for the screening assessment. The data from a special project at the N Area in which punch points were installed to monitor concentrations of strontium-90 and tritium (hydrogen-3) entering the Columbia River were provided. Because of the uniqueness of the punch point sampling, these data were used for comparison purposes and were not fully analyzed in the screening assessment.

3.3.4 Summary of Data Gathered

Environmental data used in the screening assessment originated from the following federal, state, municipal, and private sources (listed by medium):

- ◆ Groundwater (GW)
HEIS
- ◆ Sediment (SD)
Ecology, HEIS, ORDOE, PNNL, Supply System, USACE, WADOH
- ◆ Seeps (SP)
ERC, HEIS, PNNL, WADOH
- ◆ Surface Water (SW)
City of Pasco, City of Richland, ERC, HEIS, ORDOE, PNNL, Supply System, USGS, WADOH, WHC
- ◆ External Radiation (TLD)
PNNL, Supply System, WADOH

The abbreviations given in parentheses following the media names are used throughout this report and in naming data files. These data were processed into concentration input files (media files).

Additional data sets were used for model validation, comparison to other media, and/or special analyses that are limited in scope. The type of additional data and the data source are as follows:

- ◆ Biota
HEIS, ORDOE, PNNL, Supply System, WADOH
- ◆ Cobalt-60 Particles
PNNL
- ◆ Drive Point Groundwater and Pore Water (Chromium Data)
ERC
- ◆ N Springs Punch Point Water
WHC

3.3.4.1 Data Quality

The analytical procedures used for the environmental sampling data are known for most of the data used in the screening assessment. The following sections contain a summary of the laboratory analytical protocols under which the samples were analyzed. The analytical procedures used for the samples are given in the raw data files in Appendix A of Volume II (see final publication of Volume II of the original draft data report).

Groundwater. The groundwater data are available only from Hanford Site programs. These data fall into three major categories by program: Site-wide monitoring by PNNL, CERCLA, and RCRA. These programs all use standard laboratory methods for sample analysis. Two percent of the data were marked with an analysis protocol of "none."

Sediment. Fifty-five percent of the sediment analyses were for PNNL's SESP program. These samples were analyzed through contracts administered by PNNL using standard laboratory procedures. Thirty-two percent of the sediment data were analyzed under CERCLA procedures, and the remainder from various sources were analyzed using standard laboratory procedures.

Seeps. All of the seep data were analyzed using standard laboratory procedures. Forty-three percent of the seep data were for PNNL's SESP program, 27 percent were for CERCLA, 18 percent were other Hanford programs, and 12 percent were from miscellaneous sources.

Surface Water. Sixty-four percent of the surface water samples were analyzed for PNNL's SESP program using standard laboratory procedures. Eighteen percent of the data were analyzed by the Supply System using analytical techniques and laboratory quality assurance procedures documented in their annual environmental monitoring reports. The remainder of the data were analyzed under various agencies and programs using standard laboratory procedures.

3.3.4.2 Raw Data Files

The raw data from all sources were combined into a single Microsoft Access database for each medium. Access is a WindowsTM-based database management system that stores and retrieves data, presents information, and automates repetitive tasks. The raw data are provided in Appendix A of Volume II (see final publication of Volume II of the original draft data report) and are as received. Therefore, not all fields are available for all analyses. Some fields, such as sampling location, had to be estimated for the data evaluation. These estimated fields were not loaded into the raw data files.

Once the data were gathered we stored them in a database. This database contains the raw data. Raw data is the name we use to denote data not yet prepared for use in the screening assessment.

3.3.4.3 Raw Data Summary

The raw data are summarized by segment to show the sample coverage across the media. This summary is presented in Table 3.3. For each segment, the major feature of the segment is identified, and the number of analyses and sampling locations for each medium is given. For the groundwater, the corridor width is also presented.

Table 3.4 presents a further breakdown of the sample counts by media into the number of analyses in each medium by identified contaminant.

Table 3.3. Number of Raw Data Analyses per Medium and Segment

Segment	Segment Description	Groundwater			Sediment		Seep		Surface Water		External Radiation	
		Corridor Width	Number of Wells	Number of Analyses	Number of Locations	Number of Analyses	Number of Locations	Number of Analyses	Number of Locations	Number of Analyses	Number of Locations	Number of Analyses
1	Priest Rapids Dam	1/2 mile	3	291	28	364	0	0	13	1842	2	35
2	B/C Area	1/4 mile	3	653	8	79	6	114	2	150	2	33
3	Between B/C and K Areas	1/2 mile	1	319	2	19	1	14	1	14	0	0
4	K Reactor Area	3/8 mile	16	3867	4	45	2	34	0	0	1	23
5	K mile-long trench	1/4 mile	6	1612	3	28	2	44	2	30	0	0
6	N Area	1/4 mile	38	4936	5	38	9	144	44	554	6	278
7	Upstream D Area	1/4 mile	1	220	1	18	6	21	43	83	0	0
8	D Area	1/4 mile	9	2111	6	129	10	173	42	196	3	61
9	The Horn	1/2 mile	2	75	8	140	3	61	3	45	0	0
10	H Area	1/4 mile	20	5326	3	42	11	144	3	45	0	0
11	Between H and White Bluffs Slough	1/2 mile	0	0	1	12	0	0	0	0	1	23
12	White Bluffs Slough	1/2 mile	2	93	7	89	0	0	0	0	2	46
13	F Area	1/4 mile	9	1862	3	23	3	42	32	438	2	46
14	F Slough	1/2 mile	0	0	20	212	5	68	1	14	0	0
15	Between F and Hanford sloughs	1/2 mile	1	70	4	56	3	60	3	52	2	46
16	Hanford Slough	1/2 mile	0	0	11	142	2	42	2	42	1	4
17	Hanford Townsite	1/2 mile	7	363	4	42	3	82	35	508	3	68
18	Supply System	1/2 mile	0	0	3	78	0	0	8	2046	9	195
19	Between Supply System and 300 Area	1/2 mile	6	747	1	18	0	0	2	176	1	23
20	300 Area	1/4 mile	34	5366	5	39	5	87	10	843	6	110
21	1100 Area to Richland pumphouse	1/2 mile	5	599	6	69	0	0	49	3200	6	110
22	Pumphouse to Columbia Point	1/2 mile	0	0	2	34	0	0	0	0	0	0
23	Yakima River influence	NA	NA	NA	4	106	0	0	1	34	1	22
24	Snake River influence	NA	NA	NA	7	94	0	0	0	0	0	0
25	Boise Cascade	NA	NA	NA	2	44	0	0	0	0	0	0
26	Walla Walla River influence	NA	NA	NA	4	63	0	0	0	0	0	0
27	McNary Dam	NA	NA	NA	34	433	0	0	1	8	1	4
	Total		163	28510	186	2456	71	1130	297	10320	49	1127

Table 3.4. Number of Raw Data Analyses per Contaminant, Medium, and Segment

Table 3.4. Number of Raw Data Analyses per Contaminant, Medium, and Segment																													
Segment	Medium	Ammonia	Benzene	Carbon-14	Cesium-137	Chromium	Cobalt-60	Copper	Cyanide	Diesel oil	Europium-152	Europium-154	Iodine-129	Kerosene	Lead	Mercury	Neptunium-237	Nickel	Nitrate	Nitrite	Phosphate	Strontium-90	Sulfate	Technetium-99	Tritium (H-3)	Uranium-234	Uranium-238	Xylenes (total)	Zinc
1	GW	4	15	9	6	22	6	22	5	0	4	5	0	0	17	16	0	22	17	7	11	10	16	11	21	4	4	15	22
	SD	0	5	0	43	21	43	17	0	0	3	35	0	0	17	9	0	21	5	5	5	44	0	0	0	21	44	5	21
	SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	SW	5	39	0	207	47	207	47	9	0	0	175	21	0	25	27	0	59	35	62	35	161	50	79	167	158	158	23	46
	GW	12	28	27	16	51	16	51	12	0	12	12	1	0	48	47	0	51	30	3	12	32	28	31	30	12	12	28	51
	SD	0	0	0	8	8	8	8	0	0	3	4	0	0	5	5	0	8	0	0	0	8	0	0	4	1	5	0	8
3	SP	0	4	0	6	9	6	9	0	0	0	5	0	0	2	2	0	9	5	5	6	8	6	6	4	5	5	3	9
	SW	2	0	0	25	4	25	4	0	0	0	23	0	0	0	0	0	4	2	2	2	26	0	0	27	0	0	0	4
	GW	5	14	13	6	27	6	27	5	0	5	5	1	0	25	24	0	27	12	2	5	13	15	16	16	4	5	14	27
4	SD	0	0	0	2	2	2	2	0	0	1	1	0	0	1	1	0	2	0	0	0	2	0	0	0	0	1	0	2
	SP	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	2	1	1	1	1	1	1	1	0	0	2	
	SW	1	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	2	1	1	1	1	1	1	1	0	0	2	
5	GW	39	91	160	160	285	160	285	50	0	41	54	16	0	142	134	0	285	247	180	232	104	247	59	374	68	78	91	285
	SD	0	0	0	4	4	4	4	0	0	3	4	0	0	3	3	0	4	0	0	0	4	0	0	0	0	4	0	4
	SP	0	3	0	3	1	3	1	0	0	0	3	0	0	0	0	0	1	1	1	1	3	1	3	0	3	3	2	1
6	SW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	GW	28	55	62	46	129	46	129	31	0	33	34	4	0	99	99	0	129	61	24	55	58	65	36	107	44	54	55	129
	SD	0	0	0	3	3	3	3	0	0	3	1	0	0	1	1	0	3	0	0	0	3	0	0	0	0	1	0	3
7	SP	0	0	0	0	6	0	6	0	0	0	0	0	0	2	2	0	6	2	2	2	3	2	2	3	0	0	0	6
	SW	2	0	0	0	4	0	4	0	0	0	0	0	0	0	0	0	4	2	2	2	2	2	2	2	0	0	0	4
	GW	74	39	4	196	464	197	464	1	12	28	36	7	4	340	297	0	464	298	261	277	364	335	8	243	10	10	39	464
8	SD	0	0	0	5	5	5	5	0	0	3	0	0	0	0	0	0	5	0	0	0	5	0	0	0	0	0	0	5
	SP	0	4	0	8	12	8	12	0	0	0	6	0	0	0	0	0	12	7	7	7	13	7	11	7	4	4	3	12
	SW	5	30	0	29	29	30	29	0	0	0	29	0	0	10	0	0	29	25	25	25	44	10	34	44	39	39	20	29
9	GW	8	7	4	4	20	4	20	4	0	3	3	0	0	14	14	0	20	17	3	8	10	9	4	10	4	4	7	19
	SD	0	0	0	1	2	1	2	0	0	1	1	0	0	2	2	0	2	0	0	0	1	0	0	0	1	0	2	
	SP	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0
10	SW	0	0	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0	0	0	0	0	0	0	0
	GW	39	63	33	36	207	36	207	34	0	11	12	2	9	121	153	0	207	146	76	91	66	103	38	103	28	29	55	206
	SD	0	0	0	12	10	12	10	0	0	11	9	0	0	9	9	1	10	0	0	0	12	0	2	0	2	10	0	10
11	SP	0	5	0	7	32	7	32	0	0	0	6	0	0	2	2	0	12	18	7	7	10	7	8	4	6	6	3	12
	SW	0	1	0	24	38	24	0	0	0	0	22	0	0	0	1	0	0	38	0	0	23	0	0	24	0	0	1	0
	GW	1	2	1	1	8	1	8	1	0	0	0	1	0	3	2	0	8	5	4	4	2	4	3	4	1	1	2	8
12	SD	0	0	0	13	12	13	12	0	0	11	9	0	0	9	9	1	12	0	0	0	13	0	3	0	1	10	0	12
	SP	0	0	0	0	8	0	8	0	0	0	0	0	0	2	2	0	8	3	3	4	4	4	3	4	0	0	0	8
	SW	3	0	0	0	6	0	6	0	0	0	0	0	0	0	0	0	6	3	3	3	3	3	3	3	0	0	0	6

3.0 Data for the Screening Assessment

Segment	10 GW	11 GW	12 GW	13 GW	14 GW	15 GW	16 GW	17 GW	18 GW	SW
Ammonia	47	0	0	48	2	0	0	0	4	108
Benzene	38	0	0	90	0	0	0	0	0	0
Carbon-14	42	0	0	66	0	0	0	0	0	0
Cesium-137	65	0	0	53	0	0	0	0	0	0
Chromium	612	1	10	140	34	0	15	19	13	223
Cobalt-60	65	1	5	52	0	0	10	8	24	74
Copper	612	1	10	140	34	0	10	19	13	331
Cyanide	47	0	0	52	0	0	0	0	0	0
Diesel oil	0	0	0	0	0	0	0	0	0	0
Europium-152	7	1	6	48	0	0	10	0	0	0
Europium-154	12	0	0	48	0	0	12	0	0	0
Iodine-129	6	0	0	1	0	0	0	0	0	0
Kerosene	0	0	0	0	0	0	0	0	0	0
Lead	65	0	0	136	10	0	0	0	0	230
Mercury	63	1	4	100	2	0	0	0	0	4
Nephthium-237	0	0	0	0	0	0	0	0	0	0
Nickel	612	0	0	140	34	0	0	0	0	231
Nitrate	485	5	1	105	32	0	0	0	0	104
Nitrite	366	0	0	8	32	0	0	0	0	0
Phosphate	413	0	0	38	32	0	0	0	0	123
Strontium-90	111	0	0	70	32	0	0	0	0	0
Sulfate	437	0	0	75	20	0	0	0	0	226
Technetium-99	260	0	0	54	0	0	0	0	0	0
Tritium (H-3)	186	0	0	77	0	0	0	0	0	91
Uranium-234	63	0	0	47	30	0	0	0	0	0
Uranium-238	63	0	0	48	30	0	0	0	0	0
Xylenes (total)	38	0	0	48	20	0	0	0	0	0
Zinc	611	0	0	86	34	0	0	0	0	230

Table 3.4. (Cont'd)

Table 3.4. (Cont'd)

Segment	19		20		21		22		23		24		25		26		27		GW = Groundwater		SD = Sediment
	GW	SD	GW	SD	GW	SD	GW	SD	GW	SD	GW	SD	GW	SD	GW	SD	GW	SD	SP	SW	
Ammonia	13	31	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Benzene	13	31	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Carbon-14	0	32	1	1	0	170	396	170	396	14	0	0	0	0	0	0	0	0	0	0	
Cesium-137	32	54	1	1	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Chromium	54	32	1	1	0	396	170	396	170	3	4	3	4	3	3	3	3	3	3	3	
Cobalt-60	32	54	1	1	0	170	396	170	396	0	0	0	0	0	0	0	0	0	0	0	
Copper	54	32	1	1	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cyanide	3	3	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Diesel oil	0	3	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Europium-152	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Europium-154	7	7	1	1	0	45	17	17	2	4	3	4	3	3	3	3	3	3	3	3	
Iodine-129	7	7	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Kerosene	1	49	0	0	0	2	343	361	2	0	0	0	0	0	0	0	0	0	0	0	
Lead	44	49	1	1	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Mercury	0	44	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Neptunium-237	0	54	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Nickel	54	49	1	1	0	396	290	238	227	3	1	1	1	1	1	1	1	1	1	1	
Nitrate	49	39	1	1	0	290	238	227	227	0	0	0	0	0	0	0	0	0	0	0	
Nitrite	38	12	1	1	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Phosphate	12	42	1	1	0	148	238	148	238	7	7	7	7	7	7	7	7	7	7	7	
Strontium-90	42	19	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sulfate	19	50	0	0	0	52	194	147	147	0	0	0	0	0	0	0	0	0	0	0	
Technetium-99	50	13	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tritium (H-3)	13	31	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Uranium-234	16	31	1	1	0	186	414	186	414	0	0	0	0	0	0	0	0	0	0	0	
Uranium-238	54	31	1	1	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Xylenes (total)	31	16	1	1	0	414	396	414	396	1	3	3	3	3	3	3	3	3	3	3	
Zinc	54	31	1	1	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0

3.3.4.4 Data Sampling Locations

Each media database was queried to identify the set of unique sample locations for the data used for that medium. Some additional work was required to estimate coordinates for sampling locations whose coordinates were not given in the raw data. The coordinates for these samples locations were fed into the Geographic Information System for plotting on a map. Figure 3.8 shows all of the sampling locations used in the screening assessment for all of the media. Because of concurrent sampling (for example, for seeps and sediment) in some of the locations, not all locations are visible on the map. The media are listed in the legend in the order of plotting. The number of locations on the map is given in the legend for each medium. A map for each of the media sampling locations is also provided. These are Figure 3.9 for groundwater, Figure 3.10 for sediment, Figure 3.11 for seeps, Figure 3.12 for surface water, and Figure 3.13 for external radiation. Detailed maps with coordinate grids are provided in Appendix B of Volume II (see final publication of Volume II of the original draft data report). Each map shows a single segment and the sample locations for all media in that segment. The coordinate grid is provided so that samples may be tracked from the coordinates provided in the raw data.

3.4 Data Selection Process

This section describes the analysis process used to select concentration input for the screening assessment models from the raw concentration data. This process was repeated for each segment and for each contaminant being evaluated. The process involved choosing a maximum representative value for the concentration of each contaminant for a deterministic run and calculating the parameters that define the concentration probability density function needed for a stochastic run. The term “maximum representative value” is used to mean the highest concentration value that is considered representative of the sampling location. This maximum value was determined after an outlier test was applied to identify at most one outlier.

It was necessary to automate the data selection process. This is due to the volume of data, the desire to reduce subjectivity, and the need for repeatability of the processing. Computational techniques were applied to all concentration data to select the parameters needed for the assessment. Graphical displays (data plots) of the raw data were used to track the results of the computational techniques and identify needed modifications to final data files. These data plots are published in Appendix C of Volume II (see final publication of Volume II of the original draft data report).

3.4.1 Deterministic and Stochastic Analyses

To meet the needs of the screening assessment, data were prepared to support two types of analyses:

The CRCIA Team decided we should do both deterministic and stochastic analyses.

- ◆ A deterministic analysis means a single (conservatively high) data value is used to represent the existing condition.
- ◆ A stochastic analysis means the entire range of data values is used.

Figure 3.8. Sampling Locations for All Data Used in the Screening Assessment

Figure 3.9. Sampling Locations for Groundwater Data Used in the Screening Assessment

Figure 3.10. Sampling Locations for Sediment Data Used in the Screening Assessment

Figure 3.11. Sampling Locations for Seep Data Used in the Screening Assessment

Figure 3.12. Sampling Locations for Surface Water Data Used in the Screening Assessment

Figure 3.13. Sampling Locations for External Radiation Data Used in the Screening Assessment

- ◆ A **deterministic analysis** wherein a single calculation is performed with a single value selected for each parameter, such as a concentration value of a contaminant entering the river.
- ◆ A **stochastic analysis** wherein a set of calculations is performed over the range of some of the input parameters.

For the deterministic analysis, the maximum representative concentrations for each contaminant in each medium was used to represent the segment. For the stochastic analysis, a probability density function of the concentration parameter was assumed to be a lognormal distribution truncated at the 99th percentile. The probability density function expresses the state of knowledge about alternative values for the parameter. The particular lognormal distribution assumed is determined by specifying the geometric mean and geometric standard deviation that represent concentration data for each river segment for which risk is computed.

3.4.2 Data Evaluation Conventions

Some general data evaluation conventions were applied in the course of selecting the data and preparing it for the automated processing. These conventions are the result of CRCIA Team decisions and EPA risk assessment guidance (EPA 1990).

- ◆ Data for both filtered and unfiltered water were used in the data selection process.
- ◆ If any non-radiological datum was reported by the laboratory as “less than” the equipment detection limit, then the data value (which is the equipment detection limit) was replaced with half the reporting limit for that datum.
- ◆ Any non-radiological data value labeled with a laboratory qualifier of “R” for “rejected” was removed from the data set. These data values were marked for rejection in data validation process. Rejected radiological analyses were retained.
- ◆ Non-radiological data values labeled with a laboratory qualifier of “U” for “undetected” were not used when choosing maximum values but were considered in determining the stochastic parameters.
- ◆ If a contaminant in a medium in a segment was analyzed for but never detected, then the maximum value was set to “ND” for “not detected,” and no stochastic parameters were selected.

3.4.3 Process Used to Select Groundwater Data

One of the key parameters in the screening assessment calculations is the concentration of the contaminants in the groundwater entering the Columbia River from the Hanford Site. For the purpose of the screening assessment, Hanford groundwater data were compiled that represent water quality in the upper part of the unconfined aquifer. This hydrologic unit offers the most direct pathway for contaminants to reach environmental receptors and humans. It also is believed to contain the majority of contaminants. Where data exist for wells that monitor deeper zones, the general pattern is lower concentrations or non-existent contamination with increasing depth in the aquifer (Peterson 1994).

To estimate potential risk, we needed to

- ◆ standardize all raw data so, for instance, all units of measurement are comparable
- ◆ reduce the number of raw data for the deterministic analysis to a single data value (a maximum representative value) for each segment
- ◆ reduce the number of raw data for the stochastic analysis to a distributional shape to account for the wide variety in quality, quantity, and sources of the raw data
- ◆ prepare all raw data in a form suitable for use in the computer models

This section describes the methods we used to reduce and, thereby, select the data. Our goal was to ensure that each data value selected best represents its respective contaminant, media, and segment.

3.4.3.1 Selection of Groundwater Wells

The first step in selecting the set of groundwater wells as sources of data for the screening assessment was to identify all wells that have been sampled over the time period of interest. The next step was to use the Geographic Information System to determine which of these wells fell within the groundwater corridors specified for study. The well drilling information was then examined to determine the screening depth of the wells. Groundwater data from wells that monitor zones deeper than the upper unconfined aquifer were not included in the data compilation. Table 3.5 gives the list of wells by segment that were eliminated because they monitor at depths below the upper unconfined aquifer.

3.4.3.2 Selection of Data

This section presents the data selection process for groundwater data. The process was followed for each contaminant and river segment.

Process the Raw Data for Inconsistencies. All groundwater data used in the assessment were from HEIS. ERC supplied Microsoft Access macros to standardize the data set. These macros are described in Ford et al. (1996). In addition, all data were converted to standardized units. All non-radionuclide data were converted, if necessary, to micrograms/liter. All radionuclide data were converted, if necessary, to picocuries/liter.

Table 3.5. Groundwater Wells Eliminated as Sources of Data for the Screening Assessment

Segment	Well Name
2	199-B2-12
2	199-B3-2P
4	199-K-32B
6	199-N-69
6	199-N-80
6	199-N-8P
8	199-D8-54B
10	199-H4-12C
10	199-H4-15C
10	199-H4-2
13	199-F5-43B
20	399-1-16C
20	399-1-17C
20	399-1-9
21	699-S29-E16C

Identify at Most One Outlier. For each well, Dixon's test (Barnett and Lewis 1994) was conducted to decide if the largest data value is an outlier. The test assumes that the distribution (probability density function) of the data is normal except possibly for the potential single outlier. Because the groundwater data are assumed to be lognormally distributed, the data were log-transformed before this test was applied. If the data are lognormal, the log-transformed data will be normal as required by the test. When the data values were zero or negative, they were not used in testing the data for an outlier value.

The Dixon test examines the ratio between the difference in the largest and second largest data values and the range of the data. If this ratio is large, then the largest point is declared to be an outlier. An example of outlier data is shown in Figure 3.14. The confidence level used for the test was 0.05. Any data identified as an outlier by the Dixon test received individual attention to determine whether they should indeed be deleted from the data set. This was done through a review of the data plots (see Appendix C in final publication of Volume II of the original draft data report). All data points that were removed from the data set because they were identified as outliers are presented in Table 3.6.

Test for a Trend Over Time. After any outlier was removed, the concentration data were tested for an upward or downward trend over time using the Mann-Kendall test (Gilbert 1987). To determine what data value is representative of current conditions in a well, it was necessary to know if the well data had a consistent trend over time. The Mann-Kendall test can be used regardless of the underlying data distribution. To

Table 3.6. Outlier Data Eliminated from the Groundwater Data Set

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
1	Ammonia	80	µg/L	B070H7	HEISPROD	19-Jul-92	199-B2-13
1	Lead	38.4	µg/L	B07ZG7	HEISPROD	23-Jan-93	199-B2-13
1	Nickel	74.8	µg/L	B070H7	HEISPROD	19-Jul-92	199-B2-13
1	Mercury	0.17	µg/L	B07K64	HEISPROD	22-Oct-92	199-B2-13
1	Sulfate	50200	µg/L	B00L67	PNLGW	23-Aug-91	699-72-88
2	Nickel	122	µg/L	B0BNX6	HEISPROD	13-Apr-94	199-B3-1
2	Technetium-99	197	pCi/L	H000G134	PNLGW	1-Mar-90	199-B3-1
2	Xylenes (total)	10	µg/L	B06M65	PNLGW	7-May-92	199-B3-1
2	Ammonia	80	µg/L	B070K2	HEISPROD	18-Jul-92	199-B3-47
2	Carbon-14	130	pCi/L	B070K2	HEISPROD	18-Jul-92	199-B3-47
2	Cesium-137	12	pCi/L	B070K2	HEISPROD	18-Jul-92	199-B3-47
2	Europium-152	30	pCi/L	B07K46	HEISPROD	19-Oct-92	199-B3-47
2	Nickel	55.6	µg/L	B07K46	HEISPROD	19-Oct-92	199-B3-47
2	Sulfate	56200	µg/L	B0F8R0	HEISPROD	13-Apr-95	199-B3-47
3	Cyanide	20	µg/L	B072X9	HEISPROD	21-Jul-92	699-72-73
3	Europium-152	23	pCi/L	B070G2	HEISPROD	21-Jul-92	699-72-73
3	Mercury	0.62	µg/L	B070G5	HEISPROD	21-Jul-92	699-72-73
3	Sulfate	36300	µg/L	B072X9	HEISPROD	21-Jul-92	699-72-73
4	Chromium	2500	µg/L	B09GZ4	WHCRCRA	9-Feb-94	199-K-106A
4	Copper	2900	µg/L	B09GZ4	WHCRCRA	9-Feb-94	199-K-106A
4	Nickel	3300	µg/L	B09GZ4	WHCRCRA	9-Feb-94	199-K-106A
4	Zinc	5500	µg/L	B09GZ4	WHCRCRA	9-Feb-94	199-K-106A
4	Zinc	81	µg/L	B0C7L2	WHCRCRA	13-Jul-94	199-K-108A
4	Chromium	1900	µg/L	B0BWD9	WHCRCRA	29-Aug-94	199-K-109A
4	Copper	1800	µg/L	B0BWD9	WHCRCRA	29-Aug-94	199-K-109A
4	Nickel	2100	µg/L	B0BWD9	WHCRCRA	29-Aug-94	199-K-109A
4	Nitrite	300	µg/L	B0D5K9	WHCRCRA	3-Nov-94	199-K-109A
4	Zinc	4100	µg/L	B0BWD9	WHCRCRA	29-Aug-94	199-K-109A
4	Cyanide	20	µg/L	B088N1	HEISPROD	16-Mar-93	199-K-11
4	Tritium (H-3)	499000	pCi/L	B09ZZ2	WHCRCRA	1-Mar-94	199-K-11
4	Chromium	410	µg/L	B0C233	WHCRCRA	28-Jun-94	199-K-111A
4	Copper	460	µg/L	B0C233	WHCRCRA	28-Jun-94	199-K-111A
4	Nickel	700	µg/L	B0C233	WHCRCRA	28-Jun-94	199-K-111A

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
4	Tritium (H-3)	2480	pCi/L	B09H65	WHCRCRA	20-Jun-94	199-K-111A
4	Zinc	1100	µg/L	B0C233	WHCRCRA	28-Jun-94	199-K-111A
4	Ammonia	100	µg/L	B08L10	HEISPROD	8-Jul-93	199-K-13
4	Cyanide	20	µg/L	B08L10	HEISPROD	8-Jul-93	199-K-13
4	Europium-154	20	pCi/L	B07QT9	HEISPROD	12-Dec-92	199-K-13
4	Zinc	370	µg/L	B0DLX3	HEISPROD	17-Jan-95	199-K-13
4	Ammonia	100	µg/L	B08L40	HEISPROD	6-Jul-93	199-K-23
4	Carbon-14	170	pCi/L	B07B16	HEISPROD	29-Sep-92	199-K-23
4	Cyanide	20	µg/L	B08L40	HEISPROD	6-Jul-93	199-K-23
4	Ammonia	100	µg/L	B08L45	HEISPROD	4-Jun-93	199-K-27
4	Cyanide	20	µg/L	B08L45	HEISPROD	4-Jun-93	199-K-27
4	Carbon-14	2090	pCi/L	B0G864	HEISPROD	11-Jul-95	199-K-27
4	Europium-152	30	pCi/L	B079T6	HEISPROD	22-Sep-92	199-K-27
4	Nickel	77.6	µg/L	B07QN4	HEISPROD	5-Dec-92	199-K-27
4	Nitrate	48000	µg/L	B09F61	WHCRCRA	25-Jan-94	199-K-27
4	Nitrite	1000	µg/L	H0007B72	PNLGW	28-Feb-90	199-K-27
4	Cesium-137	9.67	pCi/L	B07J82	WHCRCRA	15-Oct-92	199-K-28
4	Nitrite	1000	µg/L	H0007BC5	PNLGW	28-Feb-90	199-K-28
4	Tritium (H-3)	4310	pCi/L	B09ZZ8	WHCRCRA	1-Mar-94	199-K-28
4	Benzene	5	µg/L	H0007BH8	PNLGW	5-Mar-90	199-K-29
4	Cesium-137	6.68	pCi/L	B09F65	WHCRCRA	19-Jan-94	199-K-29
4	Copper	89	µg/L	B09CY6	WHCRCRA	27-Oct-93	199-K-29
4	Nitrite	1000	µg/L	H0007BH8	PNLGW	5-Mar-90	199-K-29
4	Zinc	840	µg/L	B09CY6	WHCRCRA	27-Oct-93	199-K-29
4	Ammonia	100	µg/L	B08L50	HEISPROD	3-Jun-93	199-K-30
4	Cyanide	20	µg/L	B08L50	HEISPROD	3-Jun-93	199-K-30
4	Chromium	27	µg/L	B0C7L4	WHCRCRA	11-Jul-94	199-K-30
4	Copper	57	µg/L	B0G817	HEISPROD	10-Jul-95	199-K-30
4	Nitrite	1000	µg/L	H0007BN4	PNLGW	2-Mar-90	199-K-30
4	Carbon-14	200	pCi/L	B079V6	HEISPROD	23-Sep-92	199-K-31
4	Cyanide	20	µg/L	B088N5	HEISPROD	25-Mar-93	199-K-31
4	Mercury	0.29	µg/L	B079V9	HEISPROD	23-Sep-92	199-K-31
4	Nitrate	14608.44	µg/L	B08L55	HEISPROD	16-Jun-93	199-K-31
4	Tritium (H-3)	3100	pCi/L	B09W62	HEISPROD	24-Jan-94	199-K-31

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
4	Cyanide	20	µg/L	B08L60	HEISPROD	14-Jun-93	199-K-32A
4	Europium-152	30	pCi/L	B088F1	HEISPROD	17-Mar-93	199-K-32A
4	Europium-154	20	pCi/L	B088F1	HEISPROD	17-Mar-93	199-K-32A
4	Nickel	69.4	µg/L	B079W1	HEISPROD	23-Sep-92	199-K-32A
4	Zinc	278	µg/L	B079W1	HEISPROD	23-Sep-92	199-K-32A
4	Cyanide	20	µg/L	B08L70	HEISPROD	10-Jun-93	199-K-33
4	Strontium-90	4.5	pCi/L	B079X1	HEISPROD	30-Sep-92	199-K-33
4	Tritium (H-3)	35000	pCi/L	B08L70	HEISPROD	10-Jun-93	199-K-33
4	Cyanide	20	µg/L	B08L75	HEISPROD	1-Jun-93	199-K-34
4	Cyanide	20	µg/L	B09W70	HEISPROD	13-Jan-94	199-K-34
5	Carbon-14	120	pCi/L	B079R1	HEISPROD	21-Sep-92	199-K-18
5	Cyanide	20	µg/L	B08L15	HEISPROD	7-Jun-93	199-K-18
5	Europium-152	30	pCi/L	B08886	HEISPROD	19-Mar-93	199-K-18
5	Phosphate	1000	µg/L	B0DLX5	HEISPROD	4-Jan-95	199-K-18
5	Tritium (H-3)	21200	pCi/L	B0FZ55	PNLGW	7-Jul-95	199-K-18
5	Lead	2.4	µg/L	B08891	HEISPROD	13-Mar-93	199-K-19
5	Carbon-14	630	pCi/L	B079R6	HEISPROD	21-Sep-92	199-K-20
5	Chromium	261	µg/L	B08896	HEISPROD	30-Mar-93	199-K-20
5	Nickel	57.9	µg/L	B08896	HEISPROD	30-Mar-93	199-K-20
5	Cyanide	20	µg/L	B08L25	HEISPROD	9-Jun-93	199-K-20
5	Chromium	2040	µg/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Copper	195	µg/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Lead	91.9	µg/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Nickel	953	µg/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Strontium-90	100	pCi/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Uranium-238	1.1	pCi/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Zinc	168	µg/L	B088B1	HEISPROD	24-Mar-93	199-K-21
5	Mercury	0.14	µg/L	B079S6	HEISPROD	21-Sep-92	199-K-22
5	Sulfate	4100000	µg/L	B07QZ3	HEISPROD	7-Dec-92	199-K-22
5	Cyanide	20	µg/L	B08L35	HEISPROD	8-Jun-93	199-K-22
5	Benzene	10	µg/L	B07B30	HEISPROD	24-Sep-92	199-K-37
5	Phosphate	400	µg/L	B088J1	HEISPROD	23-Mar-93	199-K-37
5	Technetium-99	10.6	pCi/L	B07B40	HEISPROD	24-Sep-92	199-K-37
5	Uranium-238	3.6	pCi/L	B06M18	HEISPROD	28-May-92	199-K-37

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
6	Copper	91	µg/L	H0007C68	PNLGW	1-Feb-90	199-N-14
6	Mercury	0.36	µg/L	B09TC1	WHCRCRA	28-Feb-94	199-N-14
6	Nitrite	1000	µg/L	H0007C68	PNLGW	1-Feb-90	199-N-14
6	Phosphate	11000	µg/L	H00072X9	PNLGW	18-Sep-91	199-N-14
6	Zinc	95	µg/L	H0007C68	PNLGW	1-Feb-90	199-N-14
6	Tritium (H-3)	7350	pCi/L	B08KL6	WHCRCRA	18-May-93	199-N-16
6	Chromium	910	µg/L	B0CJ43	WHCRCRA	15-Aug-94	199-N-17
6	Nickel	650	µg/L	B0CJ43	WHCRCRA	15-Aug-94	199-N-17
6	Phosphate	1000	µg/L	H0007CS4	PNLGW	1-Feb-90	199-N-17
6	Copper	12	µg/L	B08HY5	WHCRCRA	11-May-93	199-N-2
6	Strontium-90	1960	pCi/L	H0007D87	PNLGW	2-Feb-90	199-N-2
6	Tritium (H-3)	60000	pCi/L	H0007D87	PNLGW	2-Feb-90	199-N-2
6	Zinc	77	µg/L	H0007D87	PNLGW	2-Feb-90	199-N-2
6	Chromium	24000	µg/L	B0DX98	HEISPROD	3-Mar-95	199-N-21
6	Copper	24000	µg/L	B0DX98	HEISPROD	3-Mar-95	199-N-21
6	Lead	24000	µg/L	B0DX98	HEISPROD	3-Mar-95	199-N-21
6	Nickel	24000	µg/L	B0DX98	HEISPROD	3-Mar-95	199-N-21
6	Strontium-90	4.77	pCi/L	B01VB4	PNLGW	14-Feb-92	199-N-21
6	Tritium (H-3)	5230	pCi/L	B08722	WHCRCRA	26-Feb-93	199-N-23
6	Zinc	10	µg/L	B0CJ52	WHCRCRA	17-Aug-94	199-N-23
6	Lead	11	µg/L	H0007F50	PNLGW	12-Feb-90	199-N-26
6	Tritium (H-3)	20300	pCi/L	B08KM0	WHCRCRA	21-May-93	199-N-26
6	Lead	40	µg/L	B0C235	WHCRCRA	13-Jun-94	199-N-3
6	Phosphate	1000	µg/L	H0007G71	PNLGW	14-Feb-90	199-N-3
6	Strontium-90	83500	pCi/L	B09KY0	WHCRCRA	9-Nov-93	199-N-3
6	Zinc	2400	µg/L	B0C235	WHCRCRA	13-Jun-94	199-N-3
6	Ammonia	100	µg/L	B08J71	WHCRCRA	7-May-93	199-N-47
6	Chromium	81	µg/L	B01W15	WHCRCRA	10-Feb-92	199-N-47
6	Nickel	39	µg/L	B01W15	WHCRCRA	10-Feb-92	199-N-47
6	Nitrate	894213.6	µg/L	B0GJT9	HEISPROD	7-Sep-95	199-N-51
6	Sulfate	90300	µg/L	B0GJT9	HEISPROD	7-Sep-95	199-N-51
6	Ammonia	100	µg/L	B08J74	WHCRCRA	12-May-93	199-N-54
6	Lead	11	µg/L	B01BB4	WHCRCRA	5-Nov-91	199-N-54
6	Phosphate	1000	µg/L	H0007JM9	PNLGW	1-Feb-90	199-N-54

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
6	Lead	5.5	µg/L	B01W20	WHCRCRA	10-Feb-92	199-N-55
6	Copper	44	µg/L	B00L94	WHCRCRA	5-Sep-91	199-N-56
6	Nitrite	1000	µg/L	H0007JS3	PNLGW	1-Feb-90	199-N-56
6	Phosphate	2400	µg/L	H0007JS3	PNLGW	1-Feb-90	199-N-56
6	Chromium	2500	µg/L	B0C985	WHCRCRA	6-Sep-94	199-N-57
6	Nickel	1300	µg/L	B0C985	WHCRCRA	6-Sep-94	199-N-57
6	Nickel	680	µg/L	B09KZ5	WHCRCRA	16-Nov-93	199-N-67
6	Ammonia	100	µg/L	B07P30	WHCRCRA	20-Nov-92	199-N-72
6	Lead	25	µg/L	B0BWN6	WHCRCRA	12-May-94	199-N-72
6	Ammonia	200	µg/L	B07P02	WHCRCRA	19-Nov-92	199-N-75
6	Nitrate	8900	µg/L	B0C9B0	WHCRCRA	6-Sep-94	199-N-75
6	Sulfate	25900	µg/L	B0GB60	HEISPROD	20-Jul-95	199-N-75
6	Ammonia	100	µg/L	B07P07	WHCRCRA	20-Nov-92	199-N-76
6	Strontium-90	154	pCi/L	B0GB61	HEISPROD	2-Aug-95	199-N-76
6	Xylenes (total)	1	µg/L	B0DTJ7	PNLGW	3-Mar-95	199-N-76
6	Zinc	120	µg/L	B07P07	WHCRCRA	20-Nov-92	199-N-76
6	Ammonia	500	µg/L	B07P40	WHCRCRA	19-Nov-92	199-N-77
7	Ammonia	60	µg/L	B09WW3	HEISPROD	6-Feb-94	199-D5-20
7	Europium-152	30	pCi/L	B07KZ0	HEISPROD	2-Nov-92	199-D5-20
7	Nitrate	1035871	µg/L	B0GF99	HEISPROD	14-Aug-95	199-D5-20
7	Phosphate	1000	µg/L	B0DQX9	HEISPROD	7-Feb-95	199-D5-20
8	Carbon-14	39	pCi/L	B06CF0	HEISPROD	27-May-92	199-D5-13
8	Chromium	326	µg/L	B06CL9	HEISPROD	28-May-92	199-D8-3
8	Europium-152	23	pCi/L	B07336	HEISPROD	28-Jul-92	199-D8-3
8	Cyanide	20	µg/L	B07356	HEISPROD	28-Jul-92	199-D8-3
8	Lead	56	µg/L	B0GFD7	HEISPROD	9-Aug-95	199-D8-3
8	Lead	5	µg/L	B064Z1	WHCRCRA	16-Apr-92	199-D8-4
8	Sulfate	27000	µg/L	B064Z1	WHCRCRA	16-Apr-92	199-D8-4
8	Zinc	35.8	µg/L	B0DR08	HEISPROD	14-Mar-95	199-D8-4
8	Nitrate	5000	µg/L	B0C930	WHCRCRA	9-Aug-94	199-D8-5
8	Ammonia	140	µg/L	B072C4	HEISPROD	26-Jul-92	199-D8-53
8	Cesium-137	13	pCi/L	B06CM2	HEISPROD	17-May-92	199-D8-53
8	Ammonia	240	µg/L	B072F9	HEISPROD	26-Jul-92	199-D8-54A
8	Phosphate	800	µg/L	B072F9	HEISPROD	26-Jul-92	199-D8-54A

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
8	Ammonia	260	µg/L	B072L9	HEISPROD	26-Jul-92	199-D8-55
8	Phosphate	500	µg/L	B0GFB9	HEISPROD	14-Aug-95	199-D8-55
8	Chromium	820	µg/L	B0C935	WHCRCRA	9-Aug-94	199-D8-6
8	Copper	140	µg/L	B0C935	WHCRCRA	9-Aug-94	199-D8-6
8	Lead	4	µg/L	B08LR3	WHCRCRA	1-Jun-93	199-D8-6
8	Nickel	760	µg/L	B0C935	WHCRCRA	9-Aug-94	199-D8-6
8	Cobalt-60	14	pCi/L	B07387	HEISPROD	2-Aug-92	699-97-51A
8	Nickel	23.6	µg/L	B0DQZ7	HEISPROD	6-Feb-95	699-97-51A
9	Chromium	5.1	µg/L	B0DD94	PNLGW	15-Dec-94	699-101-48B
9	Copper	7.3	µg/L	B0DD94	PNLGW	15-Dec-94	699-101-48B
9	Nitrate	960	µg/L	B0GG99	PNLGW	16-Sep-95	699-101-48B
10	Zinc	950	µg/L	B0CJG0	HEISPROD	28-Jul-94	199-H4-10
10	Nitrate	66000	µg/L	B00M20	WHCRCRA	12-Sep-91	199-H4-11
10	Nitrite	1000	µg/L	H00076J5	PNLGW	23-Apr-90	199-H4-11
10	Ammonia	100	µg/L	B091V5	HEISPROD	26-Aug-93	199-H4-15A
10	Copper	66.3	µg/L	B0G048	HEISPROD	29-Jun-95	199-H4-15A
10	Nitrate	97389.6	µg/L	B091V5	HEISPROD	26-Aug-93	199-H4-15A
10	Nitrite	1000	µg/L	H0007702	PNLGW	18-Apr-90	199-H4-15A
10	Nitrite	1000	µg/L	H0007762	PNLGW	20-Apr-90	199-H4-17
10	Sulfate	103000	µg/L	H0007762	PNLGW	20-Apr-90	199-H4-17
10	Chromium	1100	µg/L	B0CYC5	WHCRCRA	16-Sep-94	199-H4-3
10	Benzene	10	µg/L	B06CV2	HEISPROD	4-Jun-92	199-H4-4
10	Xylenes (total)	10	µg/L	B06CV2	HEISPROD	4-Jun-92	199-H4-4
10	Zinc	901	µg/L	H0007854	PNLGW	17-Jan-90	199-H4-4
10	Ammonia	70	µg/L	B072M9	HEISPROD	3-Aug-92	199-H4-45
10	Phosphate	500	µg/L	B0G055	HEISPROD	23-Jun-95	199-H4-45
10	Nickel	57.1	µg/L	B0DHN4	HEISPROD	20-Dec-94	199-H4-47
10	Phosphate	500	µg/L	B0G059	HEISPROD	22-Jun-95	199-H4-47
10	Chromium	210	µg/L	B08CP2	WHCRCRA	1-Apr-93	199-H4-5
10	Nitrite	1000	µg/L	H00078R1	PNLGW	23-Apr-90	199-H4-7
10	Tritium (H-3)	4790	pCi/L	H00072Q0	PNLGW	6-Jun-91	199-H4-7
10	Nitrite	1000	µg/L	H00078T0	PNLGW	25-Apr-90	199-H4-8
10	Sulfate	81900	µg/L	H00078T0	PNLGW	25-Apr-90	199-H4-8
10	Ammonia	290	µg/L	B072N4	HEISPROD	1-Aug-92	199-H6-1

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
10	Nitrate	1164248	µg/L	B0G067	HEISPROD	23-Jun-95	199-H6-1
10	Uranium-234	16	pCi/L	B06CQ5	HEISPROD	8-May-92	199-H6-1
10	Uranium-238	14	pCi/L	B06CQ5	HEISPROD	8-May-92	199-H6-1
12	Chromium	17	µg/L	B08QQ8	PNLGW	16-Aug-93	699-89-35
13	Ammonia	100	µg/L	B0BMP0	HEISPROD	17-May-94	199-F1-2
13	Carbon-14	82	pCi/L	B08Y11	HEISPROD	28-Jul-93	199-F1-2
13	Uranium-238	1.9	pCi/L	B08Y11	HEISPROD	28-Jul-93	199-F1-2
13	Chromium	1710	µg/L	B0BMP5	HEISPROD	18-May-94	199-F5-1
13	Lead	5.3	µg/L	B07RG7	HEISPROD	15-Dec-92	199-F5-1
13	Nickel	625	µg/L	B0BMP5	HEISPROD	18-May-94	199-F5-1
13	Chromium	30.6	µg/L	B088R0	HEISPROD	7-Apr-93	199-F5-3
13	Cobalt-60	20	pCi/L	B07RD1	HEISPROD	14-Jan-93	199-F5-3
13	Europium-154	20	pCi/L	B07RD1	HEISPROD	14-Jan-93	199-F5-3
13	Phosphate	1000	µg/L	H00074J2	PNLGW	28-Feb-90	199-F5-3
13	Ammonia	100	µg/L	B0BMR0	HEISPROD	11-May-94	199-F5-42
13	Europium-154	18	pCi/L	B0BMR0	HEISPROD	11-May-94	199-F5-42
13	Copper	13.4	µg/L	B0FK70	HEISPROD	25-May-95	199-F5-42
13	Cobalt-60	30	pCi/L	B07R56	HEISPROD	28-Jan-93	199-F5-43A
13	Europium-152	40	pCi/L	B07R56	HEISPROD	28-Jan-93	199-F5-43A
13	Technetium-99	56	pCi/L	B08Y41	HEISPROD	18-Jul-93	199-F5-43A
13	Ammonia	100	µg/L	B0BMR8	HEISPROD	11-May-94	199-F5-44
13	Phosphate	400	µg/L	B088V0	HEISPROD	1-Apr-93	199-F5-44
13	Cobalt-60	20	pCi/L	B08Y56	HEISPROD	18-Jul-93	199-F5-46
13	Europium-152	30	pCi/L	B08Y56	HEISPROD	18-Jul-93	199-F5-46
13	Europium-154	20	pCi/L	B08Y56	HEISPROD	18-Jul-93	199-F5-46
13	Cyanide	20	µg/L	B09DH0	HEISPROD	26-Oct-93	199-F5-6
13	Phosphate	1000	µg/L	H00074Z3	PNLGW	14-May-90	199-F5-6
13	Ammonia	540	µg/L	B0BMT8	HEISPROD	12-May-94	199-F6-1
13	Carbon-14	39	pCi/L	B088X5	HEISPROD	6-Apr-93	199-F6-1
13	Nitrate	4072.656	µg/L	B0BMT8	HEISPROD	12-May-94	199-F6-1
13	Copper	55.8	µg/L	B09DG2	HEISPROD	26-Oct-93	199-F6-1
17	Tritium (H-3)	153000	pCi/L	B09QB4	PNLGW	19-Jan-94	699-44-4
17	Nitrate	34900	µg/L	H00072V5	PNLGW	19-Jul-91	699-46-4
19	Nitrite	1000	µg/L	H000BSW7	PNLGW	29-May-90	399-1-18A

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
19	Ammonia	180	µg/L	B01DK8	HEISPROD	6-Dec-91	399-1-18B
19	Ammonia	190	µg/L	B01F03	HEISPROD	6-Dec-91	399-1-18C
19	Benzene	5	µg/L	H000FQZ3	PNLGW	13-Apr-90	699-S19-E13
19	Chromium	6.3	µg/L	B0DTH7	PNLGW	15-Feb-95	699-S19-E13
19	Technetium-99	48.5	pCi/L	H0007157	PNLGW	1-Feb-91	699-S19-E13
19	Xylenes (total)	5	µg/L	H000FQZ3	PNLGW	13-Apr-90	699-S19-E13
19	Technetium-99	11	pCi/L	B062H9	HEISPROD	20-Apr-92	699-S19-E14
20	Tritium (H-3)	86400	pCi/L	B01FP4	WHCRCRA	6-Dec-91	399-1-10A
20	Copper	3	µg/L	BOC1Z3	PNLGW	28-Jun-94	399-1-10B
20	Copper	28	µg/L	H00071T9	WHCRCRA	18-Jul-91	399-1-12
20	Lead	12	µg/L	B0FLN5	WHCRCRA	1-Jun-95	399-1-16A
20	Nitrite	1000	µg/L	H000BS40	PNLGW	24-May-90	399-1-16A
20	Nitrite	1000	µg/L	H000BS63	PNLGW	24-May-90	399-1-16B
20	Copper	31	µg/L	H00071V4	WHCRCRA	11-Jul-91	399-1-17A
20	Sulfate	48000	µg/L	B0DTK3	PNLGW	21-Feb-95	399-1-17A
20	Nitrite	1000	µg/L	H000BSQ8	PNLGW	22-May-90	399-1-17B
20	Ammonia	70	µg/L	B062L0	HEISPROD	30-Apr-92	399-1-21A
20	Cobalt-60	19	pCi/L	B062L0	HEISPROD	30-Apr-92	399-1-21A
20	Uranium-234	35	pCi/L	B062L0	HEISPROD	30-Apr-92	399-1-21A
20	Copper	11	µg/L	H0007090	PNLGW	18-Dec-90	399-1-6
20	Nitrate	163791.6	µg/L	B062C0	HEISPROD	27-Apr-92	399-1-6
20	Nitrite	120	µg/L	B062C0	HEISPROD	27-Apr-92	399-1-6
20	Uranium-238	160	pCi/L	B07P66	HEISPROD	13-Nov-92	399-1-7
20	Ammonia	100	µg/L	B01F11	HEISPROD	12-Dec-91	399-2-2
20	Copper	11.8	µg/L	B01F11	HEISPROD	12-Dec-91	399-2-2
20	Copper	8.8	µg/L	B01F13	HEISPROD	12-Dec-91	399-2-3
20	Lead	4.9	µg/L	B075X5	HEISPROD	11-Sep-92	399-2-3
20	Phosphate	400	µg/L	B062C7	HEISPROD	28-Apr-92	399-2-3
20	Nitrite	1000	µg/L	H000C030	PNLGW	22-May-90	399-3-10
20	Nitrate	18000	µg/L	B08ZT1	PNLGW	27-Aug-93	399-3-12
20	Tritium (H-3)	6010	pCi/L	B01DN5	HEISPROD	9-Dec-91	399-3-12
20	Uranium-238	29	pCi/L	B07P94	HEISPROD	14-Nov-92	399-3-12
20	Copper	24	µg/L	H00071W1	WHCRCRA	15-Jul-91	399-3-9
20	Nickel	18	µg/L	B062W6	HEISPROD	13-May-92	399-3-9

Table 3.6. (Cont'd)

Segment	Contaminant	Concentration	Units	Sample Number	Owner ID	Sample Date	Well Name
20	Cesium-137	13.79	pCi/L	B01DY9	HEISPROD	3-Dec-91	399-4-1
20	Copper	5	µg/L	B01DY9	HEISPROD	3-Dec-91	399-4-1
20	Chromium	16.9	µg/L	B075Z9	HEISPROD	14-Sep-92	399-4-10
20	Nickel	10.4	µg/L	B075Z9	HEISPROD	14-Sep-92	399-4-10
20	Uranium-238	56	pCi/L	B07PB2	HEISPROD	12-Nov-92	399-4-10
20	Ammonia	100	µg/L	B076C1	HEISPROD	9-Sep-92	399-4-12
20	Uranium-234	8.1	pCi/L	B062F8	HEISPROD	22-Apr-92	399-4-12
20	Uranium-238	59	pCi/L	B07P98	HEISPROD	15-Nov-92	399-4-7
20	Nickel	20	µg/L	B01DY5	HEISPROD	3-Dec-91	399-4-9
21	Sulfate	12000	µg/L	B08ZY0	PNLGW	5-Oct-93	3099-42-16
21	Ammonia	100	µg/L	B01DS8	HEISPROD	4-Dec-91	699-S29-E16A
21	Copper	11.7	µg/L	B062H0	HEISPROD	13-Apr-92	699-S29-E16A
21	Copper	6.1	µg/L	B062H3	HEISPROD	13-Apr-92	699-S29-E16B
21	Chromium	31.5	µg/L	B07627	HEISPROD	14-Sep-92	699-S30-E15A
21	Copper	10	µg/L	H000FT57F	PNLGW	21-Feb-90	699-S30-E15A
21	Sulfate	58000	µg/L	B086N9	PNLGW	11-Mar-93	699-S30-E15A
21	Tritium (H-3)	1670	pCi/L	H0007020	PNLGW	16-Oct-90	699-S30-E15A
21	Uranium-234	6.05	pCi/L	B00D51	HEISPROD	29-Nov-90	699-S30-E15A
21	Uranium-238	3.03	pCi/L	B00D51	HEISPROD	29-Nov-90	699-S30-E15A

Figure 3.15. Example of a Downward Trend in the Data for Tritium (Hydrogen-3) in Groundwater in Well 699-97-51A at the 100-D Area

Figure 3.16. Example of an Upward Trend in the Data for Nitrate in Groundwater in Well 199-N-57 at the 100-N Area

Choose a Representative Well Median. A representative median value was used in the calculation of stochastic parameters because the stochastic process requires that attention be focused on best-estimate parameter values rather than conservative (maximal) values. If an upward or downward trend was detected, the median of the most recent groundwater concentration measurements was used to represent the well. If a well does not have a trend, then no single data point is considered more representative of the well than any other point. In that case, the median of the data is the single most representative concentration value for the well. This approach leads to the most representative probability density function to describe the uncertainty about the concentration data for the river segment being studied.

Compute Segment Parameters. For the groundwater medium, the representative values for individual wells must be combined into parameters that are representative of the river segment because no single well is representative of the segment. Whereas the process for the wells combines the data over time into a single value at the various well locations, the segment process combines the values over space into representative data for the segment.

Compute the Segment Maximum. The segment maximum is the highest of the well representative maximum values. This value is the maximum of all the observed concentrations in any well in the segment. This value is used to represent the segment in the deterministic risk calculations.

Compute Stochastic Parameters. The stochastic parameters (the geometric mean and geometric standard deviation) were calculated from the set of median (best-estimate) well values in the segment. The first step in calculating the geometric mean and geometric standard deviation was to take the natural logarithm of the median well values. The arithmetic mean of the log-transformed median values was calculated and then exponentiated to obtain the geometric mean. To calculate the geometric standard deviation, the standard deviation of the log-transformed median values was calculated and then exponentiated.

When some of the data were reported as negative or null values, these data could not be log-transformed and so were replaced with substitute values to represent the presence of small data values at the lower end of the data set. Log probability plotting was used to find replacement values for the data (Gilbert 1987). The null data were plotted on a line in log space using the inverse normal statistic. The replacement values were included when computing the stochastic parameters for the segment. The data were first ranked, then a statistic was computed which is the rank in the data set divided by the number of values plus 1. The inverse normal function is applied to this statistic.

For the data with positive concentration values, the slope and intercept of the line that fit the log concentration versus the inverse normal statistic line were calculated. These values were used to find the log concentration for the rank of the negative or null concentration values. The geometric mean and geometric standard deviation were then calculated from the entire data set with the log concentrations replaced for the negative or null concentration values.

An example of the fitting process is given in Figure 3.17. This example is for chromium in well 199-N-55 in Segment 6. There were sixteen analyses for chromium, and six of them were reported as undetected with no numerical value reported. The six null values were fit to the line determined by the ten reported values, and all sixteen values were used to compute the stochastic parameters.

Some of the geometric standard deviations computed from the raw data were very large. This can occur when data over space with local high concentrations are combined. The problem is magnified by the fitting of the null or negative data using log probability plotting. While the actual measurements may be very similar, the fitted measurements will be spaced proportionally on the low end of a line. This causes the standard deviation of the log transformed data to be artificially large. Sampling from the distribution specified using the large geometric standard deviations created input data sets whose maximum values far exceeded the actual measured deterministic maximum. To ensure realism in the stochastic analyses, the geometric standard deviation was truncated such that the 99th percentile of the resulting distribution would be twice the deterministic maximum value. This technique was applied only if the truncated geometric standard deviation was greater than 4.

Figure 3.17. Example of Log Probability Plotting Used to Fit the Concentration Values

For example, the data for strontium-90 in the groundwater at Segment 4 resulted in a geometric mean of 0.02 and a geometric standard deviation of 282.3. Using this standard deviation, the stochastic routines would generate data with a 99th percentile in excess of 80,000 picocuries/liter. The actual maximum concentration observed in the segment is 803 picocuries/liter. In this case, the geometric standard deviation was truncated so that the 99th percentile of the stochastic distribution is 1606. This resulted in a truncated geometric standard deviation of 128. The list of truncated standard deviations is given in Table 3.7.

3.4.4 Process Used to Select Data for Other Media

For the sediment, seeps, surface water, and external radiation media, sampling locations within a segment cannot be easily pinpointed. Sampling locations tend to be regions rather than distinct locations such as a well. Also, in any one sampling period, there are few sampling events within a segment. Because the sampling does not occur at discrete locations for multiple times, it is not necessary to combine the data for a sampling location over time before calculating segment values.

The methods we used to select groundwater data are more complex than those used to select sediment, seep, surface water, and external radiation data because the groundwater sampling locations are fixed, well known, and have provided an abundance of data. This is in contrast to the sampling locations for the other media which are not fixed, often not known, and have provided less data. The goal in both methods, however, is to estimate the concentrations of the contaminants for each entire segment for which we have data.

3.4.4.1 Process the Raw Data for Inconsistencies

The data for all media other than groundwater were processed to remove inconsistencies. The number of programs from which data were used for media other than groundwater means that reporting differences produced many inconsistencies. Once again, units were standardized for various contaminants to produce concentrations in micrograms/liter or micrograms/kilogram for non-radiological concentration, and picocuries/liter or picocuries/kilogram for radiological concentrations.

3.4.4.2 Identify at Most One Outlier

For each segment, Dixon's test (Barnett and Lewis 1994) was conducted to decide if the largest datum was an outlier. This test was applied to the set of all data over all sampling locations in the segment. As with the groundwater data, the data were log-transformed before this test was applied. The Dixon test used was described in the groundwater processing section above. When the data values were zero or negative, they were not used in testing the data for an outlier. Any data identified as an outlier by the Dixon test received individual attention to determine whether they should indeed be deleted from the data set. This was done through a review of the data plots (see Appendix C in the final publication of Volume II to the draft data report). All data points that were removed from the data set because they were identified as an outlier are presented in Table 3.8.

3.4.4.3 Compute the Segment Maximum

After removing at most one outlier, the maximum detected concentration was selected as the segment maximum. This value is used for the deterministic screening assessment calculations.

Table 3.7. Truncated Geometric Standard Deviations

Medium	Segment	Contaminant	Computed Geometric Standard Deviation	Truncated Geometric Standard Deviation
GW	2	Carbon-14	6.89E+01	1.51E+01
GW	4	Carbon-14	8.26E+00	6.04E+00
GW	4	Cesium-137	6.44E+00	5.33E+00
GW	6	Cesium-137	1.04E+01	9.96E+00
GW	19	Cesium-137	7.45E+00	1.82E+00
GW	8	Chromium	4.33E+00	3.85E+00
GW	4	Cobalt-60	6.27E+00	5.06E+00
GW	19	Cobalt-60	6.54E+00	1.25E+00
GW	21	Cobalt-60	7.37E+00	2.16E+00
GW	13	Europium-152	5.17E+00	3.22E+00
GW	5	Europium-154	8.95E+00	2.69E+00
GW	5	Iodine-129	1.20E+01	5.36E+00
GW	8	Nitrate	4.83E+00	4.14E+00
GW	9	Nitrate	7.10E+00	2.45E+00
GW	17	Nitrate	4.83E+00	2.18E+00
GW	19	Nitrate	5.85E+00	2.63E+00
GW	20	Nitrate	5.98E+00	2.21E+00
GW	21	Nitrate	1.24E+01	3.58E+00
GW	4	Strontium-90	2.82E+02	1.28E+02
GW	6	Strontium-90	1.05E+02	3.25E+01
GW	8	Strontium-90	5.46E+01	1.25E+01
GW	10	Strontium-90	1.29E+01	7.95E+00
GW	13	Strontium-90	5.58E+00	3.16E+00
GW	6	Sulfate	4.16E+00	3.21E+00
GW	19	Sulfate	9.97E+00	2.85E+00
GW	20	Sulfate	6.16E+00	2.10E+00
GW	21	Sulfate	7.83E+00	2.56E+00
GW	10	Technetium-99	1.02E+02	6.65E+01
GW	19	Technetium-99	4.93E+00	3.46E+00
GW	1	Tritium (H-3)	4.38E+00	2.65E+00
GW	5	Tritium (H-3)	5.00E+00	4.24E+00
GW	6	Tritium (H-3)	8.31E+00	4.99E+00
GW	8	Tritium (H-3)	1.32E+01	5.88E+00
GW	9	Tritium (H-3)	3.84E+01	4.08E+00
GW	12	Tritium (H-3)	1.01E+01	2.96E+00
GW	20	Tritium (H-3)	6.11E+00	3.08E+00
GW	20	Uranium-234	4.59E+00	3.61E+00
GW	19	Uranium-238	5.21E+00	3.06E+00
GW	20	Uranium-238	5.46E+00	5.04E+00
GW	20	Xylenes	4.85E+00	4.70E-01
GW	17	Zinc	8.46E+00	4.79E+00
SP	4	Cesium-137	4.56E+00	2.46E+00
SP	10	Cesium-137	1.15E+01	3.09E+00
SP	7	Chromium	5.58E+00	3.31E+00
SP	8	Chromium	6.53E+00	4.84E+00

Table 3.7. (Cont'd)

SP	20	Cobalt-60	4.41E+00	4.02E+00
SP	9	Lead	5.75E+00	2.29E+00
SP	7	Nitrate	5.90E+00	2.80E+00
SP	8	Nitrate	1.32E+01	8.52E+00
SP	10	Nitrate	4.96E+00	2.60E+00
SP	2	Strontium-90	2.01E+01	1.04E+01
SP	5	Strontium-90	4.38E+00	2.28E+00
SP	6	Strontium-90	2.74E+02	3.42E+01
SP	8	Strontium-90	4.23E+00	2.29E+00
SP	8	Technetium-99	6.77E+01	1.59E+01
SP	17	Technetium-99	5.13E+00	2.15E+00
SP	5	Tritium (H-3)	8.66E+00	3.81E+00
SD	22	Benzene	4.31E+00	2.10E+00
SD	10	Cesium-137	4.75E+00	3.47E+00
SD	24	Cesium-137	4.91E+00	3.29E+00
SD	24	Chromium	2.73E+01	2.63E+00
SD	1	Cobalt-60	5.61E+00	3.33E+00
SD	23	Cobalt-60	7.24E+00	4.52E+00
SD	24	Cobalt-60	8.20E+00	4.00E+00
SD	26	Cobalt-60	4.92E+00	2.67E+00
SD	24	Copper	2.38E+01	2.78E+00
SD	10	Europium-152	9.73E+00	1.30E+00
SD	22	Europium-152	8.28E+00	2.56E+00
SD	24	Europium-152	1.22E+01	4.79E+00
SD	14	Europium-154	7.04E+00	2.73E+00
SD	20	Europium-154	5.08E+00	1.96E+00
SD	24	Europium-154	1.43E+02	1.79E+01
SD	27	Europium-154	4.20E+00	4.00E+00
SD	22	Lead	4.31E+00	2.10E+00
SD	24	Lead	2.71E+01	3.20E+00
SD	16	Mercury	4.03E+00	2.98E+00
SD	22	Mercury	9.56E+00	2.68E+00
SD	27	Nitrate	4.66E+00	3.13E+00
SD	2	Strontium-90	1.85E+01	5.72E+00
SD	6	Strontium-90	1.64E+01	7.57E+00
SD	8	Strontium-90	3.90E+01	1.57E+00
SD	9	Strontium-90	1.11E+01	3.78E+00
SD	14	Strontium-90	7.85E+00	2.82E+00
SD	16	Strontium-90	9.30E+00	1.01E+00
SD	22	Strontium-90	5.74E+00	2.29E+00
SD	24	Strontium-90	4.38E+00	4.00E+00
SD	14	Technetium-99	6.24E+00	2.35E+00
SD	21	Uranium-234	4.40E+00	2.53E+00
SD	14	Xylenes	6.13E+00	2.34E+00
SD	24	Zinc	3.68E+01	3.99E+00
SW	1	Benzene	9.90E+00	4.47E+00

Table 3.7. (Cont'd)

SW	1	Cesium-137	4.85E+01	2.99E+01
SW	2	Cesium-137	9.38E+00	5.33E+00
SW	6	Cesium-137	4.98E+00	4.01E+00
SW	18	Cesium-137	4.49E+00	3.59E+00
SW	20	Cesium-137	2.56E+01	1.68E+01
SW	21	Cesium-137	6.97E+01	2.89E+01
SW	2	Chromium	4.49E+00	2.70E+00
SW	13	Chromium	4.83E+00	3.48E+00
SW	1	Cobalt-60	1.17E+02	6.44E+01
SW	6	Cobalt-60	4.45E+00	4.03E+00
SW	8	Cobalt-60	4.20E+00	3.01E+00
SW	20	Cobalt-60	5.39E+01	3.40E+01
SW	21	Cobalt-60	6.88E+01	2.01E+01
SW	1	Europium-154	9.08E+01	4.30E+01
SW	20	Europium-154	1.70E+02	2.00E+01
SW	21	Europium-154	9.61E+01	4.00E+01
SW	1	Mercury	5.77E+00	3.50E+00
SW	21	Mercury	1.20E+01	8.77E+00
SW	1	Nickel	4.45E+00	2.30E+00
SW	1	Nitrate	4.02E+00	3.07E+00
SW	2	Nitrate	7.17E+00	2.45E+00
SW	5	Nitrate	5.10E+00	2.21E+00
SW	10	Nitrate	5.02E+00	2.20E+00
SW	17	Nitrate	1.18E+01	7.27E+00
SW	18	Nitrate	4.09E+00	2.12E+00
SW	21	Nitrite	5.31E+00	2.47E+00
SW	9	Strontium-90	1.15E+01	2.01E+00
SW	10	Strontium-90	9.07E+00	3.29E+00
SW	19	Strontium-90	8.05E+00	4.30E+00
SW	20	Sulfate	1.78E+01	2.25E+00
SW	6	Technetium-99	2.68E+01	1.18E+01
SW	17	Technetium-99	1.03E+02	7.60E+01
SW	19	Technetium-99	5.86E+00	4.60E+00
SW	20	Technetium-99	1.30E+01	1.19E+01
SW	20	Uranium-234	4.01E+00	3.24E+00
SW	19	Uranium-238	6.08E+00	4.69E+00
SW	20	Uranium-238	6.94E+00	5.97E+00
GW = Groundwater				
SD = Sediment				
SP = Seeps				
SW = Surface water				

Table 3.8. Outlier Data Eliminated from the Other Media Data Sets

Medium	Segment	Contaminant	Concentration	Units	Sample Number	Sample Date	Sample Site Name	Owner ID	East-West Coordinate	North-South Coordinate
SD	1	Nitrate	937.5	µg/kg	CR389	22-Sep-94	Wills Ranch Site	CRCIA	NA	NA
SD	1	Xylenes (total)	.975	µg/kg	SESP1_3	22-Sep-94	Priest Rapids Dam	CRCIA	545436	146075
SD	2	Chromium	131000	µg/kg	B07NF4	20-Nov-92		HEISPROD	564535.5	145279.2
SD	2	Europium-152	90	pCi/kg	B07ND1	20-Nov-92		HEISPROD	564635.7	145303.4
SD	2	Mercury	110	µg/kg	B06KS3	19-Sep-91	Seep 039-2	HEISPROD	564940	145350
SD	4	Europium-152	320	pCi/kg	B07NF9	21-Nov-92		HEISPROD	568105.9	146712.5
SD	4	Europium-154	200	pCi/kg	B07NF9	21-Nov-92		HEISPROD	568105.9	146712.5
SD	5	Europium-152	125.5	pCi/kg	B06KT3	16-Oct-91	Seep 074-1	HEISPROD	569680	148070
SD	5	Nickel	13000	µg/kg	B06KT8	18-Oct-91	Seep 080-2	HEISPROD	570415	148780
SD	8	Chromium	122000	µg/kg	B06KY0	26-Sep-91	Seep 110-2	HEISPROD	573597	152470
SD	8	Mercury	130	µg/kg	B06KX5	19-Sep-91	Seep 110-1	HEISPROD	573480	152375
SD	9	Chromium	107000	µg/kg	B06L50	20-Sep-91	Seep 144-1	HEISPROD	577255	153660
SD	9	Technetium-99	400	pCi/kg	B06L55	25-Sep-91	Seep 146-1	HEISPROD	577330	153615
SD	9	Uranium-238	2000	pCi/kg	B07NH2	23-Nov-92		HEISPROD	574306.1	153825.1
SD	10	Cobalt-60	380	pCi/kg	B07NC0	13-Nov-92		HEISPROD	578263	152108.2
SD	12	Cesium-137	5100	pCi/kg	13165	13-Nov-92	H-Slough	WDOH	NA	NA
SD	12	Cobalt-60	400	pCi/kg	13165	13-Nov-92	H-Slough	WDOH	NA	NA
SD	14	Cobalt-60	360	pCi/kg	B07NG9	23-Nov-92		HEISPROD	582731.8	146871.7
SD	15	Cobalt-60	250	pCi/kg	B06LB0	28-Sep-91	Seep 221-1	HEISPROD	583132	144317
SD	16	Zinc	1086262	µg/kg	B0CWF1	21-Jul-95	Hanford Slough	SESP	585610	140352
SD	17	Europium-152	278	pCi/kg	B0G8W4	5-Sep-95	Hanford Spring 28-2	SESPMNT	588305	138108
SD	24	Phosphate	3448.276	µg/kg	SR3	17-Sep-94	Downstream of Strawberry Island	CRCIA	NA	NA
SD	27	Phosphate	8000	µg/kg	CR310	15-Oct-94	Lake Wallula	CRCIA	NA	NA
SD	27	Xylenes (total)	.8611111	µg/kg	CR295	23-Sep-94	McNary Dam	CRCIA	596202	67431
SP	2	Phosphate	400	µg/L	B091M1	22-Sep-93	Seep 037-1	HEISPROD	564540	145275
SP	2	Uranium-238	1.4	pCi/L	B0G8B3	28-Aug-95	100-B Spring	SESPMNT	564610	145304

Table 3.8. (Cont'd)

Medium	Segment	Contaminant	Concentration	Units	Sample Number	Sample Date	Sample Site Name	Owner ID	East-West Coordinate	North-South Coordinate
SP	6	Cobalt-60	91.8	pCi/L	E122018	31-Dec-92	100 N Spring 8-13	SESP	NA	NA
SP	6	Chromium	45	µg/L	B0CSF3	26-Sep-94	100-N Spring	SESP	571676	150468
SP	6	Copper	30	µg/L	B0CSF3	26-Sep-94	100-N Spring	SESP	571676	150468
SP	6	Nickel	25	µg/L	B0CSF3	26-Sep-94	100-N Spring	SESP	571676	150468
SP	6	Nitrate	15000	µg/L	B0CSF3	26-Sep-94	100-N Spring	SESP	571676	150468
SP	6	Sulfate	26000	µg/L	B0CSF3	26-Sep-94	100-N Spring	SESP	571676	150468
SP	6	Zinc	460	µg/L	B0CSF3	26-Sep-94	100-N Spring	SESP	571676	150468
SP	8	Nickel	26	µg/L	B0CSF5	22-Aug-94	100-D Spring	SESP	573606	152482
SP	8	Nitrite	250	µg/L	B0BMK5	1-Apr-94	Seep 110-1	HEISPROD	573480	152375
SP	8	Phosphate	250	µg/L	B0BMK5	1-Apr-94	Seep 110-1	HEISPROD	573480	152375
SP	9	Copper	16.2	µg/L	B091L5	20-Sep-93	Seep 146-1	SESP	577330	153615
SP	9	Phosphate	400	µg/L	B091L5	20-Sep-93	Seep 146-1	HEISPROD	577330	153615
SP	13	Copper	2.7	µg/L	B091L7	28-Sep-93	Seep 189-1	SESP	580508.5	148524.2
SP	15	Chromium	32.1	µg/L	B06L97	28-Sep-91	Seep 221-1	HEISPROD	583132	144317
SP	15	Copper	5	µg/L	B06L96	28-Sep-91	Seep 221-1	HEISPROD	583132	144317
SP	15	Nickel	11.8	µg/L	B06L97	28-Sep-91	Seep 221-1	SESP	583132	144317
SP	15	Zinc	79.9	µg/L	B06L83	29-Sep-91	Seep 216-1	HEISPROD	582864	145130
SW	1	Zinc	94	µg/L	1006-1	17-Mar-94	Vernita-2	SESP	559051	145897
SW	2	Nickel	130	µg/L	B06KR4	18-Sep-91	Seep 037-1	HEISPROD	564540	145275
SW	2	Tritium	13000	pCi/L	B06KR3	18-Sep-91	Seep 037-1	HEISPROD	564540	145275
SW	6	Cobalt-60	44.73	pCi/L	B06KV1	15-Oct-91	N Area	HEISPROD	571300	149920
SW	6	Nickel	16	µg/L	B09J76	25-Aug-94	N Area	SESP	571432	150755
SW	9	Nitrate	540	µg/L	B06L43	20-Sep-91	Seep 143-1	HEISPROD	577080	153770
SW	9	Technetium-99	3	pCi/L	B06L43	20-Sep-91	Seep 143-1	HEISPROD	577080	153770
SW	9	Tritium	400	pCi/L	B06L48	20-Sep-91	Seep 144-1	HEISPROD	577255	153660

Table 3.8. (Cont'd)

Medium	Segment	Contaminant	Concentration	Units	Sample Number	Sample Date	Sample Site Name	Owner ID	East-West Coordinate	North-South Coordinate
SW	10	Zinc	261	µg/L	B06L59	26-Sep-91	Seep 149-1	HEISPROD	577885	153160
SW	13	Chromium	58	µg/L	B09J87	25-Aug-94	100-F 10	SESP	581458	148469
SW	13	Lead	1.8	µg/L	B0G0T5	12-Sep-95	100--3	SESP	581377	147994
SW	15	Nickel	5.5	µg/L	B06L93	28-Sep-91	Seep 218-1	HEISPROD	582962	144813
SW	16	Tritium	270	pCi/L	B06LJ5	2-Oct-91	Seep 246-1	HEISPROD	584986	140838
SW	17	Ammonia	70	µg/L	RM362A	1-Sep-91	Hanford Townsite	WHC		
SW	17	Strontium-90	.54	pCi/L	RM362D	1-Sep-91	Hanford Townsite	WHC		
SW	17	Sulfate	97000	µg/L	RM362B	1-Sep-91	Hanford Townsite	WHC		
SW	17	Uranium-234	1.8	pCi/L	B0GNP9	26-Sep-95	Hanford Townsite	SESPSPEC	588305	138108
SW	17	Uranium-238	1.09	pCi/L	B0GNP9	26-Sep-95	Hanford Townsite	SESPSPEC	588305	138108
SW	18	Phosphate	200	µg/L	WPPSSNO N290	30-Mar-95	Downstream 91 m	WPPSS		
SW	20	Copper	7.2	µg/L	BOC2S8	23-Jun-94	300 Area	HEISPROD	594585	116209
SW	20	Cyanide	40	µg/L	RM346F	1-Sep-91	300 Area	WHC		
SW	20	Mercury	.8	µg/L	RM346F	1-Sep-91	300 Area	WHC		
SW	20	Nitrite	30	µg/L	RM346F	1-Sep-91	300 Area	WHC		
SW	21	Copper	250	µg/L	5112767	9-Oct-90	City of Richland Intake	City of Richland	595593	109859
SW	21	Cyanide	1.7	µg/L	B0G144	7-Dec-95	Richland Pumphouse-9	SESP	596311	109915
SW	23	Chromium	20	µg/L	11195186	3-Nov-95	Butterfield Water Treatment Plant	City of Pasco	607500	99660
SW	23	Nickel	30	µg/L	11195186	3-Nov-95	Butterfield Water Treatment Plant	City of Pasco	607500	99660
TLD	12	TLD	.813	mR/d	E117102	28-Jun-91	Lo End Locke Island	SESPMNT	580220	151413
TLD	15	TLD	.919	mR/d	E117108	28-Jun-91	Hanford Powerline Crossing	SESPMNT	585632	140699
TLD	17	TLD	.893	mR/d	E117110	28-Jun-91	Savage Island Slough	SESPMNT	590292	137256

3.4.4.4 Compute Stochastic Parameters

To compute the stochastic parameters, the geometric mean and geometric standard deviation of all measurements for the segment were calculated after outliers for the segment were removed. The calculation of the geometric mean and geometric standard deviation are as described in Section 3.4.3.2 in the groundwater process using log probability plotting. The truncation of the geometric standard deviation was also used for computing the stochastic parameters for media other than groundwater. The geometric mean and geometric standard deviation define the specific two-parameter lognormal distribution used for the stochastic risk assessment calculations for the segment.

3.5 Final Data Sets

The concentration input files resulting from the data selection process are called the media files. The media files were derived from the Microsoft Access database of raw files (see Appendix A in the final publication of Volume II of the draft data report). The media files are provided in Appendix I-B of this report. The media files are comma separated files that can be opened and read by Microsoft Excel 5.0. Plots of the maximum values and geometric means for each segment are also shown in Appendix I-B for each contaminant that was measured in each medium. Plots for Segment 1 indicate the background levels of contaminants because Segment 1 is upstream of the operating areas.

Once the data were selected, they were organized by media into the "media files." Because data are not available for each of the 23/28 contaminants in each of the 4 media at each of the 27 segments, the CRCIA Team decided to allow substitute data for missing seep and surface water data but to not allow substitute data for missing groundwater or sediment data. The file containing the selected data in the media files plus the substituted data is the "final data file." Of the possible 3024 data values, 1153 have no data even after the substitution. The final data file was the file used in the human health (along with the external radiation media file) and ecological screening risk assessments.

3.5.1 Extrapolation and Surrogation

Measured data are not available for all media for all contaminants of interest at all of the segments of the study area. When a segment/contaminant combination has no measured data for a given medium, that represents a data gap. A set of rules was adopted by the CRCIA Team to allow some of the data gaps to be filled. The two types of data substitution are extrapolation and surrogation. Extrapolation is the filling of data gaps using data from the same medium but from a different location. Surrogation is the filling of data gaps using data from the same location but from a different medium. The following rules were applied to fill some of the data gaps:

- ◆ Groundwater: No substitutions
- ◆ Sediment: No substitutions
- ◆ Seep Water: Use groundwater data as a surrogate where available
- ◆ Surface Water: If no measured data are available for Segment 1, extrapolate from Segment 2 if available. In Segments 2-27, extrapolate from the nearest upstream segment with measured data

Four possible results of this process are 1) measured data available so no substitution, 2) measured data not available and no substitution data available, 3) measured data not available so groundwater data used as a surrogate for seep data, and 4) measured data not available so data extrapolated from another segment for surface water.

A summary of the final data availability after the surrogation/extrapolation process is given in Table 3.9. With 4 media (not including external radiation), 28 contaminants of interest, and 27 segments, there is a possible total of 3024 data values. If a measured value for a contaminant was available in a segment for one of the media, the corresponding cell in Table 3.9 contains a "+" symbol. Measured data for a contaminant/segment/medium combination were available in 1303 of the 3024 cases.

For the seep medium, if no measured value was available but a groundwater value was available as a surrogate, then the corresponding cell contains the acronym for groundwater, GW. Groundwater was used as a surrogate for seep water 206 times.

For the surface water medium, if no measured value was available, but an upstream value was available for extrapolation, then the corresponding cell contains the upstream segment number where the data were measured. For example, the "6" in the cell for strontium-90 in surface water in Segment 7 indicates that the surface water concentration from Segment 6 was used in Segment 7. Extrapolation of an upstream surface water concentration was done 362 times.

If no measured data were available and neither surrogation nor extrapolation used, then the corresponding cell contains a "-" symbol. All cells that contain a "-" represent a gap in the available data. There are 1153 data gaps.

The final data file (provided in Appendix I-B) incorporates the substituted data into the data provided in the media files. The final data file was the file used in the human health (along with the external radiation media file) and ecological screening risk assessments.

3.5.2 Contaminants Considered in Reduced Detail

Two contaminants, diesel oil and kerosene, were never detected in any medium and so were not analyzed in the screening assessment. Three metals, copper, nickel, and zinc, were near background levels and so were considered in reduced detail in the screening assessment. See Section 5.2 for discussion of these contaminants.

3.5.3 Comparison to Other Data

The media data for the screening assessment were compared to the results of special studies done by ERC on chromium and, as an aside, nitrate at the D and H Areas and by WHC on N Springs. The ERC data comparison is presented in Table 3.10. Both the drive point (aquifer sample tube) and pore water data (shaded in the table) are compared to the groundwater, seep, and surface water media data. In Segment 7, the ERC sampling identified a localized area of high chromium concentration. There is only one groundwater

Table 3.9. Data Availability after the Surrogage/Extrapolation Process

Segment	Medium	Ammonia	Benzene	Carbon-14	Cesium-137	Chromium	Cobalt-60	Copper	Cyanide	Diesel Oil	Europium-152	Europium-154	Iodine-129	Kerosene	Lead	Mercury	Neptunium-237	Nickel	Nitrate	Nitrite	Phosphate	Strontium-90	Sulfate	Technetium-99	Tritium (H-3)	Uranium-234	Uranium-238	Xylenes (total)	Zinc
1	GW	+	+	+	+	+	+	+	+	-	+	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	-	-	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	-	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
2	GW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
3	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
4	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	3	1	-	2	3	2	3	1	-	-	2	1	-	1	1	-	3	3	3	3	3	3	3	1	1	1	1	1
5	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
6	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
7	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
8	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	6	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
9	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
10	GW	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+

Table 3.9. (Cont'd)

Segment	Medium	Ammonia	Benzene	Carbon-14	Cesium-137	Chromium	Cobalt-60	Copper	Cyanide	Diesel Oil	Europium-152	Europium-154	Iodine-129	Kerosene	Lead	Mercury	Neptunium-237	Nickel	Nitrate	Nitrite	Phosphate	Strontium-90	Sulfate	Technetium-99	Tritium (H-3)	Uranium-234	Uranium-238	Xylenes (total)	Zinc		
	11	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
		SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
		SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
		SW	10	8	-	8	10	8	10	1	-	-	8	1	-	6	8	-	10	10	10	10	6	10	10	10	10	10	8	10	
	12	GW	-	+	+	+	+	+	-	-	+	-	-	-	-	-	-	-	+	+	+	+	-	-	+	+	+	+	+	+	
		SD	-	+	+	+	+	+	-	-	+	-	-	-	-	-	-	-	+	+	+	+	-	-	+	+	+	+	+	+	
		SP	-	GW	-	GW	GW	GW	-	-	-	-	-	-	-	-	-	-	GW	GW	GW	-	GW	GW	-	-	10	8	10	GW	
		SW	10	8	-	8	10	8	10	1	-	-	8	1	-	6	8	-	10	10	10	10	6	10	10	10	10	10	8	10	
	13	GW	-	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	GW	GW	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	-	+	+	-	+	+	+	+	+	GW	GW	GW	GW	GW	GW	GW	GW
		SW	+	+	-	8	+	8	+	1	-	-	8	1	-	+	8	-	+	+	+	+	+	10	+	+	+	+	+	+	+
	14	GW	-	-	-	-	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	+	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	-	+	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SW	+	13	-	8	+	8	+	1	-	-	8	1	-	13	8	-	+	+	+	+	+	13	10	+	13	13	13	13	+
	15	GW	-	+	+	+	+	+	+	-	-	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	-	-	-	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	-	GW	-	GW	GW	GW	GW	GW	-	GW	-	-	GW	GW	-	-	+	+	+	+	+	GW	GW	-	-	GW	GW	GW	GW
		SW	+	13	-	8	+	8	+	1	-	-	8	1	-	13	8	-	+	+	+	+	+	13	10	+	13	13	13	13	+
	16	GW	-	-	-	-	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	+	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	-	-	-	-	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SW	+	13	-	8	+	8	+	1	-	-	8	1	-	13	8	-	+	+	+	+	+	13	10	+	13	13	13	13	+
	17	GW	-	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	-	+	+	+	+	+	+	-	+	+	+	+	+	GW	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+
		SW	+	+	+	+	+	+	+	+	-	-	+	1	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+
	18	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	+	+	+	+	+	+	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SW	+	17	-	+	+	+	+	17	-	-	17	1	-	+	+	-	+	+	17	+	17	+	17	+	17	17	17	17	+
	19	GW	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	+	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	GW	GW	-	GW	GW	GW	GW	GW	-	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
		SW	+	+	+	18	+	18	+	17	-	+	+	1	-	+	+	-	+	18	17	+	+	18	+	+	17	+	+	+	+
	20	GW	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SD	-	+	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		SP	GW	GW	-	GW	GW	GW	GW	GW	-	GW	GW	GW	GW	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
		SW	+	+	+	+	+	+	+	GW	-	GW	+	+	+	GW	GW	-	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 3.9. (Cont'd)

Segment	Medium	Ammonia	Benzene	Carbon-14	Cesium-137	Chromium	Cobalt-60	Copper	Cyanide	Diesel Oil	Europium-152	Europium-154	Iodine-129	Kerosene	Lead	Mercury	Nepthium-237	Nickel	Nitrate	Nitrite	Phosphate	Strontium-90	Sulfate	Technetium-99	Tritium (H-3)	Uranium-234	Uranium-238	Xylenes (total)	Zinc
21	GW	+	+	-	+	+	+	+	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-
	SP	GW	GW	-	GW	GW	GW	GW	GW	-	GW	GW	GW	-	GW	GW	-	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW	GW
	SW	20	+	-	+	+	+	+	+	-	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
22	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	+	+	-	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SW	20	21	-	21	21	21	21	21	-	20	21	21	-	21	21	-	21	21	21	21	21	21	21	21	21	21	21	21
23	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SW	20	21	-	21	21	21	21	+	-	20	21	21	-	21	21	+	21	21	21	21	21	21	21	21	21	21	21	21
24	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SW	20	21	-	21	23	21	23	23	-	20	21	21	-	23	23	-	23	23	23	23	21	21	21	21	21	21	21	21
25	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SW	20	21	-	21	23	21	23	23	-	20	21	21	-	23	23	-	23	23	23	23	21	21	21	21	21	21	21	21
26	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SW	20	21	-	21	23	21	23	23	-	20	21	21	-	23	23	-	23	23	23	23	21	21	21	21	21	21	21	21
27	GW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	+	-	+	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SW	20	21	-	21	23	21	23	23	-	20	21	21	-	23	23	-	23	23	23	23	21	21	21	21	21	21	21	21

GW = Groundwater

SD = Sediment

SP = Seeps

SW = Surface Water

+ = Measured data were available for this contaminant in this segment.

- = No measured data were available and no substitution was made.

GW in contaminant column = Groundwater data were used as a surrogate for seep water for this contaminant in this segment.

= A number indicates the segment from which surface water data were extrapolated to this segment.

well in this segment, and it is not located near the area of high concentration. Therefore, the ERC maxima are an order of magnitude higher than the media maxima in Segment 7. On a geometric mean basis, the data values represent the expected pattern with pore water concentrations lower than seep concentrations but higher than surface water concentrations. The data for Segments 8 and 10 show the expected pattern for both the maximum and mean concentrations.

The data resulting from the special study of the shallow wells at N Springs in Segment 6 is compared with the groundwater, seep, and surface water data for that segment in Table 3.11. Only tritium (hydrogen-3) and strontium-90 data are available for N Springs. The maximum values for tritium show the pattern that is expected with N Springs concentrations being higher than surface water and seeps but lower than groundwater. On a geometric mean basis, the pattern is maintained except that the seep concentration is very high. This implies that the screening assessment is conservative for tritium in the 100-N Area. For strontium-90, the maximum value in the N Springs is lower than expected, but the geometric mean is slightly higher.

Table 3.10. Comparison of Media Data to Drive Point and Pore Water Data

		Maximum values (µg/L)				
Contaminant	Segment	Ground-water	Drive point data	Seep data	Pore water data	Surface water data
Chromium	7	50.6	869.0	28.0	632.0	7.8
	8	538.0	172.0	400.0	34.7	9.0
	10	1300.0	NA	84.0	130.0	ND
Nitrate	7	46924.1	NA	1300.0	6670.0	300.0
	8	201419.4	NA	46000.0	2600.0	120.0
		Geometric Mean (µg/L)				
Contaminant	Segment	Ground-water	Drive point data	Seep data	Pore water data	Surface water data
Chromium	7	46.4	84.2	3.5	2.4	1.5
	8	46.8	3.4	20.4	0.9	1.8
	10	50.1	NA	35.7	1.7	ND
Nitrate	7	30766.26	NA	237.8	260.0	71.0
	8	14830.3202	NA	631.3	110.0	51.5

Table 3.11. Comparison of Media Data to N Springs Data

		Maximum (pCi/L)				Geometric Mean (pCi/L)			
		Ground-		Seep	Surface	Ground-		Seep	Surface
Contaminant	Segment	water	N Springs	data	water data	water	N Springs	data	water data
Tritium (Hydrogen-3)	6	104000.0	63000.0	30800.0	800.0	4955.4	492.2	13805.9	58.0
Strontium-90	6	19100.0	1380.0	10900.0	65.1	11.7	31.2	5.9	0.1

4.0 Screening Assessment of Risk to the Environment

The results of the screening assessment indicate the potential risk to human health for selected scenarios and the environment for selected species from Hanford derived contaminants in the Columbia River. This section describes the process used to assess potential risk to the environment and the results. Section 5.0 describes the process used to assess potential risk to human health and the results.

4.1 Species for the Screening Assessment

The objective of the ecological risk assessment is to determine whether Hanford derived contaminants from the Columbia River pose a threat to species that exist in the river and riparian communities of the study area. Because these communities consist of numerous species, the first step was to select the species to be assessed. This section describes the process that identified which species should be assessed. The second step in the ecological risk assessment was to estimate the potential risk to the selected species. Section 4.2 describes that process and potential risk to the selected species.

To assess possible risk to the environment, we first needed to decide on which species to evaluate. Because this is a screening assessment, only a limited number of species were evaluated:

- Those most likely to be exposed to contaminants
- Those of high concern for cultural and natural resource management reasons
- Those that ensure each major group of species are represented

Both a panel of regional biologists and the CRCIA Team were involved in setting the criteria to decide which species to evaluate.

The Columbia River is a complex ecosystem that supports numerous species. Once contaminants have entered into the riparian or aquatic ecosystems, all species in the relevant food webs may be considered potential contaminant receptors. For the purposes of the screening assessment of risk to the environment, the number of species to be evaluated was reduced to those that have a high potential for exposure to contaminants and that are culturally and ecologically important to the CRCIA Team. A two-tier screening approach was used to select the species for this risk assessment.

The CRCIA assessment of potential risk to the environment is a screening study because it is limited in its spatial and temporal scope and in the number of species it evaluates, and it addresses only the issue of whether contaminants exceed levels that harm identified species. It will not attempt to address the average hazard of contaminants because this would require significantly more information on the temporal and spatial fluxes of contaminants and distributions of species than the scope of the screening assessment will allow. Instead, this risk assessment will evaluate direct effects (for example, mortality) to selected species caused by exposure to contaminants. Indirect effects (for example, repercussions in the food chain that may result from direct effects to selected species) at the population and community levels will be addressed if and where direct effects are found to be significant. The results of this risk assessment will serve to focus a subsequent and more comprehensive risk assessment which will likely evaluate 1) a larger segment of the Columbia River, 2) hazards posed by past, present, and future contaminant fluxes, and 3) a larger number of selected species.

4.1.1 Ecosystem

The portion of the river within the study area (vicinity of Priest Rapids Dam to McNary Dam) lies within the lower Columbia River Basin, which is a part of the western intermountain sagebrush steppe ecosystem (West 1988). The ecology of the aquatic and riparian systems within the study area has been studied extensively in the last 50 years, largely because of concerns about hydropower and reactor construction and operation. Major summaries of biological studies conducted in association with Hanford Site operations include Becker (1990) and Cushing (1995). Studies specific to biological resources of the river and riparian areas at the Hanford Site include Weiss and Mitchell (1992) and Landeen et al. (1993) for the 100 Areas and Brandt et al. (1993) for the 300 Area. Studies relating to the Washington Public Power Supply System reactors at the Hanford Site are summarized in Page et al. (1982). Studies in support of the proposed U.S. Army Corps of Engineers Ben Franklin Dam are summarized in Fickeisen et al. (1980). Other documents describing the climate and abiotic portions of the study area are cited in Cushing (1995). All these documents cited above will not be reviewed in this report. The reader is referred to the above sources for detailed discussions of the Hanford Reach and its biological resources. Key points of the riparian and aquatic ecosystems under study are provided below. Common names are used in the following description. Table C.1 in Appendix C in Part I provides the Latin nomenclature.

Fortunately for purposes of this study, the ecology of the aquatic and riparian systems of the Hanford Reach have been studied extensively over the past 50 years. As a result, we were able to identify existing species based on these studies without conducting additional field research. Key terms to be familiar with when reading about the ecosystem are:

- ◆ **Aquatic Ecosystem** contains those species that grow and live in or upon water
- ◆ **Semi-Aquatic Ecosystem** contains those species that grow and live partially in or upon water and partially on land
- ◆ **Riparian Ecosystem** contains those species that grow and live on the banks of a body of water, in this case the Columbia River
- ◆ **Riverine Habitat** is in the river, in this case the Columbia River
- ◆ **Food Web** describes the foraging relationships (what eats what) among groups of species. Basic groups in the food web are carnivores (meat eaters), omnivores (meat and plant eaters), herbivores (plant eaters), and producers (plants). Generally, producers are at the bottom of the food web. Carnivores are at the top. Producers are eaten by herbivores. Herbivores are eaten by omnivores. Omnivores are eaten by carnivores, which means the carnivores may also be affected by contaminants contained in the producers and herbivores as well as the omnivores. Any member of the food web may be affected by contaminants contained in its prey. The labels, carnivores I, II, and III, in Figure 4.2 indicate that carnivores II eat carnivores I and carnivores III eat carnivores II and I.

The Hanford Reach comprises the last unimpounded portion of the Columbia River in the United States above Bonneville Dam. It supports diverse plant, fish, and wildlife species that are locally abundant. Food webs that pictorially display the foraging interrelationships of species of the riparian and aquatic ecosystems in the study area are presented in Figures 4.1 and 4.2, respectively.

Figure 4.1 Riparian Food Web, as Approved by the CRCIA Team, for the Screening Ecological Risk Assessment of the Columbia River (Detrital/decomposing components are not represented. Line widths represent the approximate level of biomass flow.)

Figure 4.2. Aquatic Food Web, as Approved by the CRCIA Team, for the Screening Ecological Risk Assessment of the Columbia River (Detrital/decomposing components are not represented. Line widths represent the approximate level of biomass flow. Dashed lines indicate developmental transformation to a different life style. Legend colors apply only to organisms' names not arrows.)

4.1.1.1 Riparian Community

The dominant riparian vegetation includes black cottonwood, bulrushes, common cattail, reed canarygrass, white mulberry, willows, and numerous species of sedges and forbs. The riparian zone of the study area is known to include four plants on Washington State protected species lists (Sackschewsky et al. 1992, WNHP 1994). These are Columbia yellowcress (state endangered), dense sedge (state sensitive), false pimpernel (state sensitive), and southern mudwort (state sensitive).

Fitzner and Gray (1991) listed 39 species of mammals known to occur on the Hanford Site. Brandt et al. (1993) identified 24 as occurring within the riparian zone of the Columbia River. Principal herbivorous species include beaver, deer mice, mule deer, and muskrat. Insectivorous species include several species of *Myotis* bats that forage primarily on emergent insects, and the northern grasshopper mouse and vagrant shrew that forage primarily on terrestrial insects and other arthropods. Omnivores include coyote, raccoon, and striped skunk. Predators include bobcat, mink, river otter, and weasels. Two bats, the pallid bat and long-eared *Myotis* bat, and the northern grasshopper mouse are listed as a monitor species by Washington State (WDW 1994).

Weiss and Mitchell (1992) identified 103 bird species associated with the riparian community of the Hanford Reach. These include species that use the area only during winter (for example, American widgeon, bald eagle), only during summer (for example, cliff swallow, Forster's tern,), or year-round (for example, barn owl, mallard). Principal herbivorous species include Canada geese and mallards. Principal omnivorous species include black-billed magpie, California quail, American crow, the dabbling (primarily herbivorous) ducks (for example, Northern pintail and teal), common raven, and ring-necked pheasant. Carnivores and insectivores comprise the bulk of the avifauna, which includes species such as bald eagle, belted kingfisher, black-crowned night heron, great blue heron, gulls, hawks, owls, shorebirds, swallows, and terns. Two birds, Aleutian Canada goose and bald eagle, are listed as threatened under the Endangered Species Act. Aleutian Canada goose, American white pelican, bald eagle, ferruginous hawk, and sandhill crane, are listed as either threatened or endangered by Washington State. The common loon is a candidate for listing as threatened or endangered by Washington State (WDW 1994).

Amphibians in the study area include the bullfrog, Great Basin spadefoot toad, Pacific tree frog, and Woodhouse's toad (Brandt et al. 1993). None are abundant within the region. However, all use backwater areas of the Columbia River to complete their life cycles. Woodhouse's toad is listed as a monitor species by Washington State (WDW 1994).

Principal reptiles in the riparian zone include the gopher snake, painted turtle, side-blotched lizard, western garter snake, and western yellow-bellied racer (Fitzner and Gray 1991). The turtles are more often associated with ponds than the river but may be present in the sloughs where water velocities are low. None of the reptile species associated with the riparian zone are listed for protection by state or federal agencies.

4.1.1.2 Aquatic Community

Aquatic vegetation is comprised of three general groups: phytoplankton, periphyton, and macrophytes. Semi-aquatic or emergent vegetation, although generally rooted in standing water, is considered within the riparian vegetation described above. Diatoms dominate the Columbia River algae, comprising more than 90 percent of the biomass. The primary genera include *Asterionella*, *Cyclotella*, *Fragillaria*, *Melosira*, *Stephanodiscus*, and *Synedra* (Neitzel et al. 1982a, Brandt et al. 1993). The peak of phytoplankton abundance is in April and May with a secondary peak in late summer and early autumn. Periphyton develops on suitable substrate where light is sufficient for photosynthesis. Diatoms also predominate among this group. Macrophytes are sparse outside of McNary Pool and slack water areas because they require relatively low flow and a sediment substrate in which to root. Common species include curled leaf pondweed, duckweed, and water milfoil. Where present, macrophytes provide food and shelter for juvenile fish and spawning substrate for some species of fish.

Zooplankton are generally sparse in the study area (Neitzel et al. 1982b, Brandt et al. 1993). Dominant genera are *Bosmina*, *Cyclops*, *Diaptomus*. Densities are lowest during winter and highest during summer.

Benthic invertebrates (invertebrate species associated with the substrate rather than the water column) include all major fresh water benthic taxa (Brandt et al. 1993). The invertebrate fauna is dominated by insect larvae, particularly black flies, caddis flies, and midge flies. Other benthic organisms include crayfish, limpets, snails, and sponges. Larval insect densities peak during late fall and winter with peak emergence occurring during spring and summer. Benthic invertebrates are important food items for nearly all juvenile and adult fish in the study area. The pebblesnail and shortface lanx (another mollusc) are candidates for listing as endangered, threatened, or sensitive by Washington State (WDW 1994).

A total of 44 species of fish are known to occur in the Hanford Reach (Gray and Dauble 1977, Cushing 1995). Chinook, coho, and sockeye salmon and steelhead trout use the Reach as a migration corridor to and from upstream spawning areas. The Hanford Reach supports the only major spawning habitat for the upriver bright race of fall chinook salmon within the main stem of the Columbia River (Dauble and Watson 1990). American shad (Cushing 1995) and steelhead trout (Gray and Dauble 1977) may also spawn within the study area. Of the fish species known to occur within the study area, one, the bull (Dolly Varden) trout, is a candidate for listing as threatened or endangered under the Endangered Species Act (61 FR 7595-7613). Four others, the mountain sucker, Piute sculpin, reticulate sculpin, and sand roller, are listed as a monitor species by Washington State (WDW 1994).

4.1.2 Species Selection Approach

To identify the species that have a high potential for exposure to or effects from contaminants and that are culturally and ecologically important to the CRCIA Team, a two-tier screening approach was used (Table 4.1). Species groups considered in the screening process included fungi, algae, higher plants, and animals (fish, invertebrates, and terrestrial wildlife). Fungi were included after the master list of species (Table C.1 in Appendix C, Part I) was developed. Microbial populations in surface soil, surface water, and sediment were excluded from consideration in the master list of species. While microorganisms play a critical role in nutrient cycling and other energy processes in the Columbia River ecosystem, they are considered to be highly adaptable to environmental change. In addition, the microbial community structure may change in response to a toxicant without altering the overall functional status of that community because of the ubiquity of microbiota and the redundancy of their metabolic processes. This means that any localized effects of a toxicant are likely compensated in a relatively short time and that the potential for long-term effects to the Columbia River community are low. The steps used throughout this two-tier screen were developed with the approval of the CRCIA Team.

We used several screens to reduce an overwhelming number of species to a manageable number of species to be evaluated. An overview of the criteria for the screens and the selection process are in Table 4.1. One of the initial screens was developed by a panel of regional biologists. The other screens were developed after consulting and reaching agreement with the CRCIA Team. Each time we applied a screen the number of species was reduced. Several screens were used to arrive at the first tier, labeled the Tier I list of species. Several more screens were used to arrive at the second tier, labeled the Tier II list of species. The Tier II list shows the species evaluated in the screening assessment of potential risk to the environment. After each screening, the CRCIA Team reviewed the resulting list and reinstated any species they felt the screen had inappropriately filtered out. Key terms to be familiar with when reading about the approach used to select species are:

- ◆ biotic media are living organisms and their products
- ◆ abiotic media are inorganic (not living) materials
- biomagnifying contaminants are those that occur in higher concentrations at higher levels in the food chain
- ◆ non-biomagnifying contaminants are those that remain at the same concentration or decrease in concentration at higher levels in the food chain.

4.1.2.1 Tier I Species Screen

A list of Tier I species was identified using the following protocol. Each step of the protocol is elaborated on in the subsections.

This section describes the details of the various screens used to arrive at the species on the Tier I list.

1. A master list was developed that included plant and animal species known to occur in the riparian and aquatic ecosystems of the Columbia River between the vicinity of Priest Rapids Dam and the Columbia River estuary.
2. The master list was reduced to 368 species that occur within the study area.

Table 4.1. Selection Process and Criteria Used to Identify Species for the Screening Assessment of Ecological Risk to the Columbia River

Species Lists	Selection Process and Criteria	No. of Species
Master (listed in Table C.1, Appendix C, Part I)	List developed by PNNL staff based on species found in riverine and riparian habitats of the Columbia River between the vicinity of Priest Rapids Dam and the Columbia River estuary	496
Study Area (denoted as selected in Table C.1)	List developed by PNNL staff based on species found in riverine and riparian habitats of the study area: the Columbia River between the vicinity of Priest Rapids Dam and McNary Dam	368
Tier I (listed in Table C.2, Appendix C, Part I)	List developed by <ul style="list-style-type: none">◆ Panel of regional biologists based on<ul style="list-style-type: none">- Commercial or recreational importance- Legal protection status- Key predator or prey species- High potential exposure to contaminants- Available toxicological information- Representative of a foraging guild◆ PNNL selection of highest-scoring species from panel screening, resulting in 93 species◆ CRCIA Team identification of key species based on cultural and ecological importance, resulting in 88 additional species	181
Interim Grouping (listed in Table C.3, Appendix C, Part I)	List developed by <ul style="list-style-type: none">◆ PNNL grouping some species based on similar life styles and trophic levels, resulting in 121 species/groups of species● CRCIA Team adding 5 species based on cultural and ecological importance	126
Tentative Tier II (listed in Table 4.17)	List developed by <ul style="list-style-type: none">◆ PNNL based on highest rank in<ul style="list-style-type: none">- Exposure to biotic and abiotic media- Exposure duration- Acute radiation sensitivity◆ CRCIA Team based on<ul style="list-style-type: none">- Cultural and ecological importance	66
Tier II (denoted as selected in Table 4.17)	List developed by PNNL with concurrence of CRCIA Team based on excluding <ul style="list-style-type: none">◆ Species with a life style similar to that of another Tier II species◆ Species with low average summary scores◆ Species that virtually never occur in the river or riparian zone	52

3. The Pacific Northwest National Laboratory formed a panel of regional biologists who developed a set of criteria for screening the study area species. Ninety-three species were identified based on the scoring results of these six criteria.
4. Based on cultural and ecological importance, an additional 87 species and fungi (added as a broad taxon rather than individual species) were provided by the CRCIA Team to create a final list of 181 Tier I species.

Master List of Species. A master list of species was assembled that included terrestrial and aquatic plant and animal species known to occur in riverine and riparian habitats of the Columbia River between the vicinity of Priest Rapids Dam and the Columbia River estuary. The master list was developed by selecting species from databases and records maintained by the following federal and state resource management agencies associated with the Columbia River and its environs and by consulting USACE (1976):

- ◆ Bonneville Power Administration, Northwest Environmental Database
- ◆ Oregon Department of Environmental Quality, Columbia River Bi-State Program
- ◆ Oregon Department of Fish and Wildlife, Wildlife Diversity Plan
- ◆ Oregon Natural Heritage Program
- ◆ Pacific States Marine Fisheries Commission, Coordinated Information System
- ◆ U.S. Fish and Wildlife Service, Black Water Island Research Area
- ◆ U.S. Fish and Wildlife Service, McNary National Wildlife Refuge
- ◆ U.S. Fish and Wildlife Service, Ridgefield National Wildlife Refuge
- ◆ U.S. Fish and Wildlife Service, Umatilla National Wildlife Refuge
- ◆ U.S. Fish and Wildlife Service, Willapa National Wildlife Refuge
- ◆ Washington Department of Fish and Wildlife, Priority Habitats Database
- ◆ Washington Department of Natural Resources Natural Heritage Program
- ◆ Washington State Energy Office, Pacific Northwest Rivers Study.

Species distributions and habitat preferences were also obtained from these agencies. The majority of information was obtained from the U.S. Fish and Wildlife Service national wildlife refuges (Figure 4.3). Information on species distributions and habitat preferences was used to exclude species that primarily use upland areas. From the resulting master list, 368 species were identified as those that occur within the study area (Table C.1 in Appendix C, Part I). Because of the many aquatic and terrestrial ecological studies that have been conducted in the study area (see Section 4.1.1), the CRCIA Team concurred that no further field studies were necessary to identify study area species to be considered in the screening ecological risk assessment. (The results of the assessment are provided in Section 4.2.)

Study Area List of Species. This and the following sections present the methodology used to select a limited number of species for the screening ecological risk assessment. (See Section 4.2 for the results of the assessment.) The rationale for the small number of species is that among the major taxa (amphibian, bird, fish, insect, mammal, plant, reptile, etc.) of the 368 study area species on the master list, many have similar life styles (either fully aquatic, semi-aquatic, or primarily riparian) and belong in the same trophic levels (carnivore, herbivore, omnivore, etc.). Where such similarities exist, these species likely

Figure 4.3. Locations of U.S. Fish and Wildlife Service National Wildlife Refuges Consulted in Preparation of the Master List of Species

contact contaminated media in much the same way. Thus their potential exposure to contaminants is probably similar. Also, much of the data required to estimate contaminant exposure and the effects for many of the 368 species are lacking. This lack of data would greatly increase the uncertainty of the risk assessments for these species. Because of the redundancy in exposure and increased uncertainty in the risk assessments of the species for which data are lacking, the 368 study area species on the master list were reduced further in number.

The Pacific Northwest National Laboratory formed a panel of regional biologists who developed a set of criteria for screening the study area species (Table 4.2).

The criteria developed by the panel were:

- ◆ Commercial or recreational importance
- ◆ Protection status under the Endangered Species Act or similar state legislation
- ◆ Critical component of either the riparian or aquatic ecosystem: key predator or prey
- ◆ High potential exposure to contaminants
- ◆ Availability of toxicological information for the species
- ◆ Representative of a foraging guild
- ◆ Exotic versus native species

Table 4.2. Panel Members of Regional Biologists Who Developed the Criteria Used to Screen Study Area Species

Pacific Northwest National Laboratory	Federal and State Resource Management Agencies
D. Becker C. Brandt C. Cushing D. Dauble S. Friant D. Geist J. Hall D. Maughan R. Mazaika D. Neitzel W. Rickard M. Sackschewsky D. Schreffler	L. Block (U.S. Fish and Wildlife Service) P. Camp (Bureau of Land Management) C. Christiansen (U.S. Army Corps of Engineers) G. Dorsey (U.S. Army Corps of Engineers) L. Fitzner (Washington Department of Wildlife) D. Linehan (U.S. Fish and Wildlife Service) G. McCabe (National Marine Fisheries Service) L. Mettler (U.S. Army Corps of Engineers) S. Norwood (Washington Department of Natural Resources) T. Panskey (Bonneville Power Administration) D. Pock (Grant County Public Utility District) D. Rondorf (National Biological Survey) B. Shank (Bonneville Power Administration) D. Yon (Oregon Department of Environmental Quality)

Each species received a positive or negative response to each of the six criteria. Three or more positive responses were selected as an arbitrary cutoff, resulting in selection of 93 (roughly 25 percent) of the 368 study area species. These 93 species were submitted to the CRCIA Team for review and input. An additional 88 species (based on their cultural and ecological importance) were provided by the CRCIA Team to create a list of 181 Tier I species (Table 4.3 and C.2 in Appendix C). These species provided a balanced representation of the taxa in the study area list and were thus identified for further evaluation in the screening assessment of ecological risk.

4.1.2.2 Tier II Species Screen

A list of Tier II species was identified using the following protocol. The 181 Tier I species were ranked based on a scoring of their exposure to contaminants and acute radiation sensitivity using a conceptual exposure model for the study area that was approved by the CRCIA Team. In the model, species scores were assigned based on:

This section describes the details of the various screens used to arrive at the species on the Tier II list.

- ◆ Potential dietary exposure to biomagnifying and non-biomagnifying contaminants
- ◆ Potential dermal and inhalation exposure to contaminants
- ◆ Potential exposure to contaminated media weighted to reflect the relative importance of these contaminated media at the two types of source areas (outfall structure and in-river, see Section 4.1.2.2.8)
- ◆ Exposure duration
- ◆ Acute radiation sensitivity

Table 4.3. Number of Species by Taxonomic Group at Various Stages of the Tier I Screening Process

Stages	Algae	Amphibians	Aquatic Invertebrate	Birds	Emergent Vegetation	Fish	Fungi	Macrophytes	Mammals	Reptiles	Terrestrial Invertebrate	Terrestrial Vegetation	Total
No. of Study Area Species on the Master List	17	6	12	112	21	51	0	5	30	1	1	112	368
No. of Study Area Species Selected by Panel Screening	12	2	9	29	7	17	0	5	9	0	0	3	93
Percent of Study Area Species Selected by Panel Screening	71%	33%	75%	26%	33%	33%	0%	100%	31%	0%	0%	3%	25%
No. of Species Added by the CRCIA Team	0	2	6	19	1	7	1 ^(a)	0	12	7	7	26	88
Total No. of Tier I Species ^(b)	12	4	15	48	8	24	1	5	21	7	7	29	181
Percent of Total Number of Tier I Species	7%	2%	8%	26%	4%	13%	1%	3%	12%	4%	4%	16%	100%

(a) Fungi were added by the CRCIA Team as a broad taxonomic group and were evaluated as such in the Tier II species screen.

(b) The number of Tier I species was derived by summing the number of study area species identified by the panel with the number of species added by the CRCIA Team.

The resulting ranks, which indicated the qualitative, relative exposure of species within taxonomic groups, were presented to the CRCIA Team. The CRCIA Team then identified 65 of these as tentative Tier II species based on their rank and cultural and ecological importance. These 65 were further reduced to 52 final Tier II species by excluding 1) those with a life style similar to that of another Tier II species, 2) those with low average summary scores, and 3) those that virtually never occur in the river or riparian zone. These 52 Tier II species are those for which contaminant exposures and effects will be analyzed in the screening assessment of ecological risk, the results of which are presented in Section 4.2).

4.1.2.2.1 Methods. In general, the magnitude of an individual's exposure to a contaminant is a function of the

- ◆ Concentration of the contaminant in the media (in other words, air, groundwater, prey, sediment, soil, and surface water) contacted by the individual
- ◆ Number of media contacted by the individual
- ◆ Number of pathways (in other words, dermal, ingestion, inhalation) by which contaminated media may enter the organism
- ◆ Duration of an individual's contact with the contaminated media

To arrive at a simplified conceptual exposure model, species were first grouped by life style as either fully aquatic, semi-aquatic, or primarily riparian. Within life styles, species were grouped primarily by major taxa; for example, amphibian, bird, fish, insect, mammal, plant, reptile. Within taxonomic groups, species were grouped largely by trophic level; for example, carnivore, herbivore, omnivore. The species in each taxonomic group and trophic level were evaluated to determine their potential exposure to contaminated abiotic media (air, groundwater, pore water, sediment, soil, and surface water) at source areas believed to have contaminant loads sufficient to pose a substantial hazard at one or more critical life stages using a general conceptual exposure model approved by the CRCIA Team. The contaminant source areas are shown in Table 4.4 and evaluated further in Section 4.1.2.2.8. Results are shown in Tables 4.5, 4.6, and 4.7 for aquatic, semi-aquatic, and terrestrial species, respectively. Exposure to biotic media such as prey is addressed in Section 4.1.2.2.2.

Of the 181 Tier I species, some were grouped based on similar life styles and trophic levels resulting in 121 species. The CRCIA Team added 5 species to the 121 for a total of 126 species. The 126 species were scored, using the conceptual exposure model described above, for their potential exposure to contaminated media. Scores were scaled to reflect the general magnitude of a species potential exposure to contaminants in each medium, the duration of exposure, and acute radiation sensitivity. These scores represent an index of the relative exposure of species within taxonomic groups. These scores do not represent real differences in exposure. Species were scored specifically on:

- ◆ **Exposure to Biotic and Abiotic Media:** Exposure to media occurs when a species 1) ingests prey, sediment/soil, pore water/groundwater, or surface water which are contaminated; 2) comes in dermal contact with those media; or 3) inhales air-borne contaminants. Scores were assigned to each species for each medium. For the ingestion of prey, scores were differentiated depending on whether the

Table 4.4. Contaminant Source Areas and Their Potentially Contaminated Media within the Study Area

Contaminant Source Areas	Media					
	Sediment	Surface Water	Pore Water	Groundwater	Soil	Air
Outfall Structure	•	•	•	•	•	•
In-River						
McNary Pool	•	•	•			
Sloughs	•	•	•			
Deep Holes	•	•	•			
Near-Shore Areas	•	•	•			
Seep/Spring		•		•	•	•
Note: Filled cells indicate contaminated media at the source areas. Blank cells indicate media at the source areas that are not contaminated or have very low contamination levels relative to the other media.						

contaminants were biomagnifying or non-biomagnifying. All media scores were scaled from 1 to 4 to ensure that all pathways/media were considered of equal importance in their contribution to an individual's overall exposure. In some pathway/media exposure scenarios, scores were scaled from 0 to 4 (see Sections 4.1.2.2.3-4.1.2.2.6) because these scenarios included the possibility of no exposure. The use of the zero, however, did not change the sum of the species' scores or the ultimate rankings. Sections 4.1.2.2.2-4.1.2.2.8 describe the basis and provide examples of the score assignments.

- ◆ **Exposure Duration:** Scores were assigned to each species based on the amount of time they reside in the study area. Exposure duration scores were scaled from 1 to 4. Section 4.1.2.2.9 describes the basis and provides examples of the score assignments.
- ◆ **Acute Radiation Sensitivity:** For exposure to radiation, scores were assigned to each species based on the dose that is lethal to 50 percent of test organisms (LD₅₀) (Whicker and Schultz 1982). Acute radiation sensitivity scores were also scaled from 1 to 4. Section 4.1.2.2.10 describes the basis and provides examples of the score assignments.

Three types of score summaries were performed:

First, scores of exposure to media were summed separately for biomagnifying and non-biomagnifying contaminants with all media assumed to contribute equally to exposure.

Second, media scores were weighted to reflect the degree of exposure to contaminants at the two types of source areas (in-river and outfall structure, see Section 4.1.2.2.8). Weighted scores were summed for biomagnifying and non-biomagnifying contaminants at the two types of source areas. Weighted scores

Table 4.5. General Conceptual Exposure Model Depicting Generic Exposure Pathways/Abiotic Media for Several Aquatic Species

Primary Group	Secondary Group/Species	Exposure Pathways/Abiotic Media					
		Dermal Exposure ^(a)			Ingestion Exposure ^(b)		
		Sediment	Pore Water/ Groundwater	Surface Water	Sediment	Pore Water/ Groundwater ^(c)	Surface Water ^(c)
Primary producers	Algae	• ^(d)	•	•	NA ^(e)	NA	NA
	Macrophytes	•	•	•	NA	NA	NA
Invertebrates	Benthos	•	•	•	•	•	•
	Zooplankton			•			•
	Macroscopic Arthropods	•	•	•	•	•	•
	Mollusks	•	•	•	•	•	•
Resident fish	Herbivores; e.g., ♦ sucker	• ^(f)	• ^(f)	•	•	•	•
	Carnivores; ^(g) e.g., ♦ rainbow trout ♦ squawfish ♦ sturgeon ♦ bass	• ^(f)	• ^(f)	•	• ^(h)	• ^(h)	•
Non-resident fish; i.e., anadromous species	Carnivores; e.g., ♦ lamprey ♦ shad ♦ chinook salmon	• ^(f)	• ^(f)	•	Anadromous species do not feed in the river		
Amphibians	Bullfrog	•	•	•	• ⁽ⁱ⁾	• ⁽ⁱ⁾	• ⁽ⁱ⁾
<p>Note: Filled cells indicate scenarios where exposure pathways are complete at one or more life stages. Blank cells indicate scenarios where exposure pathways are incomplete.</p> <p>(a) Dermal exposure to surface water includes exposure via respiration of water. Exposure via respiration of water is assumed to be a complete pathway for all these aquatic species except the bullfrog. The air inhalation pathway was not included here because it applies only to the bullfrog. For the bullfrog, the air inhalation pathway is assumed to be complete.</p> <p>(b) Ingestion of biotic media (prey) is described in Section 4.1.2.2.2 and Table 4.8.</p> <p>(c) Aquatic species ingest water only incidental to prey consumption.</p> <p>(d) All • = Exposure at all life stages unless otherwise indicated.</p> <p>(e) NA = Not Applicable.</p> <p>(f) Exposure of eggs only.</p> <p>(g) Carnivorous fish include those which ingest invertebrates and/or other fish.</p> <p>(h) None for piscivores.</p> <p>(i) Exposure of larvae only.</p>							

were averaged across source areas and across biomagnifying/non-biomagnifying contaminants to obtain a grand average exposure score. Species were ranked based on these grand average exposure scores.

Third, grand average exposure scores (divided by 15 to retain the same scale as exposure duration and acute radiation sensitivity) were added to exposure duration and acute radiation sensitivity scores to obtain a single composite score. Species were also ranked based on these composite scores.

Table 4.6. General Conceptual Exposure Model Depicting Generic Exposure Pathways/Abiotic Media for Several Semi-Aquatic Species

Primary Group	Secondary Group/Species	Exposure Pathways/Abiotic Media ^(a)					
		Dermal Exposure			Ingestion Exposure ^(b)		
		Sediment/ Soil	Pore Water/ Groundwater	Surface Water	Sediment/ Soil	Pore Water/ Groundwater	Surface Water
Plants	Emergent Vegetation	•(c)	•	•	NA ^(d)	NA	NA
Birds	Wading Birds and Aquatic Insectivores	•		•	•	•	•
	Piscivores; e.g., ♦ merganser ♦ loon ♦ pelican ♦ cormorant	•(e)		•	•		•
	Herbivores; e.g., ♦ redhead duck ♦ goose/mallard	•(e)		•	•		•
Mammals	Carnivores; e.g., ♦ river otter	•		•			•
	Herbivores; e.g., ♦ beaver	•		•	•		•
	Omnivores; e.g., ♦ muskrat	•		•	•	•	•
Amphibians	Woodhouse's toad	•	•(f)	•	•(f)	•(f)	•(f)

Note: Filled cells indicate scenarios where exposure pathways are complete at one or more life stages. Blank cells indicate scenarios where exposure pathways are incomplete.

(a) The air inhalation pathway was not included here because it is assumed to be complete for these semi-aquatic species.

(b) Ingestion of biotic media (prey) is described in Section 4.1.2.2.2 and Table 4.8.

(c) All • = Exposure at all life stages unless otherwise indicated.

(d) NA = Not Applicable.

(e) Includes preening exposure.

(f) Exposure of larvae only.

All rankings were assigned within taxonomic groups (algae, amphibians, aquatic invertebrates, birds, emergent vegetation, fish, fungi, macrophytes, mammals, reptiles, terrestrial invertebrates, and terrestrial vegetation). These ranks indicated the qualitative, relative exposure of species within taxonomic groups. The results of the scoring are shown in Table C.3 in Appendix C (Part I). The following sections explain the basis of the score assignments and thus the ultimate rankings.

4.1.2.2.2 Biotic Ingestion Pathway: Exposure to Contaminants in Prey. The magnitude of an individual's ingestion exposure due to consumption of prey depends on the composition of the individual's prey, the quantity of prey, and the contaminant body burdens of the various prey. The latter is related to

Table 4.7. General Conceptual Exposure Model Depicting Generic Exposure Pathways/Abiotic Media for Several Terrestrial Species

Primary Group	Secondary Group/Species	Exposure Pathways/Abiotic Media ^(a)					
		Dermal Exposure			Ingestion Exposure ^(b)		
		Soil	Groundwater	Surface water	Soil	Groundwater	Surface Water
Plants	Deep-Rooted	• ^(c)	•	•	NA ^(d)	NA	NA ^(d)
	Shallow-Rooted	•		•	NA	NA	NA
Insects	Insects	•		•	•		•
Birds	Insectivores; e.g., ♦ swallow ♦ kingbird	• ^(e)		•	•		•
	Carnivores; e.g., ♦ kingfisher ♦ bald eagle ♦ osprey	• ^(e)		•			•
Mammals	Bats						•
	Insectivores; e.g., ♦ shrew ♦ grasshopper mouse	•		•	•		•
	Herbivores; e.g., ♦ mice ♦ porcupine ♦ deer	•		•	•		•
	Carnivores/Omnivores; e.g., ♦ coyote ♦ skunk	•		•			•
Reptiles	Lizards	•			•		
	Snakes	•		•	•		

Note: Filled cells indicate scenarios where exposure pathways are complete at one or more life stages. Blank cells indicate scenarios where exposure pathways are incomplete.

(a) The air inhalation pathway is not included here because it is assumed to be complete for these terrestrial species.

(b) Ingestion of biotic media (prey) is described in Section 4.1.2.2.2 and Table 4.8.

(c) All • = Exposure at all life stages.

(d) NA = Not Applicable.

(e) Includes preening exposure.

the predator's position in the food chain (Figures 4.1 and 4.2) and whether biomagnifying or non-biomagnifying contaminants are present. Biomagnifying contaminants are those that occur in higher concentrations at higher food chain levels through dietary accumulation. Non-biomagnifying contaminants are those that remain at the same concentration or decrease in concentration at higher levels in the food web. Consequently, species at the top of the food chain received a higher score for biomagnifying contaminants and a lower score for non-biomagnifying contaminants. Conversely, species at the base of the food chain received a lower score for biomagnifying contaminants and a higher score for

non-biomagnifying contaminants (Table 4.8). For example, the bald eagle is a top level carnivore. It received a biomagnifier score of 4 and a non-biomagnifier score of 1. In contrast, the suckers are herbivores. They received a biomagnifier score of 2 and a non-biomagnifier score of 3. Emergent vegetation is classified as a producer. It received a biomagnifier score of 1 and a non-biomagnifier score of 4. To note is that individual contaminants were not identified as biomagnifying or non-biomagnifying but rather were grouped only generically as such.

Table 4.8. Scoring Scheme for Tier I Species' Ingestion Exposure to Contaminants in Prey

Predator Food Chain Level	Type of Contaminant in Prey	
	Biomagnifying	Non-Biomagnifying
Producer	1	4
Herbivore	2	3
Omnivore	3	2
Carnivore	4	1

4.1.2.2.3 Abiotic Ingestion Pathway: Exposure to Contaminants in Sediment/Soil and Pore Water/Groundwater. The magnitude of an individual's ingestion exposure to contaminants in sediment/soil and pore water/groundwater depends on the frequency and intimacy of an individual's contact with these media. Species whose foraging and life style allow frequent ingestion of sediment/soil and pore water/groundwater throughout their entire lives received a higher score. Species whose foraging and life style allow only occasional ingestion of these media throughout only a portion of their lives received a lower score (Table 4.9). For example, channel catfish forage on the river bottom throughout most of their lives where they ingest sediment and pore water incidental to consumption of benthic invertebrates. Thus, channel catfish received a score of 4 for ingestion of these media. Chinook salmon feed in the river only as juveniles when they feed both in the water column and on the river bottom. Thus, they occasionally ingest sediment and pore water incidental to consumption of aquatic insect larvae. Although adult chinook return to the study area to spawn, they do not feed during their up-river migration or spawning.

Table 4.9. Scoring Scheme for Tier I Species' Ingestion Exposure to Contaminants in Sediment/Soil and Pore Water/Groundwater

Frequency of Exposure	Life Stage		
	Juvenile	Adult	Whole Life
None	0	0	0
Occasional	1	1	2
Often	2	2	4

Thus, chinook received a score of 1 for ingestion of sediment and a score of 1 for ingestion of pore water. The western harvest mouse occasionally ingests soil throughout its entire life incidental to consumption of vegetation and invertebrates. The harvest mouse does not consume prey from the river. Thus, the harvest mouse received a score of 2 for ingestion of soil and a score of 0 for ingestion of pore water/groundwater. Juvenile and adult life stages were weighted the same because for most Tier II species too little toxicological information exists about general life-stage-dependent differences in sensitivities to contaminants to weight one life stage heavier than another. Where such toxicological data exist, the data have been compared to life-stage specific contaminant exposure estimates for Tier II species (see the ecological risk assessment in Section 4.2).

4.1.2.2.4 Abiotic Ingestion Pathway: Exposure to Contaminants in Surface Water. The magnitude of an individual's ingestion exposure to contaminants in surface water depends primarily on whether it drinks from the river or consumes prey from the river. Because seeps and springs at the river shoreline are small and few in number, terrestrial species' ingestion exposure to contaminants in water likely comes mostly from the river. Nonetheless, because contaminant concentrations in river water are generally much less than in seeps, springs, and groundwater, 100 percent of terrestrial animals' exposure to contaminants via ingestion of water will be estimated in the screening assessment of ecological risk (see Section 4.2) using contaminant data from seeps and springs where such data are available. Species that consume water from the river incidental to prey consumption, such as fish and benthic invertebrates, and species that both drink water and consume prey from the river, such as piscivorous birds and muskrat, all received a score of 4 for ingestion of surface water (Table 4.10). Species that drink from, but do not feed in the river, such as beaver, California quail, and owls, received a score of 2 for ingestion of surface water.

Table 4.10. Scoring Scheme for Tier I Species' Ingestion Exposure to Contaminants in Surface Water

Degree of Exposure			
Neither Drinks nor Consumes Prey from the River	Drinks from the River	Consumes Prey from the River	Drinks and Consumes Prey from the River
0	2	2	4

4.1.2.2.5 Dermal Pathway: Exposure to Contaminants in Sediment/Soil and Pore Water/Groundwater. Those species whose life styles allow frequent dermal contact with sediment/soil and pore water/groundwater throughout their entire lives were scored higher. Species whose life style allows only occasional dermal contact with these media throughout only a portion of their lives received a lower score (Table 4.11). For example, all of the avian species occasionally bathe in dust after fledging and thus received a score of 2 for dermal exposure to soil. However, avian species that virtually never make dermal contact with sediment will also not likely make dermal contact with pore water. Thus, these received a score of 0 for this medium. All of the mammals make occasional extensive dermal contact with soil via burrowing, resting, etc., throughout their entire lives and thus received a score of 2 for dermal exposure to soil. Like birds, however, mammal species virtually never make dermal contact with pore water and thus received a score of 0 for this medium. In contrast, benthic species, such as channel catfish and aquatic

invertebrates, spend most of their lives in contact with sediment and pore water and thus received a score of 4 for dermal exposure to both these media. Juvenile and adult life stages were weighted the same because for most Tier II species too little toxicological information exists about general life-stage-dependent differences in sensitivities to contaminants to weight one life stage heavier than another. Where such toxicological data exist, the data have been compared to life-stage specific contaminant exposure estimates for Tier II species (see the ecological risk assessment in Section 4.2). The data required to determine sensitivity differences at the life-stage level have been assembled for use in the screening assessment of ecological risk.

Table 4.11. Scoring Scheme for Tier I Species' Dermal Exposure to Contaminants in Sediment/Soil and Pore Water/Groundwater

Frequency of Exposure	Life Stage		
	Juvenile	Adult	Whole Life
None	0	0	0
Occasional	1	1	2
Often	2	2	4

4.1.2.2.6 Dermal Pathway: Exposure to Contaminants in Surface Water. The magnitude of an individual's dermal exposure to contaminants in surface water depends on whether it is never immersed, seldom immersed, frequently immersed, or always immersed in the river (Table 4.12). Because seeps and springs at the river shoreline are small and few in number, terrestrial species' dermal exposure to contaminants in water likely comes mostly from the river. Nonetheless, because contaminant concentrations in river water are generally much less than in seeps and springs and groundwater, 100 percent of terrestrial animals' dermal exposure to contaminants in water will be estimated in the screening assessment of ecological risk (see Section 4.2) using contaminant data from seeps and springs where such data are available. For example, species whose life style is completely aquatic, such as aquatic vegetation, benthic invertebrates, and fish, received a score of 4 for dermal exposure to surface water. For the purpose of scoring fully aquatic species, dermal exposure to surface water also includes exposure via respiration of water; consequently, exposure via respiration of water by fully aquatic species was not addressed under the inhalation pathway, the subject of Section 4.1.2.2.7. Species which are semi-aquatic, such as the piscivorous birds and some of the mammals, received a score of 2. Species which are terrestrial and are seldom immersed in the river, such as the red-winged blackbird, bald eagle, and mule deer, received a score of 1. Terrestrial species which are virtually never in the river, such as mice, northern harrier, American kestrel, and owls, received a score of 0.

Table 4.12. Scoring Scheme for Tier I Species' Dermal Exposure to Contaminants in Surface Water

Frequency of Immersion in River Water			
Never	Seldom	Frequently	Always
0	1	2	4

In general, the primary mechanism of contaminant uptake for many fully aquatic species is via direct uptake across permeable membranes such as gill structures (addressed under dermal uptake in this section and Section 4.1.2.2.5). This can occur as a passive transfer or an active biological process (osmoregulation). Prey consumption (Section 4.1.2.2.2), incidental ingestion of sediment and pore water/groundwater during prey consumption (Section 4.1.2.2.3), and incidental ingestion of surface water during prey consumption (Section 4.1.2.2.4) are probably secondary uptake mechanisms.

4.1.2.2.7 Inhalation Pathway: Exposure to Contaminants in Air. Because the source of airborne contaminants in the study area is soil or surface water, the magnitude of an individual's inhalation exposure is a function of the amount of time the individual is close to these media. For example, species that spend most of their time within 0.5 meter (an arbitrary distance) of surface water received a higher score than those that spend most of their time more than 1.0 meter (also an arbitrary distance) from surface water (Table 4.13). Ground-nesting birds that forage on the water or ground, such as Canada geese and dabbling ducks (primarily herbivorous), received a score of 3 for inhalation exposure. Birds that forage on the water or ground but nest in trees, such as the great blue heron and red-winged blackbird, received a score of 2. Birds that occasionally forage on the water or ground and nest in trees, such as the raptors, received a score of 1. Completely aquatic species, such as macrophytes, benthic invertebrates, and fish, respire water and thus received a score of 0 for inhalation of air-borne contaminants. Respiration of water-borne contaminants by fully aquatic species was scored under dermal exposure to surface water (see Section 4.1.2.2.6).

Table 4.13. Scoring Scheme for Tier I Species' Inhalation Exposure to Contaminants in Air

Distance above the Surface (meters)		
Mostly > 1.0 m	Mostly < 1.0 m	Always < 0.5 m
1	2	3

4.1.2.2.8 Media Weighting. As noted in Table 4.4, media contamination varies between source areas. A weighting scheme was devised to account for this variation by scoring media according to their level of contamination at the two types of source areas, outfall structure and in-river. In-river source areas include deep holes, McNary Pool, near-shore areas, sloughs, and seeps/springs (see Table 4.4). Scores consist of 0 (little or no contaminant burden), 1 (moderate contaminant burden), and 2 (high contaminant burden).

For the in-river source areas, most of the contaminant burden is associated with in-flowing contaminated groundwater, pore water, and sediment. The high volume and flow rate of the Columbia River rapidly dilutes water-borne contaminants to well below groundwater levels so surface water has lower concentrations of contaminants than groundwater, pore water, and sediment (Dirkes and Hanf 1996). The air contaminant burden is thus very low for in-river source areas. In contrast, surface soil, not groundwater, is the primary contaminated medium at the outfall source areas. Air, therefore, received a score of 2 at the outfall and 0 at the in-river source areas. Many aquatic and terrestrial prey species are likely to contact contaminants at the outfall and in-river areas (for example, in prey, sediment, soil, groundwater, pore water, surface water, air). Thus, prey received a score of 2 for both areas. Sediment and soil serve as a sink for contaminants at both the in-river and outfall areas, respectively, and thus received a score of 2 for both. Groundwater/pore water received a score of 1 at the outfall areas and a score of 2 at the in-river areas. Although contaminants enter surface water directly from the outfall and in-river areas, water-borne contaminants are highly diluted by the river. Thus, surface water received a score of 1 for both of these source areas (Table 4.14).

Table 4.14. Media Weighting Reflecting Relative Levels of Contamination at Outfall Structure and In-River Source Areas (see also Table 4.4)

Contaminant Source Areas	Media				
	Air	Prey	Sediment/Soil	Groundwater/ Pore Water	Surface Water
Outfall Structure	2	2	2	1	1
In-River	0	2	2	2	1

4.1.2.2.9 Exposure Duration. The magnitude of an individual's exposure to contaminants also depends on exposure duration. As there is neither specific information regarding where migratory species go after they leave the study area nor information about the contaminants they might be exposed to, residence time in the study area is the only indicator of exposure duration available for this species screen. Exposure duration scores were scaled to cover the same range as the other exposure scores (Table 4.15). Species that migrate through the study area received a score of 1. Species that migrate but remain in the area for one or two seasons received a score of 2. Species that reside in the study area year-round received a score of 4.

Table 4.15. Scoring Scheme for Exposure Duration

Residence Time in Study Area		
Only Briefly in Study Area	In Study Area 1 or 2 Seasons	Lifetime Resident of Study Area
1	2	4

4.1.2.2.10 Acute Radiation Sensitivity. Acute radiation sensitivity scores were scaled to cover the same range as the scores for exposure to biotic media (Section 4.1.2.2.2), abiotic media (Sections 4.1.2.2.3-4.1.2.2.7), and exposure duration (Section 4.1.2.2.9), in other words, from 1 to 4. Because eleven of the 23 contaminants of concern are radionuclides (see Section 2.0), acute radiation sensitivity was used as the basis for scoring species. Acute radiation sensitivity is not believed to be an a priori risk driver. It is used here only to select species. In the screening assessment of ecological risk (see Section 4.2), potential risk to species will be evaluated on a contaminant-by-contaminant basis using all 23 contaminants and considering both radiological and chemical toxicities). Because too little information was available on the sensitivity of all Tier I species to these individual radionuclides, species were put into broad groups. These groups were scored based on LD₅₀ thresholds for acute radiation exposure (Whicker and Schultz 1982). For example, lower plants received the lowest score, and mammals and birds received the highest score because they are the most sensitive to radiation exposure (Table 4.16).

Table 4.16. Scoring Scheme for Acute Exposure to Radiation
(scores based on LD₅₀ for radiation exposure)

Lower Plants	Higher Plants/Insects	Amphibians/ Fish/Reptiles	Birds/Mammals
1	2	3	4

4.1.2.2.11 Summary of Scores. The scores (qualitative, relative exposure of species within taxonomic groups) for each species' exposure to media, exposure duration, sensitivity to radiation, and the media weightings were summarized as follows in Table C.3 (Appendix C, Part I):

1. Scores of abiotic ingestion exposure to sediment/soil (row 5), groundwater/pore water (row 6), and surface water (row 7) were summed and added separately to scores of biotic ingestion exposure to biomagnifying contaminants in prey (row 3) and non-biomagnifying contaminants in prey (row 4). This provided summary scores indicating ingestion exposure to biomagnifying contaminants (row 1) and non-biomagnifying contaminants (row 2) in all media with all media treated equally.
2. Scores of dermal exposure to sediment/soil (row 9), groundwater/pore water (row 10), and surface water (row 11) were summed. This provided summary scores (row 8) indicating dermal exposure to contaminants in all media with all media treated equally.
3. Inhalation scores (row 12) and dermal summary scores (row 8) were summed and added separately to ingestion summary scores for biomagnifying contaminants (row 1) and non-biomagnifying contaminants (row 2). This provided summary scores indicating overall exposure to biomagnifying contaminants (row 13) and non-biomagnifying contaminants (row 14) in all media with all media treated equally.
4. Media weightings for the outfall structure and in-river source areas (see Table 4.14) were multiplied with scores of abiotic ingestion exposure to sediment/soil (row 5), groundwater/pore water (row 6),

and surface water (row 7), with scores of dermal exposure to sediment/soil (row 9), groundwater/ pore water (row 10), and surface water (row 11), with scores of inhalation exposure (row 12), and with scores of biotic ingestion exposure to biomagnifying contaminants in prey (row 3) and non-biomagnifying contaminants in prey (row 4). These products were summed separately for biomagnifying contaminants and non-biomagnifying contaminants. This provided summary scores indicating overall exposure to biomagnifying contaminants and non-biomagnifying contaminants at the in-river (rows 16 and 17) and outfall structure (rows 20 and 21) source areas.

5. Species were rank-ordered within major taxonomic groups (rows 18 and 19) based on summary scores of overall exposure to biomagnifying and non-biomagnifying contaminants at the in-river source areas (rows 16 and 17). Species were rank-ordered within major taxonomic groups (rows 22 and 23) based on summary scores of overall exposure to biomagnifying and non-biomagnifying contaminants at the outfall source area (rows 20 and 21).
6. The rank order of species was very similar between the in-river biomagnifier and outfall biomagnifier scenarios (rows 18 and 22). The rank order of species was very similar between the in-river non-biomagnifier and outfall non-biomagnifier scenarios (rows 19 and 23). Consequently, in-river biomagnifier summary scores (row 16) and outfall biomagnifier summary scores (row 20) were averaged (row 24). Likewise, in-river non-biomagnifier summary scores (row 17) and outfall non-biomagnifier summary scores (row 21) were averaged (row 25).
7. Species were rank-ordered within major taxonomic groups (rows 26 and 27) based on average biomagnifier summary scores (row 24) and average non-biomagnifier summary scores (row 25). The maximum of these two ranks was selected (row 28). The maximum rank provided an indication of relative exposure among species within taxonomic groups.
8. The highest of the average biomagnifier summary scores (row 24) and average non-biomagnifier summary scores (row 25) was selected. Because the highest average summary scores ranged up to 61 (see tule under emergent vegetation, row 24), it was necessary to re-scale by dividing these by 15 so that the composite effects scores would have approximately the same weight as the exposure duration and acute radiation sensitivity scores. The result was then added to the acute radiation sensitivity scores (row 30) and exposure duration scores (row 32) to produce composite scores (row 34). Species were also ordered by rank within major taxonomic groups (row 35) based on these composite scores (row 34).

The acute radiation sensitivity scoring did not differentiate species within taxonomic groups. Scoring these groups on the basis of other toxicological thresholds, such as the lowest observed adverse effects level or no observed adverse effects level, would not change the relative exposure of species within taxonomic groups as determined by the scoring using LD₅₀ thresholds. However, it did emphasize that representatives of major taxonomic groups should be included in the screening ecological risk assessment (see Section 4.2). Where radionuclide and chemical toxicity data are available for individual species, they will be compared to contaminant exposure estimates for Tier II species (see Section 4.2). Also, the exposure duration scoring is less meaningful because toxicity data are often based on 48-hour to 96-hour exposures. Even the lowest exposure duration for species given a score of 1 exceeds 48-hours. Finally,

there was virtually no difference in the ranking of species within taxonomic groups based on composite scores and highest average summary scores (see point 8 above). Therefore, because the effect of the composite scores in the ranking of species is minimal, the highest average summary scores were considered to be more valuable than the composite scores for the purposes of this species screen.

4.1.2.2.12 Identification of Final Tier II Species. The CRCIA Team selected 65 of the ranked Tier I species (Table C.3, Appendix C, Part I, rows 28 and 35) as tentative Tier II species based on their rank and cultural and ecological importance. These were further reduced to 52 final Tier II species by excluding 1) those with a life style similar to that of another Tier II species, 2) those with low average summary scores, and 3) those that virtually never occur in the river or riparian zone.

Table 4.17 presents the results of ranking the Tier I species, based on highest average summary scores and composite scores, and identifies those selected as Tier II species with a (+) in the right hand column. The Tier II species are those evaluated in the screening assessment of ecological risk (Section 4.2). A high rank (a low numeric value) represents a high potential exposure to contaminated media. Footnote letters (c, d, and e) in the right-hand column indicate that a species was not selected for the final list of Tier II species for the reasons specified in the footnotes.

The number and percent of Tier I species retained during the Tier II screening process are shown in Table 4.18.

Table 4.17. Tier II Species

Taxa/Species ^(a)	Rank Based on Highest Average Summary Scores	Rank Based on Composite Scores	Selected by CRCIA Team as Tentative Tier II Species	Final Tier II Species
Algae				
Periphyton	1	1	*	+
Phytoplankton	1	1	*	+
Amphibians				
Bullfrog	1	1	*	(b)
Spadefoot toad	2	1	*	(c)
Woodhouse's toad	2	1	*	+(b)
Aquatic Invertebrates				
Caddis fly	1	1	*	(c)
Crayfish	1	1	*	+
Fresh water shrimp	1	1	*	+
Mayfly	1	1	*	+
Midge	1	1	*	(c)
Clams/mussels/snails	1	1	*	+
Water flea	10	10	*	+
Birds				
American coot	1	1	*	+
Common snipe	3	2	*	+
Canada goose/mallard	6	6	*	+
Diving ducks (primarily carnivorous; e.g., bufflehead)	7	20	*	+
Great blue heron	8	5	*	+
Forster's tern	9	22	*	+
American white pelican	10	6	*	+
Pied-billed grebe	10	6	*	(c)
Common merganser	10	21	*	(c)
California quail	13	11	*	+
Cliff swallow	17	23	*	+
Red-winged blackbird	18	24	*	(c)
Belted kingfisher	18	24	*	(c)
Osprey	18	24	*	(c)
Bald eagle	22	28	*	+
Northern harrier	26	13	*	+

Table 4.17. (Cont'd)

Taxa/Species ^(a)	Rank Based on Highest Average Summary Scores	Rank Based on Composite Scores	Selected by CRCIA Team as Tentative Tier II Species	Final Tier II Species
American kestrel	27	14	*	+
Barn owl	27	14	*	(d)
Emergent Vegetation				
Tule	1	1	*	+
Fish				
Channel catfish	1	1	*	+
Largescale sucker	2	2	*	+
Mountain sucker	2	2	*	+
Piute sculpin	4	4	*	(c)
White sturgeon	6	6	*	+
Common carp	6	7	*	+
Mountain whitefish	6	7	*	+
Pacific lamprey	8	16	*	+
Small mouth bass	11	9	*	+
Trout (rainbow)	11	11	*	+
Trout (bull)	11	11	*	(c)
Northern squawfish	11	11	*	(d)
Salmon (all)	11	17	*	+
Steelhead trout	18	18	*	(c)
Fungi	1	1	*	+
Macrophytes				
Columbia yellow cress ^(f)	1	1	*	+
Water milfoil	1	1	*	+
Duckweed	4	4	*	(c)
Mammals				
Muskrat	1	1	*	+
Beaver	3	3	*	+
Coyote	3	3	*	+
Raccoon	3	3	*	+
Short-tailed and long-tailed weasel	3	3	*	+
Mule deer	3	10	*	+
Great Basin pocket mouse	4	11	*	(e)
Western harvest mouse	9	11	*	+

Table 4.17. (Cont'd)

Taxa/Species ^(a)	Rank Based on Highest Average Summary Scores	Rank Based on Composite Scores	Selected by CRCIA Team as Tentative Tier II Species	Final Tier II Species
Reptiles				
Western garter snake	1	1	*	+
Side-blotched lizard	3	6	*	+
Terrestrial Vegetation				
Black cottonwood	1	1	*	+
Dense sedge	1	1	*	+
Fern (all)	1	1	*	+
White mulberry	1	1	*	+
Reed canary grass	1	1	*	+
Rushes (all)	1	1	*	+
Willow (all)	1	1	*	(c)

- (a) Terrestrial invertebrates are not included in this table because no species in these taxon were selected by the CRCIA Team as tentative Tier II species.
- (b) The bullfrog, which received the highest rank, was not selected as the final Tier II species for the amphibian group. It is known to occur in ponds at the base of the White Bluffs along the Columbia River and in the W-B10 Wasteway Lake. According to an unpublished report by L.A. Hallock at the Nature Conservancy of Washington, the bullfrog may occur along the Hanford Reach, based on calls, but its presence there has not been confirmed by observation. Also according to Hallock, the adult Woodhouse's toad has been observed in the Columbia River sloughs, although it is not known whether it uses these sloughs for breeding. Because Woodhouse's toad has actually been observed using the Columbia River and because it is a state monitor species, Woodhouse's toad was selected as the final Tier II species for the amphibian group, although it received a lower rank than the bullfrog.
- (c) Species with a life style and exposure scenario similar to that of another Tier II species:
- Belted King Fisher and osprey similar to bald eagle
 - Bull trout similar to rainbow trout
 - Caddis fly similar to mayfly
 - Common merganser similar to American coot
 - Duckweed similar to Columbia yellowcress
 - Midge similar to mayfly
 - Pied-billed grebe similar to diving duck
 - Piute sculpin similar to channel catfish
 - Red-winged blackbird similar to cliff swallow
 - Spadefoot toad similar to Woodhouses's toad
 - Steelhead trout similar to salmon
 - Willow similar to all the other selected terrestrial vegetation
- (d) Species with low average summary scores.
- (e) Species that virtually never occur in the river or riparian zone.
- (f) Although not strictly a macrophyte, Columbia yellowcress is grouped with them because it is submerged part of the year and has much the same exposure characteristics as macrophytes.
- + One of the 52 Tier II species

Table 4.18. Number of Tier I Species by Taxonomic Group Retained in the Tier II Species Screen

	Algae	Amphibians	Aquatic Invertebrates	Birds	Emergent Vegetation	Fish	Fungi	Macrophytes	Mammals	Reptiles	Terrestrial Invertebrates	Terrestrial Vegetation	Total
No. of Tier I Species	12	4	15	48	8	24	1	5	21	7	7	29	181
No. of Tier I Species Selected by the CRCIA Team as Tentative Tier II Species	2 ^(a)	3	7	18	1	14	1	3	8	2	0	7	66
Percent of Tier I Species Selected by the CRCIA Team as Tentative Tier II Species	17%	75%	47%	38%	13%	60%	100%	60%	38%	29%	0%	24%	36%
No. of Tier I Species Selected as Final Tier II Species	2 ^(a)	1	7	13	1	10	1	2	7	2	0	6	52
Percent of Tier I Species Selected as Final Tier II Species	17%	25%	47%	27%	13%	42%	100%	40%	33%	29%	0%	21%	29%

(a) Periphyton and phytoplankton, two broad taxa that include many algae species, were selected as tentative and final Tier II species (see Table 4.17).

4.2 Results: Ecological Risk Screening Assessment

To estimate the potential risk to the environment, we put the data described in Section 3.0, the species described in Section 4.1, and the parameters for those species described in this section into a computer model. The computer model consisted of a series of equations that estimated exposure to contaminants. In this section, we describe how the information from the three sources was used in the equations and what the results of the equations are. We used the exposure results to estimate the possible risk to the environment from contaminants in the Columbia River.

This section presents the analysis of the risk posed by contaminants for the Tier II species. Exposures are estimated using deterministic and stochastic models. Deterministic models use maximum source term and exposure data in a single run of the exposure model. Stochastic models use the same exposure model in a regime that uses the probability density functions for the input parameters. The deterministic models are run for all portions of the study area. The stochastic models are run for those portions of the

study area where deterministic exposure exceeds a toxicological threshold. Model composition, toxicological benchmarks, and model results are described below.

This screening ecological risk assessment generally follows EPA guidance for conducting such assessments (EPA 1992a, 1996a), with specific guidance employed as deemed appropriate to the scope and requirements set by the CRCIA Team. The methodology used included defining conceptual exposure models, defining assessment endpoints, characterizing biotic exposure and effects, and characterizing risk to the assessment endpoints. However, this assessment has changed some of the terminology for easier understanding.

4.2.1 Endpoints for Ecological Species of Interest

Following EPA usage, we use the term "endpoint" to denote the biological resources and their attributes that are of concern for this assessment. "Assessment endpoints" denotes the attributes of interest for the species. "Measurement endpoint values" or "measurement endpoints" denotes the toxicological response used to represent the assessment endpoint. For radionuclides and carcinogenic chemicals, the measurement endpoints are the levels known to be lethal to 50 percent of an exposed population (expressed as LD₅₀ or LC₅₀) and the lowest levels known to produce a toxic response in any member of a population (expressed as LOEL). We were not always able to find measurement endpoints for each species. In those cases, we used the measurement endpoint value of a similar species.

Assessment endpoints comprise those biological resources and attributes that are to be protected and maintained within the ecosystems potentially at risk (EPA 1992a). Consequently, these endpoints are defined by CRCIA Team concerns for the study area. The species evaluated as assessment endpoints under this risk assessment are described in Section 4.1. The CRCIA Team specified that the resource values to be protected center on the long-term survival and health of the populations of these species within the study area and throughout the Columbia River system. Consequently, the measurement endpoints (the measurable ecological characteristics related to the

ecological values to be protected, EPA 1992a) selected for this assessment include the concentrations of contaminants that are known to be lethal to 50 percent of an exposed population (LD₅₀ or LC₅₀), and the lowest concentrations that are known to produce clinically toxic responses in any member of a population (the lowest observed effective level or LOEL).

Comparing chemical and radiological toxicity benchmarks (chemical concentrations or doses of ionizing radiation that produce harmful effects on test organisms in a toxicity test) with estimated exposures (quantification of an organism's contact with contaminants or contaminated media expressed as a chemical concentration or dose of ionizing radiation) of Tier II species (see Section 4.2.2) forms the basis for assessing the magnitude of risk posed to those species. EPA refers to this method as the quotient method (EPA 1996a).

This section presents the methodology used in selecting chemical and radiological toxicity benchmarks for each of the contaminants of interest for the Tier II species.

4.2.1.1 Toxicological Database and Literature Review

Chemical toxicities of the contaminants of interest to Tier II species were obtained by searching five toxicological databases as well as primary and secondary literature sources. Information in three toxicological databases (AQUIRE - Aquatic Information Retrieval Database, TERRATOX - Terrestrial Toxicological Effects Database, and PHYTOTOX - Phytotoxicological Effects Database), was accessed simultaneously through a central database retrieval system (ECOTOX - Ecotoxicology Database System, EPA 1996b). The other two toxicological databases searched were the HSDB (Hazardous Substances Databank, NLM 1996) and OHM-TADS (Oil and Hazardous Materials Technical Assistance Data System Databank, EPA 1996c).

Effects of radionuclides on Tier II species were obtained from primary and secondary literature sources. Radiological effects are a function of the energy deposited in the receiving biological tissues and the relative biological effectiveness of the radiation. The National Research Council has determined that the relative biological effectiveness of beta and gamma radiations may be assumed to be the same (NRC 1990). All the radionuclides in this risk assessment are beta and gamma emitters, except for uranium, which emits alpha particles. Alpha particles have a higher ionizing potential than beta or gamma particles per unit distance traveled. However, the energy of alpha particles is rapidly absorbed by any moderately dense material such as water.

Chemical and radiological endpoint data were seldom available for the Tier II species. Consequently, endpoint data were collected initially for all species for which effects data for the contaminants of interest were available. From these species, one or more species were selected as surrogates for the Tier II species based on similarities of taxonomic group, life style, and/or toxicological response. Endpoint values for surrogate species were then extrapolated to Tier II species.

4.2.1.2 Selection of Endpoints for Tier II Species

The endpoint values collected from the literature and databases were generally derived from chemical toxicity tests on 1) aquatic animals and plants for which uptake was from water, 2) terrestrial animals for which uptake was by ingestion, and 3) terrestrial and emergent plants and fungi for which the chemical was introduced either in soil or in a hydroponic growth chamber. The "Measurement Endpoint Values Used in the Risk Assessment" section of Appendix I-D identifies the benchmark species and toxicological responses used in determining toxicological values for the species of interest.

Terrestrial and Emergent Plants. No chemical LD₅₀ or LC₅₀ values were available for terrestrial or emergent plants in the databases or literature that was reviewed. One radiological LD₅₀ value was available for terrestrial plants. No radiological LD₅₀ values were available for emergent plants.

Phytotoxic effects are seldom reported in terms of lethality. Of the many types of sublethal phytotoxic effects reported, reduction in growth and yield parameters (for example, production and growth of shoots and roots, production and viability of seeds, etc.) were assumed to be the most ecologically relevant in both the plant populations themselves and their use as forage. An environmental or tissue concentration that produced a 20 percent reduction in a growth or yield parameter was selected as the LOEL value for that plant/contaminant combination. The use of 20 percent is consistent with other screening benchmarks for ecological risk assessment and with current regulatory practice. Most regulatory phytotoxicity criteria are based on concentrations that produce effects significantly different from controls. On average, those concentrations correspond to greater than 20 percent effects (Will and Suter 1995).

Consequently, the phytotoxicity databases were screened to obtain toxicity values for the contaminants of interest that corresponded to approximately 20 percent reduction in growth and/or yield (or a parameter that directly contributes to growth and yield, such as photosynthesis). Where available, both tissue and soil LOEL concentrations were collected for terrestrial plants, and both tissue and water concentrations were collected for emergent plants.

Of the databases and literature sources reviewed, Will and Suter (1995) provided the most comprehensive and conservative summary of chemical toxicities for terrestrial plants. Will and Suter's (1995) screening-level LOEL benchmarks are based on numerous toxicity tests performed on a relatively wide variety of terrestrial plant species. Will and Suter (1995) provide three categories of confidence in their LOEL benchmarks: low confidence benchmarks were derived from 10 or fewer literature values, moderate confidence benchmarks were derived from 11 to 20 literature values, and high confidence benchmarks were derived from more than 20 literature values. Moderate to high confidence benchmarks were derived by selecting the tenth percentile of the reported values. Low confidence benchmarks were derived by selecting the lowest reported value.

In this risk assessment, toxicity LOEL values were selected on the basis of similarity of the test species to the Tier II species, on the reliability of the reported toxicity value, and how similar the toxic response was to our selected LOEL responses. The order of preference for identifying suitable species was

- ◆ Tier II species
- ◆ closely-related species in riparian or riverine habitats
- ◆ all other species

Toxicity values were selected in the following order of preference:

- ◆ Will and Suter's (1995) high or moderate confidence LOEL benchmarks, whichever was reported for the contaminant of interest in question

- ◆ Will and Suter's (1995) low confidence LOEL benchmarks or other values that were based on a greater than 20 percent reduction in growth or yield, whichever was lowest
- ◆ the lowest of the values based on unspecified levels of adverse effects in growth or yield
- ◆ the lowest of the reported values based on unspecified toxic effects

For example, if only a low-reliability toxicity value was available for a Tier II species and a higher-reliability value was available for another related species, the low-reliability value for the Tier II species was selected. Where toxicity values were available only for distantly related species, as was commonly the case, values were selected based solely on the four reliability criteria, irrespective of the species used in the toxicity test.

Fungi. Several chemical LC₅₀ values were available for fungi. Because fungi were treated as a broad taxonomic group in this risk assessment (no individual Tier II fungal species are identified), there was no selection of surrogate species per se. Instead, the fungal LC₅₀ values used in this risk assessment were those associated with the lowest reported values for the taxonomic group. One radiological LD₅₀ and two radiological LD₆₃ (dose of ionizing radiation that produces mortality in 63 percent of the test organisms in an acute exposure test) values were available. The lowest of these values was selected.

Available chemical toxicity values were screened to select those reporting a reduction in growth or yield of approximately 20 percent. These values were classified as LOELs (after Will and Suter 1995), and the lowest of these were selected for each contaminant of interest. Several radiological LOEL values were available that were based on lethality. The lowest of these were selected where no growth or yield effects were reported.

Terrestrial Animals. The databases and literature sources reviewed yielded relatively few data on the toxicity of most chemicals to wildlife. Most of the data obtained from these sources apply to laboratory animals such as rats, house mice, guinea pigs, mallards, and quail. As a result, many toxicological values for the species of interest were derived by extrapolating across taxonomic groups. In the few instances that a toxicological value was available for a species of interest, it was used without any extrapolation.

Toxicological values were extrapolated from a benchmark species to a species of interest separately for each contaminant. A hierarchical decision making process was used to determine which benchmark toxicological values would be used for a given species of interest. Values, in decreasing order of importance, by species, genus, family, order, class, and superclass were sought. Where values were available for several different species, the species closest in life style to the species of interest was used. The lowest LD₅₀ value found in our sources was used to extrapolate to an LD₅₀ for the species of interest by using an adjustment factor for the differences in body size. LD₅₀ values for mammalian species of interest were calculated using the following equation (based on Sample et al. 1996):

$$LD_{50soc} = LD_{50b} * (bw_b/bw_{soc})^{1/4} \quad (4.1)$$

where

$$\begin{aligned}LD_{50\text{soc}} &= LD_{50} \text{ value for the species of interest} \\LD_{50\text{b}} &= LD_{50} \text{ value for the benchmark species} \\bw_b &= \text{body weight of the benchmark species} \\bw_{\text{soc}} &= \text{body weight of the species of interest}\end{aligned}$$

For avian and herpetilian species, a 1:1 conversion was used (Sample et al. 1996).

As with LD_{50} values, where a LOEL value was available for a species of interest it was used without any extrapolation. In most instances, however, LOEL values were derived from the calculated LD_{50} value for a given species of interest. A range of $LOEL_{Lo}$ and $LOEL_{Hi}$ values were calculated by taking 1/15th and 1/30th of the LD_{50} values, respectively (Tucker and Lietzke 1979, Urban and Cook 1986).

Aquatic Species. One endpoint selected for evaluating potential aquatic effects was LC_{50} . The length of exposure for the reported toxicity tests varied, usually ranging from 24 to 96 hours for an acute exposure. The longest exposure time available for LC_{50} was selected because exposures within the study area are assumed to be chronic. Endpoints for aquatic plants and phytoplankton were usually EC_{50} s (an effective concentration resulting in a 50 percent reduction in cell growth rates) determined for a 5 to 14-day exposure period.

Besides differences in exposure duration, the toxicity studies also used test organisms of differing sizes and life stages. To limit the effects of this variability on the chosen measurement endpoints for the risk assessment, data were grouped only from tests conducted from aquatic organisms of similar size and age. The form of the metal used in the test solutions also varied among reported tests (for example, using $NiSO_4$ versus $NiCl_2$), and in those cases, the lowest toxicity value for the exposure series was used.

The process used to select measurement endpoint values for each species and contaminant from the data review was as follows: where two or fewer toxicological studies for a given endpoint and species of interest were available, the lower (most conservative) reported value was selected. Where more than two references for the same endpoint were available, the mean reported value was used.

The other endpoint review in the toxicological literature was LOEL. However, because of the wide variation in reported data, a standard endpoint for these values was not established. For example, LOELs included such endpoints as lethality, immobilization, reduced growth, and biochemical alterations. Where such variation occurred within a single species for a chemical, the lowest value consistent with a toxic response was used. Where LOELs were unavailable, they were estimated using 1/15th the LC_{50} (Tucker and Lietzke 1979, Urban and Cook 1986, Suter 1993).

Toxicity data were not available for all species. Therefore, toxicological data from taxonomically related species were used as needed. However, the closeness of the taxonomic relationship varied according to contaminant and species. For example, toxicological data for some contaminants in primary producers were available only for green algae. These data were then used for phytoplankton, periphyton, and water milfoil. While the relationship between unicellular algae and phytoplankton is relatively close,

the relationship to a vascular plant is more remote. Frequently, only general terms such as crustacea and mollusca were included in the toxicological references in the toxicological databases that were searched. In the absence of species-specific data, values for crustacea were used for crayfish, *Daphnia magna*, and *Hyallela*, and values for mollusca were used for clams, Columbia pebblesnail, and mussels. Similarly, values for *Daphnia magna* were used for other crustacea when additional data were not available. Uncertainties in the parameters and their use in the model are discussed in Section 4.2.4.

There were more species-specific data available for fish than for any other taxonomic group. Our criteria for surrogate species selection was based first on similarities in feeding habits, then on taxonomic closeness. For example, bluegill might be taxonomically closer to smallmouth bass than squawfish, but squawfish have a similar predatory life style and feed on the same food organisms in the Hanford Reach. Thus, toxicological data from squawfish were used for smallmouth bass when data for the latter were unavailable. In the absence of data for a Tier II fish, toxicological data from the most commonly tested species such as rainbow trout, fathead minnow, and goldfish were substituted.

4.2.2 Estimating Biotic Exposure to Contaminants of Interest

Exposures of individuals and populations to contaminants had to be estimated for each Tier II species and their primary prey within the study area. The amount of each contaminant an individual might encounter via all exposure pathways had to be quantified. A preliminary, qualitative estimate of exposure was performed earlier to assist in identifying Tier II species (see Section 4.1). That estimate was based on evaluating the degree to which the average life styles of individuals of a particular species brought them into contact with potentially contaminated media (air, food, groundwater, pore water within sediment, sediment, and surface water).

To estimate the contaminant levels in each species, we had to take several factors into consideration:

- ◆ the pathways by which each species is exposed
- ◆ the degree of contact the species had with potentially contaminated media (air, food, groundwater, pore water within sediment, sediment, and surface water)
- ◆ the uptake rate by each species of each contaminant
- ◆ the availability and applicability of computer models that address the diverse types of contaminants studied.

The contaminants addressed by this assessment include organic chemicals, metals (both radioactive and non-radioactive), tritium (hydrogen-3) (water with tritium incorporated as part of the water molecule), and non-metallic ions. These diverse contaminants vary widely in their chemical and physical properties, which makes modeling exposures problematic. A review of available exposure models found none capable of addressing the full range of contaminants in both aquatic and terrestrial systems simultaneously. However, a set of aquatic exposure models developed by Thomann et al. (1992, 1995) presented sufficient generality that they could be adapted for use in the aquatic system. Similarly, the EPA modeling system for human health exposures contained in *Risk Assessment Guidance for Superfund* (EPA 1991), the *Dermal Exposure Assessment: Principles and Applications* manual (EPA 1992b), and the terrestrial exposure methodology contained in the *Wildlife Exposure Factors Handbook* (EPA 1993) also could be adapted to address the terrestrial system. These submodels could be combined to incorporate biomass transfers from the aquatic to the terrestrial component to allow foraging by air-breathing species on aquatic

components of the ecosystem. The CRCIA Team chose to adapt the Thomann/EPA systems into a single spreadsheet-based model, the components of which are described below.

Aquatic animals may be exposed to environmental contaminants via two pathways: dietary (ingestion) and dermal/gill exposures (Figure 4.4). Exposure of primary producers occurs entirely by dermal exposure.

Uptake of a contaminant into the body of an organism is a function of both the amount of contaminant present in the media contacted by the organism and the rate or fraction of the contaminant crossing the organism's integument (for example, gill membrane) or gut membrane. For uptake directly from water, a standard parameter is the species- and chemical-specific bioconcentration factor, which is the ratio of the equilibrium body burden of a chemical in a species versus the water concentration when uptake is limited to the water phase only (meaning no contaminated food is eaten by the species in question). Therefore, the most appropriate bioconcentration factor values from the literature are those for which estimates have been obtained from controlled laboratory studies rather than from field-derived observations because the latter reflect exposures to both water and contaminant-bearing food.

Exposure of terrestrial or air-respiring species may occur via ingestion of contaminated food or water, dermal exposure to contaminated soil or water, and/or inhalation of airborne contaminants (EPA 1993). These various routes of exposure and the key information required to estimate these exposures are shown in Figure 4.5.

Figure 4.4. Conceptual Model of Exposure for Water-Respiring Species

Figure 4.5. Conceptual Model of Exposure for Air-Respiring Species

The hierarchical nature of exposure is depicted by the three levels of foraging life styles represented in the figure. The body burden of plants is from uptake of contaminants from air, soil, pore water, and groundwater. Uptake may be either via the roots or via transport across aboveground membranes containing aerial deposits of vapor-phase contaminants. Herbivores and omnivores consume this plant material along with the contaminants that have been deposited on the plant tissues as particulate matter. They may also ingest soil directly, and all are assumed to consume some amount of water, which may itself contain contaminants. Omnivores and carnivores also consume animal prey that have integrated the various contaminants encountered throughout the prey's lifetime.

In this risk assessment, the contaminant body burdens of the prey are assumed to be at equilibrium with the environment. The contaminant concentrations in the prey are those most likely to be encountered under long-term, steady-state exposure and depuration/loss conditions. Also, the amount of prey consumed by a predator is assumed to be a function of its field metabolic rate, the amount of energy contained in each prey type consumed, and the proportion of each prey type consumed (EPA 1993).

A detailed description of the model and its parameters are provided in the "Exposure Model Description and Parameters" section of Appendix I-D.

4.2.3 Approach for CRCIA Ecological Risk Assessment

In this section we describe the key techniques and assumptions we used to estimate ecological risk:

- ◆ The ratio of the level of estimated exposure to a contaminant for a species to the measurement endpoint denotes the level of risk. That ratio is the Environmental Hazard Quotient. Any Environmental Hazard Quotient over 1 denotes a potential hazard.
- ◆ We used computer models to do the exposure calculations. The three types of data we needed for the computer models were parameters describing the attributes of the species (see Section 3.0 and the factors described in Section 4.2.2), contaminants and their behavior in biological systems (data from literature referenced in text), and locations (segments along the Columbia River) into the computer models. To ensure the models provided reasonable estimates of exposure, we compared the estimated movement of contaminants using data for which the results are known.
- ◆ We first analyzed the data (see Section 3.0) using the deterministic method. If the Environmental Hazard Quotient for any species-contaminant-location combination was more than 1, then we further analyzed that combination using the stochastic method.

The approach employed in this screening assessment of ecological risk was discussed with and approved by the CRCIA Team. The approach was selected to make the best use of available data given the time and funding constraints of the study, use assumptions that the team determined were reasonable, follow an internal screening approach that would further reduce the amount of area subject to detailed analyses, and incorporate comments from the Technical Peer Reviewers that the team deemed important.

The following are the key set of assumptions used in this analysis:

For estimating the level of hazard posed by contaminants, the ratio of estimated exposure to measurement endpoints (often termed an Environmental Hazard Quotient or EHQ) was used. Environmental Hazard Quotients greater than 1 represent an exposure that meets the level

determined to pose a hazard (LOEL or LD/LC₅₀). Environmental Hazard Quotients were estimated separately for each species but were combined for similar acting contaminants (for example, radionuclides).

Each parameter in the exposure model needed a defined value (Jorgensen 1990). For these values, Hanford Site data were used as much as possible. Preliminary model validation and calibration were performed first using data sets from other locations. Data sets from Hanford Site studies that were not used as parameters in the model were used to evaluate model output but were not used to adjust the model. This constraint was chosen because the CRCIA Team agreed that the conditions defined for the exposure model may not be well represented by biological samples obtained under the various Hanford Site monitoring programs, which have focused on protecting human rather than ecological health.

The media data were first used in a deterministic exposure analysis to identify those location-species-contaminant sets that indicate a potential hazard. This analysis used observed maxima for media concentrations and mean or geomean parameters for the exposure models. Measurement endpoints used for the EHQs were LOELs. Species-contaminant-location combinations that met or exceeded an EHQ of 1 were further evaluated using stochastic exposure modeling. The others were dropped from further consideration.

Stochastic modeling used media geomeans and standard deviations and known or estimated uncertainties in the exposure model parameters. Measurement endpoints used were both LOELs and LD/LC₅₀.

Finally, results of exposure modeling were compared to measured tissue concentrations obtained from biota samples within the study area and compared to population health data obtained from the study area to provide a basis for comparison for the risk assessment results.

4.2.4 Setting Input Values and Uncertainties for Exposure Modeling

Model parameters included chemical attributes (for example, K_{ow} , molecular diffusivity), species attributes (for example, body weights, fraction organic carbon), site attributes (for example, average air temperature, average wind speed), species-by-chemical attributes (for example, bioconcentration factors, depuration rates), and chemical-by-site attributes (for example, chemical concentration in sediment). Many of these parameter values were defined using literature references because site-specific measurements were unavailable. All chemical-by-site attributes, however, were defined using values measured within the study area (see Section 2.0). Chemical-specific parameter values were obtained from standard references with little ambiguity in the values. Parameterization of species and chemical-by-species parameters, however, incorporated more ambiguity. Much of the ambiguity resulted from lack of information for the specific species evaluated in this risk assessment, which necessitated selection of values based on degree of relevance to the species and/or chemicals being evaluated.

In the section, we give the rules we followed when we had to use substitute values, and we define the uncertainty of the values used in the stochastic analyses.

The first level of relevance was defined primarily on the bases of major life style and taxonomic similarities (Table 4.19). Under this scheme, when data were unavailable for a species of interest, values for closely related species at the immediately more general level of similarity were used instead. For example, if bioconcentration factor data for suckers were unavailable, data from the Cyprinoideae family were used (see Table 4.19). If no data were available for that family, then the average value for bony fishes was used instead. This rule was not required for parameterization of species-specific parameters, but was invoked for a number of chemical-by-species parameters.

The organisms dominating the phytoplankton and periphyton groups in the study area are diatoms (Neitzel et al. 1982). Therefore, diatom data were used for these groups where such data were available.

Data were generally rounded to one or two significant digits, depending on average data quality among taxonomic groups.

Parameterization of the uncertainties for the stochastic simulations of exposure generally followed the recommendations of MacIntosh et al. (1994) with regard to known versus unknown properties. The general distributions and their parameters used for each model parameter are shown in Table 4.20.

Stochastic parameters are those that are expected to vary in the populations being modeled. For example, body weights of bald eagles within the study area vary among individuals, and lipid content of salmon varies among individuals. Uncertain parameters are those that may or may not vary in the environment, but for which the necessary information to fully characterize them is lacking. For example, contaminant uptake by plants from soil varies among species that have been studied, but data are unavailable on this parameter for the species evaluated in this risk assessment. Additional research on these species could reduce the uncertainty for this parameter. Other uncertain parameters were assumed not to vary significantly with respect to the measurement endpoints (for example, K_{ow}).

The following rules were used to establish distributions for the variable parameters in the exposure model: where data were available to provide estimates of geometric means and standard deviations, lognormal distributions were used. For certain components, uniform or triangular distributions were used with upper and lower limits set using a consistent fraction of the mean of the available data. These limits were a factor of 2 about the mean or geomean for data-rich parameters, a factor of 5 for data-poor parameters, and a factor of 10 for parameters extrapolated from widely different taxonomic groups or for which higher variability was expected. These uncertainties are shown in Table 4.21.

The uniform and triangular distributions are commonly used in stochastic modeling when the shape of the actual distribution is unknown (Kirchner 1994). When extremes and a modal or mean value of a distribution are known, the triangular distribution is the least biased assumed distribution. When only the extremes can be estimated, the uniform distribution is the least biased assumption. Kirchner (1994) notes that in many cases the type of distribution chosen in complex models such as this one has little effect on the form of the output distribution.

Table 4.19. Hierarchy of Substitution for Species-by-Chemical Parameterization

<p>Aquatic Vegetation</p> <ul style="list-style-type: none"> Phytoplankton Periphyton Diatoms Macrophytes Water milfoil <p>Benthic Invertebrates</p> <ul style="list-style-type: none"> Crustaceans Crayfish Insect larvae Mayfly (as larvae) Molluscs Snails Bivalves Clams Mussels <p>Zooplankton</p> <ul style="list-style-type: none"> Crustaceans (planktonic forms) Branchiopods Anostracans (e.g., fairy shrimp) <i>Hyalalella</i> Cladocerans <i>Daphnia</i> <p>Aquatic Vertebrates</p> <ul style="list-style-type: none"> Amphibians Anurans (frogs and toads) Woodhouse's toad tadpoles Fishes Agnathans (jawless fishes) Lamprey Bony fishes Sturgeon Salmoniformes Whitefish Salmon Trout Rainbow trout Cyprinidae Carp Suckers Catfish Percoids Bass <p>Fungi</p> <p>Terrestrial Vegetation</p> <ul style="list-style-type: none"> Trees Grasses Forbs Ferns 	<p>Terrestrial Animals</p> <p>Nonhomeotherms</p> <ul style="list-style-type: none"> Terrestrial arthropods Reptiles Snakes Lizards Toads (note tadpoles are evaluated in aquatic portion of the model) <p>Homeotherms</p> <p>Mammals</p> <ul style="list-style-type: none"> Rodentia Beaver Muskrat Western harvest mouse Mustelidae (weasels, mink, otter) Weasels Procionidae (raccoons, skunks) Raccoon Artiodactyla (cloven-hoofed mammals) Deer Mule deer <p>Birds</p> <ul style="list-style-type: none"> Pelicaniformes (pelican order) American white pelican Ciconiiformes (heron order) Great blue heron Anseriformes (swan, duck, and goose order) Geese Canada goose Ducks Bufflehead Mallard Gruiformes (rail, gallinule, and coot order) American coot Charadriiformes (gull, tern, and snipe order) Forster's tern Common snipe Falconiformes (hawk, eagle, and falcon order) Accipitridae (kites, hawks, and eagles) Bald eagle Northern harrier Falconidae (falcons) American kestrel Galliformes (chicken, pheasant, and quail order) California quail Passeriformes Cliff swallow
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Table 4.20. Uncertainty Classification of Exposure Model Parameters and Distributions Used in the Stochastic Simulations

Model Parameter Varies with Respect to Prediction Endpoint?	Distribution Characterized	Distribution Type Used in Simulation
Yes		
Stochastic component	Population	Normal, lognormal (uniform when data were scarce)
Uncertain component	Component parameters (likeliest, maximum, minimum)	Uniform, triangular
No		
Uncertain only	Likeliest value for deterministic model, Component parameters (likeliest, maximum, minimum) for stochastic simulations	Uniform, triangular

4.2.5 Exposure Scenarios

We estimated risk for each species as if it were found in each segment even though the habitat of some segments may be unfit for certain species. For example, we have 27 estimates for the risk to spawning salmon, one estimate for each of the 27 segments. Then within each segment we estimated risk to spawning salmon from each type of contaminant: carcinogenic chemicals, radionuclides, and toxic chemicals.

Exposure conditions were selected to be conservative. All animals were assumed to spend their entire time at the Hanford Site within a single river study segment. Their entire exposure to Hanford Site contaminants was from a single segment. No foraging outside of the Columbia River and its associated riparian zone was included in the model. All Tier II species were assumed potentially to occur throughout the study

area for the purposes of the assessment, although some segments do not contain appropriate habitat (for example, gravel beds for spawning salmon).

Aquatic organisms were assumed to spend some fraction of their lives in contact with sediment and/or pore water (see Appendix I-D, diskette file paramtrs.xls). Pore water was assumed to be represented by seep/spring data where such data were available, otherwise groundwater values were used. Pore water was further assumed to extend at least 15 centimeters up from the river bed into the water column. This latter assumption was used in the absence of data on the actual mixing zone.

Terrestrial animals were assumed to consume water from within the study segment in amounts consistent with their taxonomic group and metabolic demands. The water they consumed was assumed to be seep/spring water, where such was available, or surface water where no seeps or springs occurred.

Table 4.21. Parameterization of Uncertainties Used in the Stochastic Simulations

Parameter ^(a)	Uncertainty Representation (distribution type: distribution parameters)
BW	Homeotherms: (normal: mean = observed mean, std. dev. = mean/10) Nonhomeotherms: (uniform: limits = mean $\pm$ mean/5)
f_L	(uniform: limits = mean $\pm$ mean/5)
awd	(uniform: limits = mean $\pm$ 50%)
f_{oc}	(uniform: limits = mean $\pm$ mean/10)
GE	(uniform: limits = mean $\pm$ mean/10)
AE	(uniform: limits = mean $\pm$ mean/10)
Bioconcentration Factor	Observed range <50: (triangular: observed upper and lower range, with observed mean as most likely, or range of mean $\pm$ 50% if range data absent) Observed range > 50: (logtriangular: observed upper and lower range, with observed geomean as most likely)
K_{ps1}	(normal: mean = 0.0034, std. dev. = 0.0034)
K_{pa2}	(normal: mean = 3300, std. dev. = 4950)
B_v	Tritium (hydrogen-3): (triangular: lower limit = 0.7, most likely value = 0.9, upper limit = 0.95) Other contaminants: (triangular: 10th and 90th percentiles as range, observed median as most likely, or $\pm$ 50% of mean if range is unknown)
Absorption fractions ($\alpha_{d,s,v,p}$ and K_p)	(triangular: observed upper and lower range, with observed mean as most likely, or range of mean $\pm$ 50% if range data absent, with a maximum absorption of 1 and a minimum of 0)
K_{ei}	(triangular: observed upper and lower range, with observed mean as most likely; range = mean $\pm$ 50% if range data absent and taxonomic extrapolation is within the same level; otherwise range = mean $\pm$ 100%)
Environmental Concentrations	Lognormal: (observed geometric mean and geometric standard deviation)
(a) Parameters are defined in the "Exposure Model Description and Parameters" section in Appendix I-D.	

Contaminants were made airborne (and therefore available for inhalation) via wind erosion from within the segment's riparian zone, which was assumed to have a grass cover. Where trees actually occur in the study area, this assumption will overestimate inhalation exposures. The average distances above the substrate where animals were assumed to be found (diffusion height) are shown in Appendix I-D (diskette file paramtrs.xls). Contaminant uptake by plant roots was assumed to be from sediment, the data for which

were obtained from samples of the riverbed (see Section 3.0). An exception was for tritium (hydrogen-3), which was assumed to be taken up by plants from groundwater. The sediment samples were assumed to represent the soil of the riparian zone.

4.2.6 Validation Results

Output from the exposure model was evaluated against several data sets obtained from the literature to determine whether the model produced reasonable results. The data sets used in the validation were not used in setting the

In this section, we describe how we evaluated the degree to which the modeled exposures were accurate and give the results of our tests.

parameters for the model. The basis used for comparison was the ratio of the reported body burden to that of the organism's food, or to the water concentration in the case of fish. These ratios are generally termed "transfer factors" or "concentration factors" (Peterson 1983). Results of this comparison are shown in Figure 4.6. The alpha code references for Figure 4.6 are shown in Table 4.22.

Because the exposure conditions were set conservatively, the exposure model was expected to produce transfer factors somewhat greater than those referenced in the literature. This was the case for most contaminants. Mercury and strontium-90 were underestimated in fish, and chromium, lead, and tritium (hydrogen-3) in herbivorous mammals (Table 4.23).

The mercury underestimate is likely due to a deficiency in the media data input for the model. Virtually all of the mercury data were reported at the instrument detection limits (see Section 3.0). In general, no values exceeded detection limits for sediment. Consequently, the input data did not reflect equilibrium between the abiotic compartments. The strontium-90 result suggests that one or more parameters dealing with the movement of this contaminant in aquatic biota may be underestimated.

Constituents for which exposures were overestimated in fish were technetium-99 (170 times), tritium (hydrogen-3)(10 times), cobalt-60 (5 times), zinc (2.5 times), and uranium-238 (2 times).

The behavior of technetium-99 in aquatic biota is poorly studied, in part because of difficulties in chemical analysis (Driver 1994). Based on limited data sets, recommended transfer factors range from 15-30 (surface water to fish muscle). In the CRCIA data set, however, the concentration of technetium-99 was much higher in the pore water (groundwater or seep water) than in the surface water. Although the mean transfer factor based on surface water was 2600 (geomean = 170), the factor based on pore water was 40 (geomean = 9), which is within the range of published data.

Underestimated constituent concentrations in herbivorous mammals were lead (150 times), chromium (2.5 times), and tritium (hydrogen-3) (2 times). The lead difference is not considered especially significant since the available literature reference was for mice on a skeet range (Beyer et al. 1990), where lead may have been acquired through both ingestion of contaminated plants and ingestion of the lead shot itself (Stanley and Roscoe 1996).

Figure 4.6. Comparison of Transfer Factors Estimated from the Exposure Model (± 1 standard error) and Those Reported in the Literature (alpha code references in Table 4.22)

For the mammalian results, uranium-238 concentrations were overestimated by 2.5 times. Zinc values reported in the literature ranged over 1.5 orders of magnitude. The model estimate was within the upper portion of that range. Comparisons of model output for mollusc (clams and mussels) body burden as a fraction of sediment concentration versus published benchmarks (Thomann et al. 1995) are shown in Figure 4.7. The model output matched benchmarks for chromium, copper, and nickel. Lead was slightly overestimated. The model greatly overestimated mercury and zinc. The overestimated mercury was due to the lack of data above the detection limit for sediment as noted above. The model overestimated zinc by a factor of 10 because the published bioconcentration factors vary much more widely than for any other metal except mercury. This factor is discussed later in Section 4.3.

Table 4.22. References for Transfer Factors

Table Key	Element or Isotope	Species	Reference Medium	Factor (fresh weight basis)	Reference
a	Chromium	Mammals-mice	feed	0.5 (heart & liver)	Driver 1994
b	Copper	Mammals-mice	feed	4	Beyer et al. 1990
c	Copper	Mammals-herbivores	feed	0.7	Pascoe et al. 1996
d	Lead	Mammals-mice	feed	70	Beyer et al. 1990
e	Zinc	Mammals-mice	feed	9	Beyer et al. 1990
f	Zinc	Mammals-herbivores	feed	0.15	Pascoe et al. 1996
g	Cesium-137	Golden mouse	feed	0.19	Kaye & Dunaway 1962
h	Cesium-137	Mammals-herbivores	feed	2	Driver 1994
i	Cobalt-60	Mammals-herbivores	feed	0.3	Driver 1994
j	Cobalt-60	White-footed mouse	feed	0.013	Kaye & Dunaway 1962
k	Strontium-90	White-footed mouse	feed	1.8	Kaye & Dunaway 1962
l	Strontium-90	Golden mouse	feed	0.39	Kaye & Dunaway 1962
m	Strontium-90	Mammals-herbivores	feed	2.5 (midrange)	Driver 1994
n	Tritium (Hydrogen-3)	Mammals-rabbits	feed/water	0.97	Driver 1994
o	Uranium	Mammals-deer	feed	0.7	Driver 1994
p	Chromium	Fish-Salmo	water	560	Dallinger & Kautzky 1985
q	Copper	Fish-Salmo	water	1800	Dallinger & Kautzky 1985
r	Lead	Fish	water	720	Van Hassel et al. 1980
s	Lead	Fish-Salmo	water	360	Dallinger & Kautzky 1985
t	Mercury (total)	Fish	water	6000	Hendriks 1995
u	Zinc	Fish-Salmo	water	3600	Dallinger & Kautzky 1985
v	Zinc	Fish	water	1920	Van Hassel et al. 1980
w	Cesium-137	Smallmouth bass	water	7800	Whicker et al. 1990
x	Cesium-137	Fish-walleye	water	2500	Driver 1994
y	Cobalt-60	Fish-smelt	water	1000 (largest)	Driver 1994
z	Strontium-90	Fish-carnivore	water	75 (midrange)	Driver 1994
aa	Strontium-90	Smallmouth bass	water	680	Whicker et al. 1990
ab	Technetium-99	Fish	water	15 (default)	Driver 1994
ac	Tritium (Hydrogen-3)	Fish	water	~1	Driver 1994
ad	Uranium	Fish	water	38	Driver 1994

Table 4.23. Performance of Exposure Model Versus Published Transfer Factor References

Species Group	Model < Reference	Model = Reference (within 95% CI)	Model > Reference
Herbivorous mammals	Cr, Pb, ^3H	^{137}Cs , ^{60}Co , Cu, ^{90}Sr , Zn	^{238}U
Predatory fish	Hg, ^{90}Sr	^{137}Cs , Cr, Cu, Pb, Zn	^{60}Co , ^{99}Tc , ^3H , ^{238}U

Figure 4.7. Comparison of Sediment-to-Mollusc Transfer Factors Estimated from the Exposure Model (± 1 standard error) and Those Reported in the Literature (Thomann et al. 1995)

In general, except for strontium-90, the model performed adequately. The model met the operational criteria for the risk assessment: accurate representation of exposure as much as possible with errors favoring a conservative estimate of exposure.

4.2.7 Adjusting Exposure Estimates for Nutrient/Micronutrient Metals

Models of contaminant movement in biological systems generally are linear at equilibrium, in that the equilibrium tissue concentration is directly proportional to the environmental concentration (for example, Peterson 1983; EPA 1991, 1992b, 1993; Hope 1995; Thomann et al. 1995). This is probably appropriate for elements that are not essential to

biological function, are not analogs of such metals, or are not taken up by organisms via nutrient pathways. However, these conditions are not met by several of the metals in this assessment.

Our computer models calculated the concentration of a contaminant in the tissue of a species in direct proportion to the concentration of that contaminant in the environment. However, nutrient metals do not behave in this fashion. Therefore, we needed to adjust the calculation for certain contaminants. In this section, we explain which contaminants were adjusted and how.

Organisms adjust uptake and loss of essential elements to keep internal concentrations within certain tolerance limits. The body burden for the element is maintained within a relatively narrow band despite some variation in environmental concentrations (Newman and Heagler 1991). For example, absorption of ingested copper by vertebrates is a function of the copper concentration in the body: more is absorbed when the body concentration is low, and less is absorbed when the body concentration is high (Piscator 1979). A classification of metals by their nutrient/non-nutrient status is presented in Table 4.24.

Nutrient elements include a number of the contaminants in this risk assessment, especially copper and zinc. Therefore, the degree of departure between the estimated body burdens of these elements and the true body burdens is a function of how closely regulated the element is and how far the simulated environmental conditions depart from the range over which the organisms are able to maintain homeostasis.

The CRCIA Team determined that risk to organisms from nutrient metals should be evaluated as an increment to the estimated risk posed in Segment 1. The CRCIA Team also decided that risk should be evaluated where media concentrations statistically exceeded those in Segment 1. Otherwise, the upstream value should be taken as the baseline for these contaminants.

Non-parametric statistics (Mann-Whitney U test) were used to compare sediment concentrations in Segment 1 with concentrations in the downstream segments. Nickel, lead, and zinc were nowhere in higher average concentrations than in Segment 1 (Table 4.25). Copper was significantly elevated in Segment 14. Chromium was significantly elevated in Segments 2 and 4. Cobalt-60 was elevated in a number of segments, while cesium-137 was significantly elevated only in Segment 12.

Because exposure models (including the models adapted for this assessment) assume a monotonic relationship between environmental concentration and an organism's body burden, the presence of a homeostatic zone such as that shown in Figure 4.8 will result in the model overestimating tissue concentrations over a portion of the range of environmental concentrations (Chapman et al. 1996). This overestimation will be maximal at and beyond the upper portion of the homeostatic zone. The following discusses how this information can be used to correct the model for micronutrient metals.

Table 4.24. Biological Classification of Metal Contaminants (modified from Table 1 in Beeby 1991)
(Shaded cells are non-nutrient analogs. Bolded contaminant names are toxic heavy metals.)

Period	Macronutrient		Micronutrient					Non-Essential
3	Na	Mg						
4	K	Ca	Cr	Mn	Fe, Co, Ni	Cu	Zn	
5		Sr		Tc			Cd	
6	Cs							Hg, Pb
7								U, Np, Eu

Table 4.25. Segments Where Contaminant Concentrations in Sediment Significantly Exceeded Concentrations in Segment 1 (Mann-Whitney U test, significance level of $P < 0.1$)

Analyte	Segment	χ^2	P
Cr	2	9.45	0.0021
Cr	4	2.91	0.088
Cu	14	3.33	0.068
Ni	none		
Pb	none		
Zn	none		
Co-60	6	13.2	0.0003
Co-60	8	27.2	0.0001
Co-60	9	28.11	0.0001
Co-60	10	9.9	0.0017
Co-60	12	23.5	0.0001
Co-60	13	8.1	0.0044
Co-60	14	22.7	0.0001
Co-60	15	15.2	0.0001
Co-60	16	22.6	0.0001
Co-60	17	9.8	0.0018
Co-60	21	11.8	0.0006
Cs-137	12	6.6	0.01

Figure 4.8. Equilibrium Relationships Between Environmental and Tissue Concentrations for Nutrient and Non-Nutrient Metals and Their Relationships to EHQ

To address this issue, it was assumed that

1. the upper portion of the body concentration curve for nutrient metals parallels the non-nutrient curve
2. the environmental concentrations of nutrient metals in the region immediately upriver from Hanford Site-derived inputs to the Columbia River are within the homeostatic zone

Assumption 1 is conservative in the following derivation if the slope of the curve for nutrient metals is no greater than the slope of the curve for non-nutrients (see discussion below). Assumption 2 will be made conservative by further assuming the environmental concentration is at the upper end of the homeostatic zone. The validity of assumption 2 will be evaluated by comparing media and fish tissue concentrations from samples obtained from uncontaminated areas.

As stated earlier, the fundamental comparison in this assessment is the ratio of the body concentration or its analog, such as a water or ingestion daily exposure to the LOEL benchmark for a given species, which is termed an EHQ. This is shown in red in Figure 4.8. By definition, the EHQ within the homeostatic range should be less than 1. Thus, the actual EHQ within this region should be:

$$EHQ_{\text{segment 1}} = BC_{\text{nutrient}} / LOEL \quad (4.2)$$

As shown in Figure 4.8, the non-nutrient body concentration estimate exceeds the nutrient body concentration estimate by an amount Δ at the upper inflection point, which was set to be at the upriver Segment 1:

$$BC_{\text{nutrient, 1}} = BC_{\text{non-nutrient, 1}} - \Delta \quad (4.3)$$

If a species-specific body concentration for species from uncontaminated areas can be obtained from the literature, the value for Δ can be derived by subtraction:

$$\Delta = BC_{\text{non-nutrient, 1}} - BC_{\text{nutrient, 1}} \quad (4.4)$$

Then,

$$EHQ_{\text{segment 1}} = (BC_{\text{non-nutrient, 1}} - \Delta) / LOEL, \quad (4.5)$$

which, assuming assumption 1 above holds true for any segment where $EHQ_{\text{segment } x} \geq EHQ_{\text{segment 1}}$, then

$$EHQ_{\text{segment } x} = (BC_{\text{non-nutrient, } x} - \Delta) / LOEL. \quad (4.6)$$

Note that if the non-nutrient curve diverges from the nutrient curve above the homeostatic zone, use of equation (4.6) will overestimate $BC_{\text{non-nutrient, } x}$, thus use of its use is considered conservative under these conditions.

The validity of assumption 2 (regarding environmental concentrations in Segment 1 being within the homeostatic zone for copper, chromium, and zinc) was evaluated using data collected from sediment and fish within the Columbia River upstream from the study area by Washington State Department of Ecology and others (Serdar 1993, Serdar et al. 1994, Munn et al. 1995, Fuhrer et al. 1996). The sediment concentration data for copper and zinc from Segment 1 fall within the lower range of samples obtained from Franklin D. Roosevelt Lake and downstream (Figure 4.9). Tissue data for largescale suckers collected from these sites shows no apparent relationship to sediment concentrations within this range (Figure 4.9). Similarly, benthic insect monitoring data from the Yakima River also show no relationship between tissue concentrations and sediment concentrations within the ranges found in Segment 1 (Figure 4.10). There is thus tentative support for the validity of assumption 2.

The model was therefore calibrated to produce approximate average tissue concentrations for copper and zinc within Segment 1. The calibration procedure focused on selecting ranges for bioconcentration factors, ingestion assimilation fractions, and depuration rates from within the published ranges for these parameters that would produce estimates between one-half and five times the average tissue concentrations for species obtained from uncontaminated areas. These objective concentrations are given in Table 4.26. Calibration parameters are given in the "Calibration Parameters for Copper and Zinc" section of Appendix I-D.

Figure 4.9. Sediment and Tissue Largescale Sucker Concentrations of Copper and Zinc from Lake Roosevelt and Downstream Areas (data sources given in text)

4.2.8 Deterministic Analyses Using Media Concentration Maxima

The exposure model was run in deterministic mode to identify those river segments, contaminants, and species that should be evaluated further in the stochastic evaluation. This objective was addressed by identifying areas where the maximum observed concentration of contaminants would pose a potential hazard to any Tier II species if that species were exposed continuously to those concentrations. Model settings used in the deterministic analysis were most-likely values (for example, geomeans or averages) for parameters other than media concentrations and observed maxima from the media files (obtained as described in Section 3.0). Analyses were not performed for contaminants within a segment where no data were above detection limits for either pore water or sediment. Surface water values for segments missing those data were surrogated as described in Section 3.0. Outputs used from the exposure model were equilibrium body burdens; ingestion, inhalation, and dermal doses; and average sediment and/or

We used the deterministic method in the computer model to identify the species, segments, and contaminants that posed a potential hazard and so needed to be evaluated further using the stochastic method. All segments contained contaminants at levels posing a potential hazard, including Segment 1, which is upstream from the Hanford Site and so considered to be indicative of contamination not resulting from the Hanford Site. Contaminants requiring further evaluation were: ammonia, cesium-137, chromium, cobalt-60, copper, cyanide, europium-154, lead, mercury, nickel, nitrate, strontium-90, tritium (hydrogen-3), uranium-234, uranium-238, and zinc.

Figure 4.10. Sediment and Tissue (Caddisfly larvae) Concentrations of Copper and Zinc from the Yakima River

Table 4.26. Normal Concentrations for Copper and Zinc ($\mu\text{g/g}$ dry)

Species	Tissue	Cu	Zn	Reference
Birds - ducks	Liver	44	0	NAS 1980
Birds - fowl	Liver	4.4	0	NAS 1980
Bass	Muscle	0.13	3.6	Förstner and Wittmann 1981, Munn et al. 1995
Carp	Muscle	0.24	10	Förstner and Wittmann 1981
Catfish	Whole Body	3.5	50	Förstner and Wittmann 1981
Fish	Muscle	2	20	Hopkins et al. 1984
Goldfish	Whole Body	3	25	Förstner and Wittmann 1981
Sculpin	Whole Body	0.5	16	Fuhrer et al. 1996
Sucker	Whole Body	0.83	21	Serdar 1993
Freshwater bivalves	Whole Body	1.5	70	Förstner and Wittmann 1981
Freshwater crustacea	Whole Body	2.9	40	Förstner and Wittmann 1981
Freshwater gastropods	Whole Body	36	39	Förstner and Wittmann 1981
Caddisfly larvae	Whole Body	3.3	30	Fuhrer et al. 1996
Mammals	Whole Body	0	35	NAS 1980
Mammals - monogastric	Liver	4.4	0	NAS 1980
Mammals - ruminants	Liver	44	0	NAS 1980
Potamogeton	Whole Body	2.0	33	Förstner and Wittmann 1981

water concentrations experienced by the various organisms. These values were compared to the toxicological endpoints obtained from the literature as described earlier.

Several segments (11, 18, and 22-27) lacked data on any contaminant concentrations in pore water. An attempt was made to use distribution coefficients (K_d) to estimate pore water from known sediment concentrations in these segments. However, this methodology often overestimates pore water concentrations in sediment (Campbell and Tessier 1996). As shown in Figure 4.11, using this method produced pore water estimates three orders of magnitude greater than those obtained using groundwater or seep/spring values. Consequently, pore water concentrations were not estimated using K_d s, and Segments 8, 11, and 22-27 were dropped from this assessment due to lack of data.

Figure 4.11. Estimated and Actual (geomean) Pore Water Concentrations for Zinc and Copper in Relation to Known Sediment Concentrations

Ingestion exposure was the primary exposure pathway for terrestrial species. In all cases, ingestion exposures for inorganic contaminants were from one to several orders of magnitude greater than exposures via other routes (Figure 4.12). Consequently, daily ingestion exposures were used as the basis for comparison to measurement endpoints in the chemical EHQs for terrestrial animals. Doses from all pathways were included in calculating total radiation doses, which were compared to radiological endpoint values.

The EHQs (the ratio of estimated exposure dose or concentration to LOEL endpoint values) were computed for river segments and contaminants for each Tier II species. The EHQs that were 1 or greater identified segment-contaminant-species combinations that were evaluated further in the stochastic modeling. EHQs are presented in the "Environmental Hazard Quotients" section of Appendix I-D. Summaries of contaminants and locations potentially important to terrestrial species are shown in Table 4.27. Those for aquatic species are shown in Table 4.28.

All segments (except 11, 18, and 22-27 where no pore water data were available) contained contaminants that required further evaluation, including Segment 1, which constitutes a background area. Contaminants contributing to potential risk were ammonia, cesium-137, chromium, cobalt-60, copper, cyanide, europium-154, lead, mercury, nickel, nitrate, strontium-90, uranium-238, and zinc.

Figure 4.12. Estimated Doses via Ingestion, Inhalation, and Dermal Pathways Obtained from Deterministic Analyses Using Maximum Media Concentration

Table 4.27. Number of Terrestrial Species for Which the Deterministic EHQ Exceeded 1
(Counts are displayed by contaminant-segment-species grouping.)

[illegible]

Table 4.28. Number of Aquatic Species for Which the Deterministic EHQ Exceeded 1
(Counts are displayed by contaminant, river segment, and species grouping.)

No. of Species with EHQ>1		Contaminant																					No. of Species with EHQ>1		Contaminant																					
Segment	Species Category	ammonia	benzene	cadmium-137	chromium-137	cobalt-60	copper	cyanide	europium-152	europium-154	iodine-129	lead	mercury	nickel	nitrate	strontium-90	technetium-99	thorium	uranium-234	uranium-238	xylylene	zinc	Segment	Species Category	ammonia	benzene	cadmium-137	chromium-137	cobalt-60	copper	cyanide	europium-152	europium-154	iodine-129	lead	mercury	nickel	nitrate	strontium-90	technetium-99	thorium	uranium-234	uranium-238	xylylene	zinc	
1	Invertebrate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	Invertebrate	0	0	2	0	0	0	2	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
	Vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	Vegetation	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate adult	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	Vertebrate adult	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
	Vertebrate eggs	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	Vertebrate eggs	0	0	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vertebrate larvae	0	0	0	0	0	0	3	0	0	0	0	3	3	0	0	0	0	0	0	0	0	4	Vertebrate larvae	0	0	1	0	0	1	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0
1 Total		0	0	0	2	0	14	0	0	0	0	6	4	0	0	0	0	0	0	0	0	0	18	10 Total		0	0	5	3	0	6	0	0	0	4	6	0	0	0	0	0	0	0	0	0	0
2	Invertebrate	5	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	12	Invertebrate	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vegetation	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	Vegetation	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate adult	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	Vertebrate adult	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate eggs	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	Vertebrate eggs	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate larvae	0	0	0	0	0	1	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	4	Vertebrate larvae	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2 Total		8	0	0	4	0	5	0	0	0	5	4	0	0	0	0	0	0	0	0	0	0	11	12 Total		0	0	0	2	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	Invertebrate	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	13	Invertebrate	5	0	0	1	0	5	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	
	Vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	Vegetation	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate adult	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	Vertebrate adult	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
	Vertebrate eggs	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Vertebrate eggs	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate larvae	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	Vertebrate larvae	0	0	0	1	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	
3 Total		0	0	0	2	0	0	0	0	0	5	6	0	0	0	0	0	0	0	0	0	0	13	13 Total		8	0	0	2	4	8	0	0	0	1	6	0	0	0	0	0	0	0	0	0	0
4	Invertebrate	4	0	0	0	0	4	5	0	0	0	1	2	0	0	0	0	0	0	0	0	0	7	Invertebrate	0	0	0	0	0	0	2	0	0	0	1	2	0	0	0	0	0	0	0	0	0	
	Vegetation	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	Vegetation	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate adult	2	0	0	0	0	1	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	5	Vertebrate adult	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	
	Vertebrate eggs	1	0	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	Vertebrate eggs	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate larvae	0	0	0	0	0	4	2	0	0	0	4	3	0	0	0	0	0	0	0	0	0	4	Vertebrate larvae	0	0	0	0	0	1	0	0	0	4	3	0	0	0	0	0	0	0	0	0	0	
4 Total		7	0	0	2	0	13	8	0	0	7	7	0	0	0	0	0	0	0	0	0	0	19	14 Total		0	0	0	2	0	7	0	0	0	7	7	0	0	0	0	0	0	0	0	0	
5	Invertebrate	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	3	Invertebrate	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
	Vegetation	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	Vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate adult	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	Vertebrate adult	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate eggs	1	0	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Vertebrate eggs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate larvae	0	0	0	0	0	1	1	0	0	0	3	3	0	0	0	0	0	0	0	0	0	4	Vertebrate larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 Total		1	0	0	3	0	6	2	0	0	5	4	0	0	0	0	0	0	0	0	0	0	15	15 Total		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
6	Invertebrate	5	0	0	1	5	5	0	0	0	0	4	1	0	0	3	0	0	0	0	0	0	0	16	Invertebrate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vegetation	0	0	0	1	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	16	Vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vertebrate adult	2	0	0	0	3	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	Vertebrate adult	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate eggs	1	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	Vertebrate eggs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Vertebrate larvae	2	0	0	0	2	2	0	0	0	0	4	3	0	0	0	0	0	0	0	0	0	4	Vertebrate larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 Total		10	0	0	2	14	8	0	0	0	14	6	0	3	0	0	0	0	0	0	0	0	11	16 Total		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	Invertebrate	0	0	0	0	0	6	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	7	Invertebrate	0	0	0	0	0	5	0	0	0	3	0	0	0	0	0	0	0	0	0	0		
	Vegetation	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0</

4.2.9 Stochastic Analyses Using Lognormal Media Data

Using the stochastic analysis, we identified which species-contaminant-segment combinations pose a nominal risk (0), low risk (1), medium risk (2), and high risk (3). Nominal risk defines those combinations where fewer than 25 percent of the simulated exposures exceeded a measurement endpoint. High risk defines those combinations where more than 75 percent exceeded a measurement endpoint. Figure 4.13 shows the risk scores for the aquatic species and Figure 4.14 for the terrestrial species.

The exposure model was run in stochastic mode to identify those Tier II species that could be at risk from contaminants in the study area, to define where potential risk occurs, and to determine what contaminants are contributing to that risk. The model was set to allow all uncertain parameters in the exposure model to vary according to the distributions previously described. Media concentrations were also allowed to vary as described earlier. This method provided a series of estimates of equilibrium doses

and body burdens for individuals, assuming each was exposed continuously to one set of concentration values sampled from the lognormally distributed input media concentration data sets.

In other words, the exposure frequency distributions resulting from this analysis represent exposures that could result from a population of animals residing in all portions of the study area segment being evaluated. Part of the spread in the frequency distribution represents stochastic variation in contaminant concentrations and species parameters that is expected in the study area segment. However, much of the variation is also due to uncertainty in species-by-contaminant parameter values.

Outputs used from the exposure model were body concentrations, ingestion doses, and sediment and/or water concentrations experienced by the various organisms. These are the exposure units necessary for comparison to the measurement endpoints obtained from the toxicological literature as described earlier. Measurement endpoints used in this analysis were LOELs and LC/D₅₀s.

Species-contaminant-river segment combinations were classified into four groups based on results of the stochastic simulations: nominal, low, medium, and high potential risk. The categories were based on the proportion of the simulation results that exceeded LC/D₅₀ or LOEL endpoints, as shown in Table 4.29. Results of these simulations are presented in the "Risk Categories from Stochastic Modeling" section of Appendix I-D.

Table 4.29. Classification Criteria for Stochastic Risk Results

Risk Category	Nominal	Low	Medium	High
Risk Score	0	1	2	3
Proportion of simulations exceeding LOEL or LC/D ₅₀	<25%	25-50%	51-75%	>75%

Figures 4.13 and 4.14 present the average risk that contaminants in each segment pose to terrestrial and aquatic biota. The risk scores represent the average percentage of the simulated exposures that exceeded the measurement endpoint (LOELs in upper portion of the figures, LD₅₀ or LC₅₀ in the lower portions of the figures). Averages were computed only for those species that had the potential to be adversely affected by contaminants based on deterministic analyses. These results may describe actual risk to the extent that the supporting data are representative and the contaminants conform to the assumptions of the exposure model, especially regarding the monotonic relationship between environmental concentration and body burden. These issues are discussed in more detail in the following section.

4.2.10 Uncertainty Analysis

4.2.10.1 Uncertainties Intrinsic to the Exposure Model

The exposure model contains some 140 parameters for each contaminant, approximately 400 parameters for the species, and a 45-by-45 matrix of predation fractions. Additionally, five site-specific parameters were necessary to evaluate exposures. Collectively, calculating exposures of all species to all contaminants required estimating approximately 5,500 parameters. This produces two types of uncertainties: those arising from compounding errors in a parameter-rich model, and those arising from varying levels of confidence in the data used to parameterize the model.

We use the term “uncertainty” to denote the likelihood of a certain amount of variability in model parameters or dose estimates. In this section, we discuss the uncertainty to be found in the exposure model, data, exposure scenarios, and toxicological response, as well as the effect of this uncertainty on the risk assessment results.

The parameter-rich nature of the exposure model clearly contributes a large portion of uncertainty to the overall exposure result. Although not all parameters were required to estimate exposure for every species (for example, coyote body size was irrelevant to estimating tissue concentrations of uranium in periphyton), the uncertainty in the species-specific and species-by-contaminant parameters that *are* a part of an exposure pathway act together to enhance the uncertainty in the resulting estimate. A less parameter-rich model could be expected to produce a less-variable exposure estimate, although some may place less confidence in this estimate *because* of the more simplistic nature of the model used. This illustrates an interesting paradox: increasing model complexity may lead to increased uncertainty in the output, but also may lead to increased perception of confidence. This paradox may be resolved somewhat by validating the model against tissue concentration data from the Hanford Site and elsewhere (Table 4.28).

Parameterization uncertainty can be divided into three classes: uncertainty due to cross-species extrapolations necessitated by the lack of data, uncertainty caused by extrapolating conditions reported in the literature to those present in the Columbia River study area, and uncertainty due to variability among the species and studies comprising the various references used. Although a large body of literature was reviewed to obtain estimates for each parameter, emphasizing Hanford Site-specific data as much as possible, the review was not exhaustive. The sources reviewed varied both in degree of relevance and in the quality of results. This area could be improved by conducting a more thorough review of the literature and a detailed analysis of data quality and applicability to conditions within the study area.

Terrestrial Species

Terrestrial Species

Figure 4.13. Relative Risk Indices for Terrestrial Species Based on the Stochastic Exposure Model

Figure 4.14. Relative Risk Indices for Aquatic Species Based on the Stochastic Exposure Model

Because data for Tier II species were often lacking for many contaminant-by-species parameters, data from other species had to be employed. Although this uncertainty was represented in the wide parameter bounds for the stochastic analysis, there is no established basis for accurately estimating the uncertainty introduced by such extrapolation. In some cases, such as iodine-129 depuration in terrestrial species, there was relatively little variation between such widely diverse taxonomic groups as chickens and mammals. In other cases, such as bioconcentration factors for zinc, variation both within and between taxonomic groups covered several orders of magnitude. EPA, DOE, and other agencies have funded a great deal of research into establishing methodologies for extrapolating toxicological data across taxa, with less attention to extrapolating parameters needed to estimate exposures across taxonomic groups. The toxicological data bases used for most of the input values varied in the amount of detail they provided. In most cases, toxicity values (for example, LC_{50} or LOELs) were provided without detail on the species life-stage or exposure conditions. Knowledge about test conditions is particularly important for metals such as copper and zinc because water hardness and pH dramatically affect both bioavailability and toxicity of the compounds to aquatic organisms. The effect of including this uncertainty in the stochastic simulations was to inflate the estimated range of exposures beyond that actually present.

An estimate of this inflated range is demonstrated by comparing tissue concentrations estimated from the exposure model with actual measurements from animals collected during routine and special DOE environmental monitoring programs within the study area. Biota data were obtained from the Surface Environmental Surveillance Project and HEIS data bases from the past 5 years for the 100-N Area (corresponding to Segment 6), F-Slough (corresponding to Segment 14), and the 300 Area (corresponding to Segment 20). These data consist of radionuclide concentrations in muscle tissues. To use these data, reported values that were less than the total analytical error were substituted with half the total analytical error. Reported muscle values were converted to approximate whole-body concentrations minus gut contents by applying body-fraction and radionuclide activity ratios contained in Ney and Van Hassel (1983) and Dauble and Poston (1994). The comparison of observed versus estimated ranges is shown in Figure 4.15.

The available data include the key radionuclides in the risk assessment, but none of the non-radioactive metals. As illustrated in Figure 4.15, the exposure model estimates contained and exceeded the entire range of observed body burdens for all radionuclides and species except for strontium-90 in fish and uranium in clams. Tissue levels of strontium-90 were measured in biota at the 100-N Area, at F-Slough (only in smallmouth bass), and at the 300 Area (only in clams). The range estimated for clam tissue contained that of the observed tissue data, but the estimated ranges for the fish species were farther out of alignment with observed data. This deviation may be due to bioavailability conditions prevailing in the studies reported in the literature that were used to parameterize the model, which underestimate those in the study area; to environmental media data for strontium-90 that underestimate levels experienced by the species in the 100-N Area and F-Slough; or to exposure conditions in the model that underestimate exposure conditions in the field. The latter is the least likely explanation, since estimates for all contaminant exposures were based on the same exposure data set (for example, fractional exposure to pore water), and estimates of tissue concentrations for the other contaminants were not underestimated so severely.

Figure 4.15. Comparison of Measured Versus Estimated Whole Body Concentrations of Radionuclides in Biota (Biota are those for which measured values were available. Comparisons are simulation results for a given segment and species.)

Given these data, the CRCIA Team elected not to calibrate the exposure model to better align predicted with observed body burdens. This option was rejected in part because the team recognized that the exposure scenarios were probably more conservative than reality. Thus, actual data on tissue concentrations would not be expected to match simulated results. The measured concentrations were to be used for comparative purposes only.

The influence of uncertainties in particular parameters can, to some degree, be quantified through an analysis of model sensitivity. Example results are presented in Figure 4.16 for mercury body burdens in coyotes (a top-level terrestrial predator/scavenger) and cobalt-60 body burdens in white sturgeon (a top-level aquatic predator) using data from Segment 7 in 100 simulations of exposure. For both metals, the largest single influence on body burden was pore water concentration, accounting for over 25 percent of the variability in the resulting exposure estimate. Coyote and sturgeon parameter variation accounted for less than 3 percent of the variance in the resulting estimates. Variation in the remaining species

Figure 4.16. Sensitivity of Exposure Estimates to Model Input Parameters

parameters accounted for up to 29 percent of the variance in exposure. Site-specific parameter variance accounted for less than 5 percent of the exposure variance, with all contaminant-by-species variation accounting for the remaining 30 to 34 percent.

Because uncertainty in the contaminant-by-species parameters comprised a key source of uncertainty in the exposure estimates, this source will be explored further. For a given environmental concentration of metals, including radioactive metals, the expected body burdens for exposed organisms are primarily functions of the relative magnitude of uptake/assimilation rates and loss/depuration rates. Literature-derived values for both types of rates varied widely among the various contaminants, with the most variable rates for zinc, chromium, mercury, uranium, and cobalt (Table 4.30). Uptake/loss parameters varied by three orders of magnitude for these metals.

There are several causes for this variation, including differences in uptake and metabolism of essential versus non-essential metals (Newman and Heagler 1991), differences among metals in their range of bioavailability (Förstner and Wittmann 1981), and differences in the state of the organisms and environments among the various studies reviewed.

Zinc is one of the most problematic metals in the data set because it presents a wide range of uncertainty in uptake (bioconcentration factor) rates as well as the highest geometric mean bioconcentration factor of all the contaminants. Thus, most of the variance in the estimated body burdens for zinc, as well as the extremely high upper tail of the distributions, is entirely due to uncertainty regarding parameterization for local conditions and is not due to a high level of zinc in the environment. As noted earlier, the concentrations of zinc in the affected portion of the study area are within the range of concentrations found in the upstream

Table 4.30. Average Ranges of Uptake and Metabolism Parameters Obtained from Literature Reviewed and Used in the Exposure Model (Ranges are expressed as the reported maximum for the parameter in fresh water fish divided by the reported minimum for fresh water fish.)

Parameter	Metal											
	Zn	Cr	Hg	U	Cs	Co	Ni	Np	Sr	Cu	Pb	Tc
Bioconcentration Factor	127	20	450	8	30	250	4	35	20	4	1	2
Depuration	56	28	3	2	3	23	4	•	56	•	3	4
Fractional assimilation	18	370	1	200	2	60	39	26	8	9	10	•

sediment. There is consequently less support for the conclusion that the present estimates reflect a potential biotic risk from this metal without obtaining data on tissue levels in biota within the study area and uptake/loss rates for the species evaluated in this study.

The high uncertainties in mercury and uranium are not due to their resemblance to nutrient metals. The uncertainties reflect widely different behaviors of their various forms. For example, mercury occurs primarily in an inorganic form in abiotic media, except where organic matter is relatively abundant. Inorganic mercury is poorly absorbed and readily excreted. The methyl form readily crosses tissue membranes and is depurated extremely slowly. It is also the form most common in biological tissues.

4.2.10.2 Uncertainties in Media Data

One of the primary assumptions with using the media data was that groundwater and/or spring/seep water is an appropriate surrogate for pore water. The validity of this assumption may depend on the amount and type of sediment present in the various portions of the study area and on the relative contributions of groundwater versus sediment. In areas of net deposition, such as the sloughs and McNary Pool, sediment concentrations may drive pore water concentrations of metals and other contaminants. In erosional areas such as the majority of the study area segments, the lack of sediment will enhance the importance of groundwater as the major determinant of pore water contaminant concentrations.

Hope and Peterson (1996) measured aquifer and adjacent pore waters in the 100-D Area for hexavalent chromium content. Their results demonstrated that the mean chromium concentration measured in pore waters was 1.5 to 23 times lower than the values used for surrogated pore water in the exposure model. As noted earlier, the variable driving body burden estimates for both aquatic organisms and terrestrial omnivores/predators was pore water exposure. Thus, the exposure model likely overestimated exposures in all cases. This issue is explored further in Section 4.2.11.

Using a single spatial scale as a frame of reference for describing the distributions of all contaminant data contributed to the uncertainty in the estimated (simulated) body burdens in some segments.

Problematic segments comprise areas where the spatial scale of the contaminant plume(s) entering the segment, or the scale of the sediment contamination area, is less than the scale of the segment itself. In such cases, the resulting data distribution will not be unimodal, and the assumption that the data within the entire segment are lognormally distributed will be invalid. Bi- or multi-modal distributions simulated as a unimodal lognormal will produce estimates of concentrations well beyond those observed, or likely to be observed, in the segment.

In other cases, multimodality in the input data can be traced to differences in detection limits used by the various studies that provide data for this study, and to changes in sampling strategies implemented during the time period encompassed by the data search (for example, some sampling programs changed the location of sampling efforts from one year to another). The effects on the simulated concentrations is the same as described earlier: geometric standard deviations are inflated, causing body burden distributions from the stochastic simulations to have an artificially high upper tail.

Finally, sampling programs generating the input data were primarily directed at obtaining estimates of contaminant concentrations in areas where such levels are likely to be high. They were not directed at obtaining average estimates or estimates of spatial variability. Consequently, data averages for a segment may exceed reality in those segments where such a sampling regime was used. This is certainly the case for seep/spring data, where sampling focused on those locations near known plumes and ignored the remaining seeps in the area. The resulting average estimates of exposure may therefore be overestimated in such cases.

4.2.10.3 Uncertainties in the Exposure Scenarios

One of the assumptions used in the exposure model was that pore water extends into the river in an undiluted form for some distance (10-15 centimeters, more or less). This assumption was considered conservative in the absence of other data to indicate the dilution distance. The study by Hope and Peterson (1996) described earlier was published after the exposure assumption was made. Their analysis of chromium and electrical conductivity in the aquifer, pore water, and surface water at the 100-D Area was unable to detect evidence of pore water at distances more than 2.5 centimeters above the substrate. If this study were valid for the rest of the study area, the exposure estimates for many aquatic and terrestrial biota would be overestimated by a factor of 10 to several thousand, depending on the difference between groundwater and surface water contaminant concentrations in the various segments.

Another assumption in the exposure model was that terrestrial species consumed spring/seep water when it was available or groundwater (pore water) when springs/seeps were unavailable. As described above, the use of groundwater may be untenable if the Hope and Peterson (1996) results are valid throughout the study area. If the assumption is not tenable, exposures of terrestrial organisms from ingestion of surface water are overestimated in areas lacking springs.

For the purposes of equilibrium modeling, terrestrial and aquatic animals were assumed not to travel out of a modeled segment during the animal's period of residence at the Hanford Site. For example, for

the purposes of exposure modeling, mule deer resided 100 percent of the time within the riparian portion of a given segment and did not enter the adjacent terrestrial habitat. For some species, this assumption is clearly invalid.

The assumption that a species spends all of its life in one segment or near a contaminant source may be valid for sessile aquatic organisms such as benthic insects and clams. However, mobile aquatic species such as resident and anadromous fish and other aquatic organisms that occur in the drift, for example zooplankton and insects, will experience highly variable contaminant exposures. Spatial distribution of these mobile species will vary vertically, as well as laterally, within the river. Thus, their behavior will contribute to their exposure variability. Hydrologic conditions are also highly variable across different habitats. Backwater sloughs have limited circulation, nearshore areas typically are low velocity, and midchannel areas have higher velocity. These conditions will cause contaminant concentrations to vary in time and space within a given segment.

Because most of the terrestrial environment surrounding the study area is less burdened with Hanford Site contaminants, the actual risk experienced by most animals with large home ranges will be less than that estimated here. Where significant terrestrial contamination does exist within the terrestrial Operable Units at the Hanford Site, risk to biota is estimated by the Environmental Restoration Contractor using the assumption that the organisms reside entirely within the contaminated area, as is the case in the present assessment. Hence, no exposure or risk could be greater than those evaluated in the two studies simply by assuming an organism divides its time between a contaminated terrestrial and a contaminated aquatic environment.

One of the primary starting assumptions for this study was that all species evaluated occur throughout the study area and use each segment of the study area in the same manner. Although not true for all species, this assumption was made to demonstrate the risk a species might encounter if it did use a segment of the study area. A risk assessment that only addressed areas where the species was known to occur would miss areas where the species *could* occur but was not present because of high levels of contaminants. For example, the distributions of salmon spawning within the study area have been mapped from annual aerial surveys conducted by PNNL. Salmon redds are known not to occur below the Richland pumphouse (Segment 21) or in certain other portions of the Hanford Reach. The absence of salmon redds from these locations should not be assumed to be due to contamination. Many, if not all, of these areas may not contain suitable nesting habitat, especially Segments 21-27, which are part of the McNary Pool.

In the deterministic analyses of exposure, species were assumed to be located in the most heavily contaminated spot in time and space. For stochastic simulations, individuals of each species were effectively assumed to be located in fixed portions of each river segment where concentrations were held constant, but were simulated throughout and beyond the range of observed data. In other words, the results of the equilibrium model stochastic simulations can be viewed as the estimated distribution of body burdens if some member of the population simulated lived its entire Hanford Site existence in an area represented by the simulated media concentrations. Thus, some individuals will live in the less polluted portions of the segment and others will live in the most polluted portions of the segment. Thus, the model runs should encompass all possibilities of exposure to all levels of environmental contamination currently

present within a segment, assuming the media data are representative concentrations. This will result in an overestimate for organisms with large home ranges modeled in higher concentration areas.

As noted earlier, the exposure model used in this assessment is an equilibrium model rather than a dynamic model. Tissue concentrations of an organism's prey have equilibrated with their environments and do not vary. The primary effect of this difference is that the upper tails of the exposure distributions from equilibrium models will be above those from dynamic models for animals that are mobile and can move in and out of contaminated segments. However, dynamic models are not practical for food-web exposure modeling that involves a number of species simultaneously.

4.2.10.4 Uncertainties in the Toxicological Response References

The exposure model for aquatic species estimates equilibrium body burdens via water and food uptake but toxicological data are generally given in terms of water concentrations producing a given effect. To convert the benchmark into a body burden, the water concentration was multiplied by the bioconcentration factor for the contaminant and species that was used in the deterministic calculations. This produced an estimate of the equilibrium body burden that would have resulted from continued exposure to water at the benchmark concentration. Because the bioconcentration factor is an uncertain estimate, this conversion introduces a moderate to large degree of uncertainty, depending on the contaminant (see ranges of uncertainties in bioconcentration factors in Table 4.30).

To estimate endpoint benchmarks for terrestrial species, the recommendations of Sample et al. (1996) that mammalian response is assumed to be scaled as a three-fourths power function of body weight were followed. Traditional wildlife approaches use a straight function of body weight. The consequences of selecting the Sample et al. (1996) method over the other two is that, where the reference species is smaller

than the species to which its benchmark is extrapolated, the resultant benchmark will be below that estimated by the other two methods. From this standpoint, the method chosen is conservative.

4.2.11 Analysis of Risk

The previous sections have presented the results of the deterministic and stochastic assessments of exposure to contaminants in relation to toxicological benchmarks following EPA guidelines (EPA 1996). To assess the potential risk, however, these results must be evaluated in light of the physical and ecological context of the study area and the data that served as inputs to the exposure modeling itself. The key questions to be addressed by this risk assessment are:

The key questions for which we sought answers in our assessment of risk to the environment are:

Question: Which species have the greatest likelihood of being adversely affected by which contaminant and media?

Answer: For some herbivores, omnivores and weasels, cobalt-60, chromium, cesium-137, mercury, and lead in sediment and pore water.

For aquatic species, cyanide, chromium, copper, mercury, ammonia, lead, and zinc in pore water and somewhat in sediment.

Question: Where within the study area do contaminants of interest currently pose a potential threat to ecological resources?

Answer: Segments 4, 7-10, 12-14, 17, and 20 contain contaminants that pose a potential risk above background to terrestrial and aquatic organisms.

- ◆ Where within the study area do contaminants of interest currently pose a potential threat to ecological resources?
- ◆ Which contaminant/media combinations contribute to that threat?
- ◆ Which organisms or groups of organisms have the greatest likelihood of being adversely affected in those areas?

The primary objective of this analysis is to determine whether Hanford Site-derived contaminants pose a present risk to non-human biota within the study area, and if so, where that risk is, and which ecosystem components are most at risk?

Many of the contaminants of interest for this screening-level risk assessment are elements or isotopes that are relatively ubiquitous in the environment. They derive from sources in addition to those on the Hanford Site. Several metals in the contaminants list occur in relatively high concentrations in sediment and water in the Columbia River upstream from any Hanford Site inputs (Munn et al. 1995, Serdar 1993, Johnson et al. 1990). These include mercury, lead, zinc, copper and chromium. As discussed earlier, many of the contaminant metals are also nutrients or micronutrients for most organisms. Consequently, tissue levels are generally stable over a range of environmental concentrations. For these reasons, the CRCIA Team elected to examine incremental risk from Hanford-derived contaminants, addressing risk that exceeds levels found in Segment 1 of the study area. Contaminants with non-zero risk where simulations showed no exposures above thresholds in Segment 1 for aquatic organisms were copper, lead, and zinc. For terrestrial organisms, these background contaminants also included cesium-137, chromium, mercury, nickel, and uranium. Consequently, risk for these contaminants within the study area below Segment 1 was evaluated where the estimated risk exceeded the background level.

Contaminants of interest found to pose no significant risk to non-human biota were organics, iodine-129, europium-152, europium-154, and tritium (hydrogen-3) (Table 4.31). As noted earlier, risk from carbon-14, neptunium-237, and diesel fuel was not evaluated, as recommended by the CRCIA Team because there were insufficient media data (see Tables 4.27 and 4.28).

To determine whether the study area segments listed in Table 4.31 actually contain contaminants at levels that pose a potential threat to biota, the data on which these estimates were based were first elevated. The primary medium of interest was pore water, which was the primary contributor to risk in most cases. The risk due to pore water contamination arises principally from respiratory (gill or dermal) uptake by aquatic organisms exposed to pore water and the subsequent movement of these contaminants through the food web.

One concern is to what degree does the surrogated pore water used in the exposure estimate reflect actual pore water to which organisms are exposed. As part of a special study by Bechtel Hanford, Inc. in 1995 and 1996, chromium (VI) was measured in pore water at various points within study Segments 7, 8 (Hope and Peterson 1996), and 10 (Hope and Peterson 1995). Pore water was collected through a sampling pipe driven into the substrate at a number of locations near the 100-D/DR (Segments 7 and 8) and at 100-H (Segment 10) Areas. The CRCIA Team determined that these data would be used for

Table 4.31. Segments and Contaminants Where Deterministic EHGs or Simulated Exposures Were above LOEL Benchmarks and above Segment 1 Values

Contaminant	Segments > Terrestrial Benchmarks	Segments > Aquatic Benchmarks
Cyanide	None	20
Co-60	6, 7, 8, 9, 12, 13, 17, 19, 21	None
Cr	2, 4, 5, 9, 10, 19	2, 4
Cs-137	7, 10, 12	None
Cu	4, 17	4
Eu-152, 154	None	None
Hg	9, 10, 14, 19	3, 8, 9, 10, 13, 14, 19
I-129	None	None
NH ₃	None	2, 6, 8, 13, 19, 20, 21
Ni	None	7, 20, 21
NO ₃	None	None
Organic compounds	None	None
Pb	4, 17	5, 9, 17, 19, 20, 21
Sr-90	6	None
Tc-99	8, 9, 10, 14, 20	None
Tritium	None	None
U-234	14, 17, 20	None
U-238	4, 10, 14, 17, 20	None
Zn	4, 12	4, 7, 8, 9, 12, 17, 19, 20, 21

comparison to evaluate the adequacy of the surrogated pore water used in the screening assessment, but the data would not be used in the exposure analyses or in the media summaries presented in Section 3.0.

As shown in Table 4.32, measured pore water maxima exceeded surrogated pore water maxima at Segments 7 and 10. The geometric standard deviations for these segments also showed the same pattern, with measured values exceeding surrogated values (Ln-transformed data, Levene's test for equality of variances: $P < 0.001$). Pore water measurements in Segments 7 and 10 identified a narrow band of elevated chromium at the lower end of each segment that was not reflected in the seep/spring data, which was the source for the pore water surrogate data. However, the geometric mean surrogated pore water exceeded the measured pore water in all three segments (Ln-transformed data, Welch analysis of variance for unequal variances: $P < 0.01$).

Table 4.32. Comparison of Chromium ($\mu\text{g/L}$) in Surrogate Pore Water Versus Measured Pore Water

Contaminant	Segment	Maximum		Geometric Mean		Geometric Standard Deviation	
		Surrogated	Measured	Surrogated	Measured	Surrogated	Measured
Chromium	7	28.0	632.0	3.5	2.4	5.6	11.9
Chromium	8	400.0	84.7	20.4	0.9	6.5	5.7
Chromium	10	84.0	130.0	35.7	1.7	1.6	7.4

Based on this comparison, chromium exposures estimated using surrogated pore water were higher on average than they would have been had measured values been used. Surrogated pore water maxima in all three segments were high enough that none were screened out in the deterministic analysis. The lower standard deviations for surrogated pore water in Segments 7 and 10 resulted in maximum risk estimates for these segments that were lower than would have resulted had measured values been used. The spatial extent of the higher risk, however, is extremely limited: The high-chromium area in Segment 10 covers no more than 80 meters of shoreline (Hope and Peterson 1995). The area in Segment 7 extends no more than 120 meters (Hope and Peterson 1996).

Assuming these trends held for other contaminants of interest in other areas, the average exposure estimates may be biased slightly high.

A second consideration in using the surrogated pore water data arises from assuming that the contaminants as measured were all bioavailable via gill uptake. Some of the source data contained information on whether the reported water concentrations reflected filtered or unfiltered water samples. Filtered samples are water that has been passed through a $0.45\text{-}\mu$ filter, thereby removing particulate metal, which is unavailable for uptake by aquatic organisms via dermal or respiratory surfaces (Förstner and Wittmann 1981). Although not all metal that passes a $0.45\text{-}\mu$ filter is bioavailable (Förstner and Wittmann 1981), the difference between filtered versus unfiltered data indicates where exposures have been overestimated, and by how much.

Surrogated pore water data were separated into two sets based on whether the data were from filtered or unfiltered samples. Geometric means for filtered data were then expressed as a percentage of the geometric means of the unfiltered data. These percentages are shown in Table 4.33.

Based on this comparison, chromium exposures estimated using surrogated pore water were higher on average than they would have been had measured values been used. Surrogated pore water maxima in all three segments were high enough that none were screened out in the deterministic analysis. The lower standard deviations for surrogated pore water in Segments 7 and 10 resulted in maximum risk estimates for these segments that were lower than would have resulted had measured values been used. The spatial extent of the higher risk, however, is extremely limited: The high-chromium area in Segment 10 covers no more than 80 meters of shoreline (Hope and Peterson 1995). The area in Segment 7 extends no more than 120 meters (Hope and Peterson 1996).

Concentrations for zinc in pore water differed by two to 100 times for Segments 5, 6, 9, 12, 14, and 15. Segment 12 was especially in error. Concentrations of nickel in pore

Table 4.33 Geometric Mean Concentrations of Filtered Surrogate Pore Water Expressed as a Percentage of the Geometric Mean Concentration of Unfiltered Surrogate Pore Water

Contaminant	Segment																	
	1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	19	20	21
Carbon-14	UF ^(a)	UF	UF	36%	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Cesium-137	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Chromium	104%	122%	348%	UF	97%	37%	UF	13%	83%	136%	107%	78%	17%	66%	33%	32%	UF	24%
Cobalt-60	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Copper	96%	105%	100%	UF	36%	40%	64%	69%	64%	106%	13%	88%	35%	80%	40%	94%	UF	89%
Europium-152	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	92%	UF
Europium-154	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Lead	68%	UF	120%	95%	UF	65%	96%	UF	UF	UF	UF	UF	UF	UF	UF	59%	89%	86%
Mercury	109%	UF	108%	104%	UF	119%	100%	UF	UF	UF	UF	UF	UF	UF	UF	107%	101%	100%
Nickel	68%	133%	100%	UF	82%	57%	44%	84%	136%	134%	UF	121%	74%	103%	56%	49%	UF	35%
Nitrate	235%	UF	UF	UF	UF	UF	UF	1%	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Strontium-90	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Technetium-99	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Tritium	UF	UF	UF	25%	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	65%
Uranium-234	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Uranium-238	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF
Zinc	103%	78%	100%	UF	36%	33%	89%	114%	44%	59%	1%	62%	51%	31%	54%	55%	UF	76%

(a) UF = Only unfiltered data were available.

water differed by two times for Segments 6, 7, 8, 16, 19, 20, and 21. Copper values differed by two to three times for Segments 5, 6, 12, 14, and 16. Finally, chromium concentrations differed by two to five times in Segments 6, 8, 14, 16, 19, and 21.

In each case, had exposures been estimated using filtered data for in-water respiratory source terms, exposures and risk would have been significantly reduced. For example, mean estimated body burdens of chromium for aquatic organisms in Segment 8 were reduced by up to 20 parts per million. Copper in Segment 12 was reduced by up to 40 parts per million, and zinc in Segment 12 was reduced by nearly 80,000 parts per million (Figure 4.17). The greatest decreases in relative risk were found for benthic organisms: periphyton, mayfly, Columbia pebblesnail, crayfish, water milfoil, trout and salmon eggs, and Woodhouse's toad/tadpoles. For air-respiring (or transpiring) species in these segments, chromium exposures decreased by up to 15 parts per million, copper decreased by nearly 25 parts per million, and zinc decreased by 45,000 parts per million (Figure 4.18). The greatest decreases in relative risk when data from filtered samples were used were for American coot, cliff swallow, mallard, bufflehead, common snipe, and Canada goose.

Figure 4.17. Change in Estimated Equilibrium Body Burden of Aquatic Organisms Produced by Using Filtered Versus Total Metal in Surrogated Pore Water

Because both the geometric means and standard deviations were inflated by using all data rather than just filtered data for these contaminant-segment combinations, both mean and maximum risk was overestimated. Based on these considerations, copper presents a potential risk above background to organisms in Segment 4 only. Risk from zinc above background is potentially present in Segment 4 for terrestrial organisms and in Segments 4, 7, 8, 17, 20, and 21 for aquatic organisms. Nickel poses a minor risk in Segment 20. Risk from chromium is greater than background in Segments 2, 4, 5, 9, and 10.

Taking into account all the areas where filtered concentrations were one third or less of unfiltered pore water, study area segments were grouped as follows: those where contaminants currently pose no significant risk above background (green in Figure 4.19), those where risk of chronic effects is present

Figure 4.18. Change in Estimated Equilibrium Body Burden of Air-Respiring Organisms Produced by Using Filtered Versus Total Metal in Surrogated Pore Water

above background (yellow in Figure 4.19), and those where acute effects may be present (red in Figure 4.19). Chronic effects are those that result from exposure to a contaminant in excess of LOELs, with simulated exposures greater than those in Segment 1. Acute effects are those that exceed lethal exposure benchmarks and have an exposure risk greater than those in Segment 1.

Acute effects on terrestrial systems are potentially present from chromium in Segments 4 (100-K Area) and 9 (downstream from 100-D Area), from lead in Segment 17 (corresponding to the old Hanford townsite), and zinc in Segment 4 (100-K Area).

	Location																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Terrestrial																											
C-14	No Porewater										N							N				N	N	N	N	N	N
CN											o							o				o	o	o	o	o	o
Co-60																											
Cr											P							P				P	P	P	P	P	P
Cs-137											o							o				o	o	o	o	o	o
Cu											r							r				r	r	r	r	r	r
Eu-152	No Surface water										e							e				e	e	e	e	e	e
Eu-154											w							w				w	w	w	w	w	w
Hg											a							a				a	a	a	a	a	a
I-129											t							t				t	t	t	t	t	t
NH ₃											e							e				e	e	e	e	e	e
Ni											r							r				r	r	r	r	r	r
NO ₂	No toxicity data																										
NO ₃											D							D				D	D	D	D	D	D
Np-237	No Porewater										a							a				a	a	a	a	a	a
Organics											t							t				t	t	t	t	t	t
Pb											a							a				a	a	a	a	a	a
PO ₃	No toxicity data																										
SO ₄	No toxicity data																										
Sr-90																											
Tc-99																											
H-3																											
U-234																											
U-238																											
Zn																											
Aquatic																											
C-14	No Porewater data										N							N				N	N	N	N	N	N
CN											o							o				o	o	o	o	o	o
Co-60																											
Cr											P							P				P	P	P	P	P	P
Cs-137											o							o				o	o	o	o	o	o
Cu											r							r				r	r	r	r	r	r
Eu-152	No Surface water data										e							e				e	e	e	e	e	e
Eu-154											w							w				w	w	w	w	w	w
Hg											a							a				a	a	a	a	a	a
I-129											t							t				t	t	t	t	t	t
NH ₃											e							e				e	e	e	e	e	e
Ni											r							r				r	r	r	r	r	r
NO ₂	No toxicity data																										
NO ₃											D							D				D	D	D	D	D	D
Np-237	No Porewater data										a							a				a	a	a	a	a	a
Organics											t							t				t	t	t	t	t	t
Pb											a							a				a	a	a	a	a	a
PO ₃	No toxicity data																										
SO ₄	No toxicity data																										
Sr-90																											
Tc-99																											
H-3																											
U-234																											
U-238																											
Zn																											
AREAS	B/C		K		N	D	D		H				F				HT			300							
	Not different from background																										
	≥ 5% above background (chronic)																										
	≥ 2 Σ(RRI) above background (acute)																										

Figure 4.19. Levels of Ecological Risk for Contaminants above Background Concentrations in Study Area Segments for Terrestrial and Aquatic Organisms

Potentially significant radiological doses to terrestrial organisms primarily are due to cobalt-60 and cesium-137. The background concentration of cesium-137 is relatively high. Cesium-137 is present in sediment in Segment 1 at high enough concentrations that >55 percent of simulations of exposure for terrestrial species at risk were above LOELs (Figure 4.14). No radionuclide produced doses above acute effects levels in any segment. Technetium-99 did not constitute a radiological hazard anywhere, but did pose a chronic toxic risk to plants in Segments 8-10, 14, and 20. The toxicological hazard to animals remains unknown, however, due to the lack of toxicological data for organisms other than plants.

Non-radioactive metals contributing to chronic risk in excess of background levels for terrestrial organisms were chromium, copper, lead, mercury, and zinc. Chronic risk from chromium was found below the 100-H and 100-K Areas. Chronic risk from lead and mercury was found in most segments.

Non-radiological metals contributing to an acute risk for aquatic organisms were copper, lead, mercury, and zinc. The acute risk from zinc was associated with the 100-K Area while the acute risk from lead was downstream of the 100-D, 100-F, 100-K Areas and the old Hanford townsite. Other non-radiological metals that contributed to risk to aquatic organisms included chromium (Segments 2, 4, 5, 9, and 10), copper (Segments 4 and 20), lead (Segments 7 and 20), mercury (most segments), and zinc (Segments 7, 8, and 17). Chronic risk to aquatic organisms from non-radiological metals appeared to be associated mainly with former reactor sites, for example the 100-K, -D, and -H Areas. As discussed previously, the potential risk to aquatic organisms from these metals, particularly zinc, may be less than predicted by the model because actual bioavailability in the field may be lower than the values used in the model. It also was not possible to adjust all acute toxicity values to the pore water levels of hardness and pH because of gaps in the data. Thus, many metals such as zinc may have reduced toxicity under field conditions.

There was a chronic risk to aquatic organisms posed by cobalt-60 in Segment 6. Another contaminant from Hanford Site origin that contributed to chronic risk to aquatic organisms was cyanide (Segments 20 and 21). The risk appeared to be associated with the 300 Area.

Several metals occur in relatively high concentrations in abiotic media in areas upstream of Hanford Site inputs. These include cesium-137, chromium, copper, lead, mercury, nickel, and zinc. Offsite sources for these metals include worldwide fallout (cesium-137) effluents from the COMINCO smelter at Trail, British Columbia and contaminated sediment entering the Columbia River system from the Spokane River. These have been the focus of a number of studies by the Washington State Department of Ecology, EPA, and the USGS in the Columbia River system above the Hanford Site. As noted earlier, statistical comparisons of sediment concentrations showed no significant rise above background concentrations for nickel, lead, or zinc, and showed small increases for chromium in Segments 2 and 4 and for copper in Segment 14. Consequently, additional risk due to Hanford Site inputs for these metals is expected to be small.

Species experiencing the greatest direct hazards from exposures to contaminants can be identified by summing the risk scores (see Table 4.29) across contaminants for each species within a segment. This method assumes contaminants are additive in their actions on organisms, which is not necessarily the case but is a conservative default approach recommended by EPA (1993). Species with the highest score would therefore be most at risk from exposure to contaminants. This analysis is presented in Figure 4.20 for

Figure 4.20. Levels of Risk for Terrestrial Species Based on Simulated Exposures

terrestrial species and Figure 4.21 for aquatic species. These results were then corrected for the difference between unfiltered and filtered pore water exposures for the dermal uptake pathway for aquatic organisms (and the resulting changes in dietary exposures for higher trophic-level organisms) to produce a species-by-segment risk plot (Figure 4.22) similar to the chemical-by-segment plot shown in Figure 4.19.

Terrestrial species that are potentially most affected by contaminants in the study area are American coots, Canada geese, harvest mice, mallards, raccoons, and swallows. However, risk within the study area that is above background levels is limited to only a few locations within the study area (Figure 4.22). The other species, including bald eagles, had relatively low risk in both absolute and relative (to background) terms.

Relatively high risk was estimated for many species in Segment 4, primarily on the basis of zinc, copper, and chromium. Most of this risk was due to ingestion of prey with high levels of these contaminants in tissue, which ultimately arises from high concentrations of contaminants in the pore water in these segments. However, the samples in which these analytes were measured were unfiltered. The measurement reflects particulate as well as dissolved metal. On average, filtered concentrations of copper and zinc were 70 percent and 62 percent of the unfiltered concentrations, respectively. Consequently, the estimated risk these contaminants pose to organisms in Segment 4 remains suspect pending analysis of filtered pore water samples or their surrogates in these segments.

Aquatic species most likely affected by acutely and chronically toxic effects from contaminants of Hanford Site origin are clams, Columbia pebblesnail, crayfish, *Hyalloa*, mussels, salmon/trout larvae, suckers, water fleas, and Woodhouse's toad (tadpole). Other species with potential chronic risk included carp, clams, and mussels. The principal reason for the high relative risk of these aquatic species is their exposure to pore water and sediment. Most of these organisms have a benthic lifestyle. They spend all or a high proportion of their life either in direct contact with the sediment or pore water. Thus, pore water concentrations are driving their estimated tissue burdens, and any exposure scenario that decreases the amount of time they spent exposed to 100 percent pore water would lower their risk accordingly. The acute risk shown for Segments 4 and 17 would be further mitigated if data from filtered water samples were used. Overall, the data suggest that some risk is present for aquatic organisms (mainly benthic species) and that this risk is limited mainly to the portion of the Columbia River adjacent to the 100-K Area, 100-D/H Areas, the old Hanford townsite, and the 300 Area.

The answers to the previously posed questions then are as follows. Contaminants of interest pose potential hazards to some plants, herbivores, omnivores consuming riverine organisms (especially insects as prey), and weasels in some areas. The primary contaminants driving the risk are cobalt-60, chromium, cesium-137, mercury, lead, zinc, and technetium-99. The media contributing most to risk are pore water and sediment.

For aquatic species, the organisms most at risk are benthic species or life stages. Contaminants contributing to their risk are cyanide, chromium, copper, mercury, lead, and zinc. The media contributing most to this risk are pore water and sediment with pore water most significant.

Figure 4.21. Levels of Risk for Aquatic Species Based on Simulated Exposures

Figure 4.22. Levels of Ecological Risk above Background for Species in Study Area Segments for Terrestrial and Aquatic Organisms

The segments presenting the greatest potential risk are Segment 2 (chromium and lead at the 100-B/C Area), Segment 4 (chromium, copper, mercury, and zinc at the 100-K Area), Segment 5 (chromium and lead), Segment 6 (cobalt-60 and mercury at the 100-N Area), Segment 7 (cesium-137, cobalt-60, lead, and zinc at the 100-D Area), Segment 8 (cobalt-60, mercury, and technetium-99), Segment 9 (chromium, cobalt 60, lead, and mercury), Segment 10 (cesium-137, chromium, mercury, and technetium-99 at the 100-H Area), Segment 12 (cesium-137, cobalt-60, and mercury), Segment 13 (cobalt-60, lead, and mercury at the 100-F Area), Segment 14 (mercury and technetium-99), Segment 16 (cobalt-60 and mercury), Segment 17 (lead but results suspect and zinc), Segment 19 (lead and mercury), 20 (cyanide, lead, mercury, technetium-99, and zinc at the 300 Area—all results suspect) and Segment 21 (cyanide and lead).

Segments with potential acute risk are Segment 4 (chromium and zinc), Segment 5 (lead), Segment 8 (mercury), Segment 9 (chromium, lead, and mercury), Segments 10 and 14 (mercury), Segment 13 (lead and mercury), Segment 17 (lead), and Segment 20 (copper and zinc). Data were insufficient to assess risk of any contaminant in Segments 11, 18, and 22-27. Risk from nitrite, sulfate, and phosphate was not evaluated because of the general lack of toxicity benchmarks. They present no risk from food-chain exposure, however, because they are readily metabolized. Risk from neptunium-237 and carbon-14 was not evaluated because of the lack of pore water data. Surface water data for europium-152 were absent in Segments 1-18, so risk from this isotope was not estimated in those segments. Risk from certain other contaminants was not evaluated in the central portion of the study area due to missing pore water data (see Figure 4.19).

5.0 Screening Assessment of Risk to Human Health

The results of the screening assessment indicate the potential risk to human health and the environment from Hanford derived contaminants in the Columbia River. This section describes the process used to assess potential risk to human health and the results. Section 4.0 describes the process used to assess potential risk to the environment and the results.

5.1 Human Exposure Scenarios for the Screening Assessment

Because the objective of the human risk assessment is to determine whether Hanford derived contaminants from the Columbia River pose a threat to humans in the study area, the first step was to identify possible scenarios of human activities. This section describes the scenarios selected and the exposure parameters used as the basis for estimating the potential range of risk to human health. The second step in the assessment was to estimate the potential risk to humans based on the scenarios. Section 5.2 describes the process and results of the human risk assessment.

To assess possible risk to humans, we need to make assumptions about the life styles of those who might be affected by contaminants from the Columbia River. We use these assumptions (parameters) in the equations described in Section 5.2. The results of the equations estimate the possible risk to humans. The compiled list of assumptions for any given life style is called a scenario. In this section, we describe the assumptions for the twelve scenarios we used in the screening assessment. The twelve scenarios and the key assumptions are shown in Table 5.1. The parameters for each scenario are described in the respective sections and summarized in a table in each section.

5.1.1 Scope of and Approach to Exposure Scenarios

Contaminants in the Columbia River could affect people involved in a wide range of activities. Therefore, various scenarios have been developed on which to base the risk assessment. The scenarios illustrate the range of activities possible by members of the public coming in contact with the Columbia River so that the impact of contaminants in the river on human health can be assessed. Each scenario illustrates particular activity patterns by a specific group.

Numerous proposals are being considered for the future use of the Hanford Site and, in particular, the Hanford Reach. These proposals span a variety of land uses and human activity patterns, ranging from industrial use to conservation and Native American uses. Because the goal of CRCIA is an assessment of potential impact, scenarios (based on current conditions in the Columbia River) have been developed to reflect the possible uses of the Hanford Site in the near future. The scenarios used in the screening assessment are for the purpose of this study only. They do not represent recommendations by the CRCIA Team as to actual land use. Although the scenarios are based on current conditions, that does not imply that people are currently exposed to these risks. The risk estimated is potential risk. It would be actual risk if people in the near future were to start performing the activities postulated in the scenarios.

Table 5.1. Overview of Key Assumptions for the Scenarios

Scenarios	Derived from HSRAM	Key Deviations from Hanford Site Risk Assessment Methodology (HSRAM)	Exposure Locations	Activities	Days of Exposure/ Year	Hours of Exposure/ Day	Plants and Animals Ingested	Water Ingested
Industrial Worker	Industrial Scenario	Slight Modification: Columbia River water not groundwater; only contact with environmental media not other substances	On-site Indoors with some outdoor activity	Works	250	8	None	1 liter
Fish Hatchery Worker	Industrial Scenario	Numerous Modifications: Statistics on fish hatchery work time on site used; only contact with environmental media not other substances	On-site with 50% outdoor activity	Works	250	8	None	1 liter
Ranger	Industrial Scenario	Numerous Modifications: Less time on site but more time in outdoor activity when on site	Off-site office On-site visits	Visits habitat	150	9	None	None
Avid Recreational Visitor	Recreational Scenario	Numerous Modifications: Information on fishing and hunting practices used	On-site Upland regions River	Fishes frequently Hunts frequently	365	4	Fish Deer Upland birds Waterfowl	2 liters
Casual Recreational Visitor	Recreational Scenario	Slight Modification	On/near site River	Boats Fishes occasionally Hunts occasionally Swims	7	8	Fish Deer	4 liters

Table 5.1. (Cont'd)

Scenarios	Derived from HSRAM	Key Deviations from Hanford Site Risk Assessment Management (HSRAM)	Exposure Locations	Activities	Days of Exposure/ Year	Hours of Exposure/ Day	Plants and Animals Ingested	Water Ingested
Native American Subsistence Resident	Agricultural Scenario	Numerous Modifications: Limited information on tribal activities used	On-site All habitats	Fishes Gathers Hunts Pastures Prepares Bathes (Sweat Lodge)	365	24	Fish Fruit & veg Animal protein Organs Milk Upland birds Waterfowl Wild bird eggs	6 liters
Native American Upland Hunter	Agricultural Scenario	Numerous Modifications: Limited information on tribal activities used	On-site Upland areas	Hunts	150	24	Animal protein Organs Upland birds	3 liters
Native American River-Focused Hunter and Fisher	Agricultural Scenario	Numerous Modifications: Limited information on tribal activities used	On/near site River	Fishes Hunts	150	24	Fish Waterfowl Wild bird eggs	6 liters
Native American Gatherer of Plant Materials	Agricultural Scenario	Numerous Modifications: Limited information on tribal activities used	On-site All habitats	Gathers Prepares	365	24	Fruit & veg	6 liters
Native American Columbia River Island User	Agricultural Scenario	Numerous Modifications: Limited information on tribal activities used	Near site Islands	Visits	2	24	None	None
Resident	Residential Scenario	Slight Modification: Columbia River water not groundwater	On-site	Fishes Gardens Resides	365	24	Fish Fruit Vegetables	4 liters
Agricultural Resident	Agricultural Scenario	Slight Modification: Columbia River water not groundwater	On-site	Farms Fishes Hunts Resides	365	24	Fish Fruit Vegetables Deer Beef Dairy	4 liters

People are exposed to contaminants when they come in contact with any substance that is transporting a contaminant. The substances (media) we investigated are air, cultural substances such as plants used for medicines, food, sediment, soil, and water. To determine the parameters to be used in the equations, we needed to estimate the amounts of these media that people might contact, ingest, inhale, or receive an external radiation exposure from over an assumed period of time. The U.S. Department of Energy has already developed such assumptions for people who are currently industrial workers and those who spend their leisure time in the vicinity of the Hanford Site. The U.S. Department of Energy has also developed such assumptions for people who sometime in the future might be residents or agricultural workers on the Hanford Site. The assumptions we used in our scenarios have their basis in the U.S. Department of Energy assumptions. Any changes we made to the U.S. Department of Energy assumptions are the result of information supplied by the CRCIA Team.

In line with the scope of work for the screening assessments, the scenarios are Hanford Site specific. DOE has developed generic scenarios for the Hanford Site (DOE 1995). At present, only four of these generic exposure scenarios (DOE's Hanford Site Risk Assessment Methodology, HSRAM) are available for current conditions on the Hanford Site: an industrial scenario and a recreational scenario, which represent current uses, and a residential scenario and an agricultural scenario, which represent potential future uses. HSRAM provides a set of uniform methods and inputs for use at Hanford so that assessments performed at various times by different organizations have a consistent basis. HSRAM, in turn, consolidates recommendations from other agencies such as EPA (1991a) and the Washington Administrative Code (WAC 1991). Because

HSRAM is an accepted method that has been previously reviewed, all scenarios defined for the screening assessment have their bases in one of the four HSRAM scenarios (Table 5.1).

Four of the screening assessment scenarios are almost identical to the HSRAM scenarios. These four are designated as "slightly modified HSRAM" scenarios in the list of scenarios below. Eight of the screening assessment scenarios have numerous modifications. In several instances, the parameters for the same media and exposure pathway within the HSRAM scenarios were varied. In such cases, a consistent parameter was selected with CRCIA Team guidance for the affected scenarios in the screening assessment.

The total suite of twelve scenarios is needed to capture at least the main potential human activities upon which parameters (based on current conditions) can be screened to assess potential risk. The scenarios are designed to provide insights into various exposure pathways and the range of potential risks associated with different kinds of activity. The intent is to indicate the potential range of risk associated with activities ranging from occasional, casual exposure through intensive, continual contact. The human scenarios used in the screening assessment of human risk are:

Industrial/Commercial Scenarios

- ◆ Industrial Worker (slightly modified HSRAM scenario using Columbia River water instead of groundwater) (DOE 1995)
- ◆ Fish Hatchery Worker

Wildlife Refuge/Wild and Scenic River Scenarios

- ◆ Ranger
- ◆ Avid Recreational Visitor
- ◆ Casual Recreational Visitor (slightly modified HSRAM scenario with radionuclide, carcinogenic chemical, toxic chemical information pulled into one table) (DOE 1995)

Native American Scenarios

- ◆ Subsistence Resident (an unrestricted use scenario included as a baseline for comparison)
- ◆ Upland Hunter
- ◆ River-Focused Hunter and Fisher
- ◆ Gatherer of Plant Materials
- ◆ Columbia River Island User (for application to Cobalt-60 particles)

General Population Scenarios

- ◆ Resident (slightly modified HSRAM scenario using Columbia River water instead of groundwater) (DOE 1995)
- ◆ Agricultural Resident (slightly modified HSRAM scenario using Columbia River water instead of groundwater) (DOE 1995)

As will be seen in the detailed descriptions of each scenario, not all scenarios are applicable to all areas designated for study in the screening assessment. For example, segments of the river investigated include populated areas of the cities of Richland, Kennewick, and Pasco, for which scenarios such as the hunter or park ranger are obviously inappropriate.

These scenarios were selected with present and potential use of the Hanford Site in mind. For example, if portions of the Hanford Reach of the Columbia River were established as a wildlife refuge, the activities associated with that use might include ranger, hunter/fisher, or recreational visitor. Not all activities currently occurring on the site were evaluated. Tours of the B Reactor are being conducted, for instance. Exposure information for visitors on such tours might be desired in the future, but for the initial phase of the CRCIA work, no B Reactor Visitor Scenario was defined. The exposure scenarios selected are based on general agreement by the CRCIA Team and do not represent recommendations as to actual land use or cleanup levels.

The scenario definitions are based on activities rather than location. The potential of the Hanford Reach becoming a wildlife refuge illustrates why. The ranger, avid recreational visitor, and casual recreational visitor would have different degrees of contact with the surface water, spring water, soils, sediments, and foods. Therefore, the exposures and risks to these three types of people could be quite different at the same location. Location is taken into account when the scenarios are applied to particular areas of the Hanford Site.

For consistency with other Hanford activities, the HSRAM (DOE 1995) industrial and casual recreational scenarios were adopted with few changes, although statistical ranges have been added to all parameters and the media to which people could be exposed are customized to the CRCIA situation (e.g., river water instead of groundwater is used in the industrial worker scenario). The HSRAM residential and agricultural resident scenarios were modified to account for the use of Columbia River water instead of groundwater. For the Fish Hatchery Worker Scenario, information about actual time spent on the Hanford Site by fish hatchery workers was used. The Ranger Scenario is a variant of the HSRAM industrial scenario. Information about actual hunting and fishing practices in the counties surrounding the Hanford Site was used to develop the Avid Recreation Scenario. Limited tribal information was used to develop the Native American Scenarios. For applications other than the screening risk assessment, the Native American Scenarios will require review and modification by tribal technical staff.

Key Points

- ◆ The scenarios are intended to include the activities of most importance to particular user groups and to translate those activities into activity-based exposures.
- ◆ Each of the scenarios contains assumptions about frequency and duration of the activities, ranging from a few days per year to much more intense use over long time frames. The particular assumptions are specific to individual scenarios.
- ◆ The Native American scenarios will require review and modification by tribal technical staff before being used in other studies. The Native scenarios described here are solely for use in the CRCIA screening assessment of risk.

The two main parameter groups to be defined for each scenario are the contaminant pathways (media and exposure route of that media) and the exposure parameters (intake/contact rate, exposure frequency, exposure duration, and special parameters that apply to only certain media and exposure routes).

A contaminant pathway describes a unique mechanism by which an individual is exposed to chemical or physical agents at or originating from a particular location. The media providing potential contamination to humans vary according to the particular scenario. The media considered were soil, air, seep/spring water, surface water, sediment, biota, and cultural media. (Cultural media include specific plants, animal products, or other items used in unique cultural activities.) These media come in contact with humans via the exposure routes of ingestion, external radiation exposure, dermal contact, and inhalation.

Exposure parameters were based on the scenario to be modeled. The exposure parameters defined in the scenarios for use in the screening assessment of risk are the intake/contact rate, exposure frequency, exposure duration, and other parameters that apply to only certain media and exposure routes. For instance, skin surface area is another parameter that was accounted for when estimating the dermal contact.

Each scenario is made up of components that may appear to be exclusive, for example, drinking of water from springs while simultaneously drinking water from the river. For the purpose of the screening risk assessment, the exclusive nature of these related pathways was ignored, and both components were included. Thus, for the example of drinking water, the total quantity of water consumed is actually twice what might really be expected. Because human behavior is unpredictable and to capture the potential for

risk from both the springs and river water, no attempt was made to apportion either pathway. The exposure from separate pathways will rarely be of the same magnitude, so the resulting effect is the highest exposure was automatically assigned to the most contaminated source. This philosophy is similar to that used for scenario development in HSRAM (DOE 1995).

The lifestyle of any given individual typically involves several scenarios. A fish hatchery worker might go on vacation and become a recreational visitor. However, the CRCIA screening assessment of risk to human health follows the HSRAM practice of basing risk assessments on separate scenarios rather than on an individual's lifestyle which might incorporate a variety of the scenarios. The exposures and risk may be reasonably apportioned and combined. A description of the way to perform this addition and examples are provided in Appendix I-E.

An objective of CRCIA is to provide the uncertainty of the risk information that is developed. This risk information has been developed using a stochastic analysis of the risk, which incorporates the uncertainties inherent in the concentrations of the contaminants. In addition, there will also be variability in the exposure parameters selected for the screening assessments, both inherent uncertainty about the selected parameters and the inability to capture exactly the lifestyle of people simulated in the scenarios. For each scenario, the range for each intake/contact rate is given in terms of a minimum and maximum value and a corresponding deterministic value. The deterministic values are intended to be conservatively selected, such that exposures to contaminants should be near the upper end of the anticipated range and represent a reasonable maximum exposure. The majority of these minima and maxima have been selected using the professional judgement of the authors. Thus, they serve as opening suggestions in what is anticipated to be a continuing discussion.

5.1.2 Industrial/Commercial Scenarios

In the CRCIA screening assessment, two industrial/commercial scenarios will be assessed for risk: an Industrial Worker Scenario and a Fish Hatchery Worker Scenario. Industrial, commercial, and waste management activities occur both on and off the Hanford Site along the Columbia River. The worker scenario developed in HSRAM is a standard industrial/commercial scenario focused on worker exposures to residual environmental contamination. For the scenarios in this section, only the potential exposure from contact with environmental media (as opposed to substances encountered as part of the job, unless the environmental media are encountered at work) were considered.

A Fish Hatchery Worker Scenario was developed in this section because of the current hatchery activities in the K Area and at Ringold. The new scenario is compared to the HSRAM industrial scenario. Documentation was provided when possible by employees working under these conditions. However, the data supplied by the interviewed employees have not been validated.

5.1.2.1 Industrial Worker

The HSRAM industrial scenario (DOE 1995) has been adopted with minimal modification because it is an accepted method that has been previously reviewed. However, for use in the Columbia River

screening assessment of risk, water is assumed to come from the Columbia River rather than groundwater. This scenario represents exposures that may occur to a person whose job onsite is primarily indoors but would also include some outdoor activities, for example, building and grounds maintenance. Such a scenario could represent workers with indoor/outdoor job responsibilities such as hardware/lumber sales or farm equipment sales. The scenario assumes that the workers do not wear protective clothing. The worker is assumed to spend 8 hours/day in indoor activities with incidental exposures to soil and river water, to breathe materials suspended from the soils, and to shower at work. The worker is assumed to take a 10-minute/day shower with river-derived water.

The primary pathways included in the Industrial Worker Scenario include direct soil, air, and surface water, as:

- ◆ Ingestion of contaminated soil
- ◆ External exposure from radionuclides in the soil
- ◆ Dermal contact with the soil
- ◆ Inhalation of fugitive dust
- ◆ Ingestion of surface water
- ◆ Dermal contact with surface water
- ◆ Inhalation of contaminants from water use at work

The Model Toxics Control Act Cleanup Regulation (MTCACR)(WAC 1991, sect. 745) provides standard exposure parameters for exposure to soil at industrial sites. These parameters are used in evaluating soil ingestion, and the same exposure frequency, exposure duration, body weight (70 kilograms), and averaging time (20 years) are also applied to dermal contact with soil. Other parameters are based on EPA (1992). MTCACR also provides parameters for evaluating industrial/commercial exposures to airborne contaminants under WAC (1991, sect. 750). The exposure frequency of 250 days/year is used to represent the number of working days per year (EPA 1991a). MTCACR assumes a frequency of contact of 0.4 to represent a reasonable maximum soil exposure, resulting in an exposure frequency of 146 days/year to soil. A shielding parameter (a reduction in the dose rate by building walls and other deviations from a uniformly-contaminated, flat surface) of 0.8 is used (DOE 1995). Because the climate at Hanford has hot summers and cold winters, the assumption for this scenario is that outside activities would not be likely for most workers on a daily basis.

Parameters for ingestion of water are based on EPA (1991a). These were selected because the parameters suggested in MTCACR are not typical of workplace water consumptions. Standard parameters for dermal contact and inhalation of waterborne materials are used from EPA (1991a) and EPA (1991b).

For use in this assessment, the HSRAM rates for air inhalation were revised. The HSRAM inhalation rate is given as 20 m³/day, but this value is intended to represent a full 24-hour day. Therefore, for application to an 8-hour workday, this value is reduced to 10 m³ (EPA 1989). The parameters used for the Industrial Worker Scenario are presented in Table 5.2.

Table 5.2. Exposure Parameters for the Industrial Worker Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion	50 mg	10 - 150	146 ^(a)	100 - 275	20	1 - 50	--	--
	External	8 hr	2 - 10	146	100 - 275	20	1 - 50	0.8	Shielding parameter
	Dermal	0.2 mg/cm ²	0.05 - 0.5	146	100 - 275	20	1 - 50	5,000 cm ²	Skin surface area
	Inhalation	10 m ³	8 - 20	146	100 - 275	20	1 - 50	50 µg/m ³	Air mass loading
Air	Inhalation	10 m ³	8 - 20	250	100 - 275	20	1 - 50	--	--
Surface Water	Ingestion	1 L	0 - 3	250	100 - 275	20	1 - 50	--	--
	External	8 hr	2 - 10	250	100 - 275	20	1 - 50	--	--
	Dermal	0.17 hr	0 - 1	250	100 - 275	20	1 - 50	20,000 cm ²	Total skin surface

(a) Derived from frequency of exposure of 0.4 of a year.

5.1.2.2 Fish Hatchery Worker

Currently the Yakama Indian Nation is conducting an experiment in commercial aquaculture by rearing domesticated coho salmon and steelhead/rainbow-trout hybrids in partnership with Scientific Ecology Group Inc. Northwest. This scenario is included because these projects are expected to continue. Present and proposed future operations include development of a fish hatchery at the 183-K East and West Filter Plants, Sedimentation and Flocculation Basins, Coagulation Basins, and the Purification Pools. This will be a hatchery similar in function and size of that currently administered by the State Hatchery Program.

The Fish Hatchery Worker description is based on duties described in the job classifications provided by the State Hatchery Program office for the Hanford pilot as well as information gathered from the Eastbank State Hatchery in Ringold. The Eastbank Hatchery is a mid-sized operation which should be comparable to the size of the Tribal Hatchery in the near future. A state hatchery employee may work on a full-time permanent, full-time temporary and/or seasonal basis. According to the job descriptions provided by the State Hatchery Program, the hatchery employee works an average of 250 days/year (estimate based on current employee records) and spends approximately 50-60 percent of working hours out-of-doors. The worker is assumed to be exposed 8 hours/day to pools of Columbia River derived water. The worker is assumed to drink 1 liter/day of river water while at work (following the assumptions of the Industrial Worker Scenario) and to work with the fish or around the pools for an average of 1 hour per day, resulting in dermal exposures.

The greatest distinction from the standard worker scenario developed by HSRAM is the exposure frequency. In addition, the exposure duration is raised to 30 years for the screening assessment of risk. The rationale for exposure parameter values summarized in Table 5.3 is as follows:

- ◆ **Soil: Ingestion, External Radiation Exposure, Dermal Contact, Inhalation** - The fish hatchery worker is assumed to ingest and/or inhale resuspended dust inadvertently during time spent on the Hanford Site. The daily ingestion intake (100 milligrams/day) is twice the HSRAM value to account for potentially wet and muddy conditions. External radiation exposure is based on an 8-hour working day with minimal shielding. Dermal contact with soil is increased to 1 mg/cm² per day, which is a multiple of the recommended value of 0.2 mg/cm² per day (EPA 1989). The inhalation intake (10 m³/day) is based on an 8-hour working day (EPA 1989).
- ◆ **Air: Inhalation** - While on the Hanford Site the fish hatchery worker may inhale fugitive dust or gases from varying sources. The individual is assumed to inhale 10 m³ per day, based on an 8-hour work day (EPA 1989).
- ◆ **Surface Water: Ingestion, External Radiation Exposure, Dermal Contact** - Ingestion of surface water occurs advertently from using processed Columbia River water as drinking water on site and inadvertently from surface water spray while working around the open water. For the present purposes, however, the HSRAM default value of 1 liter/day for on-the-job ingestion was used. The individual is assumed to be exposed to external radiation from river water in the

Table 5.3. Exposure Parameters for the Fish Hatchery Worker Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion	100 mg	10 - 150	250	100 - 275	30	1 - 50	--	--
	External	8 hr	2 - 10	250	100 - 275	30	1 - 50	0.8	Shielding parameter
	Dermal	1 mg/cm ²	0.1 - 5	250	100 - 275	30	1 - 50	5,000 cm ²	Skin surface area
	Inhalation	10 m ³	8 - 20	250	100 - 275	30	1 - 50	50 µg/m ³	Air mass loading
Air	Inhalation	10 m ³	8 - 20	250	100 - 275	30	1 - 50	--	--
Surface Water	Ingestion	1 L	0 - 3	250	100 - 275	30	1 - 50	--	--
	External	8 hr	2 - 10	250	100 - 275	30	1 - 50	0.25	Geometry correction
	Dermal	1 hr	0 - 1	250	100 - 275	30	1 - 50	5,000 cm ²	Skin surface area

basins. Geometry parameters account for some equivalent shielding; in other words, the worker is not immersed in the water. A parameter of 0.25 (the ratio of the skin surface area exposed to the total skin area) is used as an approximation. Frequent contact with the fish provides a route for dermal absorption. The value of 1 hour/day was selected, greater than the 0.17-hour default in HSRAM but with a reduced body surface area to acknowledge that the worker is not usually immersed while working.

- ◆ **Groundwater:** No contact with groundwater occurs at present for the tribal fish hatchery worker, although much of the water used in the Eastbank Hatchery comes from the uncontaminated Ringold Springs.

5.1.3 Wildlife Refuge/Wild and Scenic River Scenarios

In the CRCIA screening assessment, three wildlife refuge/wild and scenic river scenarios will be assessed for risk: a Ranger Scenario, an Avid Recreational Visitor Scenario, and a Casual Recreational Visitor Scenario.

The Hanford Site contains several areas of undisturbed ecosystems. Various options have been proposed to preserve some or all of these areas, including use as a wildlife refuge or designation as a wild and scenic river. If portions of the Hanford Site are designated as a wildlife refuge, no on-site continuous residence by humans is expected. Even the rangers would not live on site. The lands would be open to the public for a variety of uses, although no residential or agricultural uses would be permitted. The following recreational and professional scenarios are possible under the wildlife refuge designation although not all of them were the basis of specific exposure scenario development:

- ◆ Archeologist
- ◆ Bird watcher
- ◆ Fisher
- ◆ Hunter
- ◆ Intruder/vandal/trespasser
- ◆ Other and general recreational users
- ◆ Reactor tour guide
- ◆ Refuge ranger
- ◆ Scientific study, monitoring and surveillance workers

Recreational uses include many possible activities such as backpacking, bird watching, camping, picnicking, river boat touring, swimming, water skiing, and wildlife viewing. While there are no current plans for developing recreational facilities on the south shore of the Columbia River, possible development could include a boat-only overnight camping facility, self-guided auto tour routes, and hiking trails.

Public Law 100-605 directs the U.S. Department of Interior, in consultation with DOE, to make recommendations for preservation of the Hanford Reach of the Columbia River. One alternative considered is assignment of the Hanford Reach to the National Wild and Scenic Rivers System. If the

Hanford Reach is designated a wild and scenic river, human exposure scenarios in addition to those provided in the HSRAM recreational scenario are needed to provide insight into the spectrum of potential risks. The first step in developing the new scenarios is to define wild and scenic river. The second is to understand what significant features would be protected under this classification. The last step is to determine what future land uses are possible given the definition and significant features.

The Wild and Scenic River Act (Public Law 90-542, as amended) uses the following definitions to designate wild or scenic areas. Wild river areas are those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail with watersheds or shorelines essentially primitive and waters unpolluted. These represent the vestiges of primitive America. Scenic river areas are those rivers or sections of rivers that are free of impoundments with shorelines and watersheds still largely primitive and shorelines largely undeveloped but accessible in places by roads. Recreational wild rivers are those that are readily accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past.

The location of significant features is important when assessing an actual exposure pathway. Significant features of the area were determined in the Hanford Reach Environmental Impact Statement (NPS 1994). Nationally significant features include

- ◆ Fall chinook salmon
- ◆ Intact ecosystem
- ◆ Native American cultural resources
- ◆ Archeological sites
- ◆ Hydrology and geology (for energy facility siting)
- ◆ Federally recognized rare plant species
- ◆ Federally recognized rare animal species

Regionally significant features include

- ◆ Endangered plants and animals listed by the state
- ◆ Flat water recreation
- ◆ Historic sites
- ◆ Hunting
- ◆ Ringold agricultural area
- ◆ Sport fishing
- ◆ White Bluffs along the north bank of the Hanford Reach

Uses allowed by the Wild and Scenic River Act would include

- ◆ Backpacking
- ◆ Bird and wildlife viewing
- ◆ Camping
- ◆ Fishing

- ◆ Horse packing
- ◆ Hunting
- ◆ Motorized and non-motorized river craft
- ◆ Mountain bike riding (non-motorized)
- ◆ Picnicking
- ◆ Swimming/skiing
- ◆ Ranching, grazing, farming, and occupation of homes that exist on the date of the enactment

Several of these exposure pathways are covered under the HSRAM (DOE 1995) recreational scenario (see Section 5.1.3.3). Three scenarios have been selected for evaluation that should cover the range of potential exposures under the wildlife refuge and wild and scenic rivers possibilities. These are ranger, avid recreational visitor, and casual recreational visitor. The Ranger Scenario represents an individual who visits most habitat types on the site on a regular basis. The Avid Recreational Visitor Scenario represents an individual who visits the site frequently to fish and to hunt for deer, waterfowl, and upland game birds, and ingests the fish and game taken. The Casual Recreational Visitor Scenario is similar to the Avid Recreational Visitor Scenario, but the casual visitor spends less time in the vicinity. The following sections describe the exposure pathways and parameters for each of the three selected scenarios.

5.1.3.1 Ranger

In this scenario the ranger works out of an off-site facility and spends about 3 days/week (150 days/year) on the site. The ranger is assumed to be stationed off site because administration of Hanford as a wildlife refuge would be handled out of the Othello office of the U.S. Fish and Wildlife Service. A field facility on Hanford is unlikely to be established. While on the site, the ranger spends a third of the time in each type of habitat: 1) upland range land, 2) along the shoreline, and 3) in a boat on the Columbia River.

The ranger does not drink water from the site. The Ranger Scenario is very similar to the HSRAM industrial scenario except that, although less time is spent on site, more time is spent in outdoor activity. The ranger is assumed to work in the area for 30 years. The rationale for the exposure parameter values summarized in Table 5.4 is as follows:

- ◆ **Soil: Ingestion** - The ranger is assumed to ingest soil inadvertently during time spent on the site and in the field. The standard assumption of 100 milligrams/day is used (EPA 1991a). The entire daily intake is assumed to be related to the site.
- ◆ **Soil: External Radiation Exposure** - The ranger is assumed to be on site 9 hours/day with a third of the time spent in each of three location types: shoreline, boating, and upland. The daily exposure period is set to 3 hours representing the time distribution for the ranger. Because this is an outdoor scenario, no shielding of the radiation fields is assumed.

Table 5.4. Exposure Parameters for the Ranger Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion	100 mg	10 - 150	150	30 - 275	30	1 - 50	--	--
	External	3 hr	0 - 4	150	30 - 275	30	1 - 50	1.0	Shielding parameter
	Dermal	0.2 mg/cm ²	0.05 - 0.5	150	30 - 275	30	1 - 50	5000 cm ²	Skin surface area
	Inhalation	10 m ³	8 - 20	150	30 - 275	30	1 - 50	50 µg/m ³	Air mass loading
Air	Inhalation	10 m ³	8 - 20	150	30 - 275	30	1 - 50	--	--
Surface Water	Boating External	3 hr	0 - 4	150	30 - 275	30	1 - 50	0.5	Shielding correction
	Dermal	1 hr	0 - 4	150	30 - 275	30	1 - 50	5000 cm ²	Skin surface area
Sediment	Ingestion	100 mg	10 - 150	150	30 - 275	30	1 - 50	--	--
	External	3 hr	0 - 4	150	30 - 275	30	1 - 50	0.2	Geometry correction
	Dermal	0.2 mg/cm ²	0.05 - 0.5	150	30 - 275	30	1 - 50	5000 cm ²	Skin surface area

- ◆ **Soil: Dermal Contact** - Dermal contact is assumed to occur associated with the inadvertent soil ingestion pathway. Soil adheres to the skin at a rate of 0.2 mg/cm^2 per day. Contact occurs over a total skin surface area of $5,000 \text{ cm}^2$ (EPA 1991a).
- ◆ **Soil: Resuspended Soil Inhalation** - Resuspension of soil with subsequent inhalation is assumed to occur at all times while the ranger is on site. The amount of resuspension is determined by use of the mass loading approach based on an ambient air mass loading value of $50 \text{ } \mu\text{g/m}^3$ (40 CFR 50.5(b)). The pollutant concentration in the particulate matter in air is assumed to be the same as the pollutant concentration in soil. The ranger is assumed to inhale a total of 10 m^3 of air during the 9 hours while on site (EPA 1989). This provides an average daily intake rate of $10 \text{ m}^3/\text{day}$ for the exposure analysis.
- ◆ **Air: Inhalation** - While on site, the ranger is potentially exposed to airborne contamination via inhalation. The ranger is assumed to inhale a total of 10 m^3 of air during the 9 hours while on site (EPA 1989). This provides an average daily intake rate of 10 m^3 per day for the exposure analysis. The inhalation exposure occurs for all on-site activities and is included for the entire 9 hours/day.
- ◆ **Surface Water: Boating External Radiation Exposure** - While the ranger is involved in boating activities, s/he is exposed to radiation emitted from contamination in the water. The exposure frequency is 150 days/year and one-third of the 9-hour work day (3 hours/day). A shielding geometry parameter of 0.5 is applied because the dose rate is evaluated using parameters for total immersion in water (swimming), but while boating the source is effectively one-half that of total immersion (Jaeger et al. 1968).
- ◆ **Surface Water: Dermal Contact** - Boating and frequent contact with biota provides a route for dermal absorption. Contact is assumed to occur at the rate of 1 hour/day over a total skin surface area of $5,000 \text{ cm}^2$ (EPA 1991a).
- ◆ **Sediment: Ingestion** - Contact is assumed to occur with shoreline sediment while the ranger is involved in activities along the Columbia River. The contact rate is assumed to be the same as for general soil contact. An intake of 100 milligrams/day is assumed for the time spent along the shore, which is the total daily intake (EPA 1991a).
- ◆ **Sediment: External Radiation Exposure** - The ranger is exposed to radiation emitted from the sediment while standing on the sediment. The rate of exposure is evaluated in a manner similar to that for standing on contaminated ground, except that a geometry/shielding parameter of 0.2 is applied to account for the finite width of the shoreline (DOE 1995). The exposure frequency is 150 days/year and one-third of the 9-hour work day. The daily exposure period is set to 3 hours representing the time distribution for the ranger.

- ◆ **Sediment: Dermal Contact** - Dermal contact occurs along with sediment ingestion and is evaluated in the same manner as soil ingestion. Soil adheres to the skin at a rate of 0.2 mg/cm^2 per day (one contact event per day). Contact occurs over a total skin surface area of $5,000 \text{ cm}^2$ (EPA 1991a).

5.1.3.2 Avid Recreational Visitor

The Avid Recreational Visitor Scenario involves an individual who fishes and hunts for game birds and animals on the site. The individual is exposed to soil and air while hunting in upland regions, to shoreline sediment while fishing or hunting, and to river water while fishing and from ingestion of fish, birds, amphibians, and deer. Upland hunting is considered in this analysis for the Columbia River because game could be potentially contaminated from forays into the riparian zone to forage or drink water.

Exposure to contaminated soil occurs during hunting trips to the site. The hunter success rate is assumed to be typical, but the total catch of this reasonable maximum individual is 10 times the regional average: for waterfowl 100 ducks per season (2 ducks per day) and for upland game birds 25 pheasants per season (0.5 pheasants per day) (Washington Department of Fish and Wildlife 1992, 1993, 1994, 1995a). That implies the hunter makes 50 trips hunting for each type of bird: 50 to shoreline environments and 50 to upland areas. Each hunting trip involves 4 hours of onsite exposure with soil or sediment contact at the daily average value.

The maximum number of days that could be spent hunting deer in a season is the length of the various deer hunting seasons (bow, muzzle loader, and firearm). In state game management regions around Hanford (272, 278, 281, 284, 371, and 372) this is 48 days (Washington Department of Fish and Wildlife 1995b). However, it is unlikely that an individual hunter would spend the entire 48 days hunting. A maximum number of 20 days is used in the analysis. The total time spent in upland areas (deer hunting plus upland game bird hunting) is 70 days/year. This season could conceivably be longer if hunting seasons for other species such as doves and quail are included. This possibility is included in the uncertainty ranges assigned. The remaining 50 days is spent on the river shoreline or boating in the river. Note that the precision implied by this time distribution is an artifact of the way it was developed; the times are used to represent an average over a 70-year lifetime. Because the lifetime includes childhood years, for selected pathways slightly different parameters are used for the childhood portion. The rationale for the exposure parameter values summarized in Table 5.5 is as follows:

- ◆ **Soil: Ingestion** - The hunter is assumed to ingest soil inadvertently during time spent on-site and in the field. The entire daily intake of 100 milligrams/day for adults is assumed to be related to the site (EPA 1991a). For children, the daily intake rate is assumed to be 200 milligrams/day.
- ◆ **Soil: External Radiation Exposure** - The hunter is assumed to be on site 4 hours/day in upland areas with exposure to soil occurring during that period. Because this is an outdoor scenario, no shielding of the radiation fields is assumed.

Table 5.5. Exposure Parameters for the Avid Recreational Visitor Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion	200 mg (C) 100 mg (A)	100 - 250 10 - 150	70 70	8 - 100 8 - 100	6 24	1 - 6 1 - 64	--	--
	External	4 hr	0 - 8	70	8 - 100	30	1 - 70	1.0	Shielding parameter
	Dermal	0.2 mg/cm ²	0.05 - 0.5	70	8 - 100	30	1 - 70	5000 cm ²	Skin surface area
	Inhalation	10 m ³	7 - 15	70	8 - 100	30	1 - 70	50 µg/m ³	Air mass loading
Air	Inhalation	10 m ³	7 - 15	120	8 - 180	30	1 - 70	--	--
Surface Water	Ingestion	2 L	0 - 3	50	8 - 80	30	1 - 70	--	--
	External	4 hr	0 - 8	50	8 - 80	30	1 - 70	0.5	Geometry correction
	Dermal	1 hr	0 - 4	50	8 - 80	30	1 - 70	5000 cm ²	Skin surface area
Sediment	Ingestion	200 mg (C) 100 mg (A)	100 - 250 10 - 150	50 50	8 - 80 8 - 80	6 24	1 - 6 1 - 64	--	--
	External	4 hr	0 - 8	50	8 - 80	30	1 - 70	0.2	Geometry correction
	Dermal	0.2mg/cm ²	0.05 - 0.5	50	8 - 80	30	1 - 70	5000 cm ²	Skin surface area
Biota	Fish	54 g ^(a)	0 - 100	365	180 - 365	30	1 - 70	0.5	Diet Fraction
	Deer	15 g	0 - 30	365	180 - 365	30	1 - 70	--	--
	Upland Birds	9 g	0 - 20	365	180 - 365	30	1 - 70	--	--
	Waterfowl	35 g	0 - 50	365	180 - 365	30	1 - 70	--	--
(a) Parameter recommended in WAC 1991 (173-340-730)									
C = Child A = Adult

- ◆ **Soil: Dermal Contact** - Dermal contact is assumed to occur associated with the inadvertent soil ingestion pathway. Soil adheres to the skin at a rate of 0.2 mg/cm^2 per day (one contact event per day). Contact occurs over a total skin surface area of $5,000 \text{ cm}^2$ (EPA 1991a).
- ◆ **Soil: Resuspended Soil Inhalation** - Resuspension of soil with subsequent inhalation is assumed to occur at all times while the hunter is on site. The amount of resuspension is determined by use of the mass loading approach as described for the Ranger Scenario. The hunter is assumed to inhale a total of 10 m^3 of air during the 4 hours while on site (EPA 1989).
- ◆ **Air: Inhalation** - While on site, the hunter is potentially exposed to airborne contamination via inhalation. The individual is assumed to inhale a total of 10 m^3 of air during the 4 hours while on site (EPA 1989). The inhalation exposure occurs for all on-site activities and is included for the entire 4 hours/day.
- ◆ **Surface Water: Ingestion** - While on site, the visitor is assumed to drink 2 liters/day from available surface water.
- ◆ **Surface Water: Boating External Radiation Exposure** - While the individual is involved in boating activities, s/he is exposed to radiation emitted from contamination in the water. The exposure frequency is 50 days/year and 4 hours/day. A shielding geometry parameter of 0.5 is applied because the dose rate is evaluated using parameters for total immersion in water (swimming), but while boating, the source is effectively one-half that of total immersion (Jaeger et al. 1968).
- ◆ **Surface Water: Dermal Contact** - While engaged in boating or fishing activities, the visitor is assumed to come in contact with surface water for 1 hour/day.
- ◆ **Sediment: Ingestion** - Contact is assumed to occur with shoreline sediment while the hunter is involved in waterfowl and deer hunting along the Columbia River. The contact rate is assumed to be the same as for general soil contact. An intake of 100 milligrams/day for adults is assumed, which is the total daily intake (EPA 1991a). For children, the daily intake rate is assumed to be 200 milligrams/day.
- ◆ **Sediment: External Radiation Exposure** - The hunter is exposed to radiation emitted from the sediment while standing on the sediment. The rate of exposure is evaluated in a manner similar to that for standing on contaminated ground, except that a geometry shielding parameter of 0.2 is applied to account for the finite width of the shoreline. The exposure frequency is 50 days/year and 4 hours/day.
- ◆ **Sediment: Dermal Contact** - Dermal contact occurs along with sediment ingestion and is evaluated in the same manner as soil ingestion. Soil adheres to the skin at a rate of 0.2 mg/cm^2 per day (one contact event per day). Contact occurs over a total skin surface area of $5,000 \text{ cm}^2$ (EPA 1991a).

- ◆ **Biota: Fish Ingestion** - The fish are assumed to be consumed by the individual and family. The HSRAM recreational rate of 54 grams/day is retained (DOE 1995 from WAC 1991, sect. 730).
- ◆ **Biota: Deer Ingestion** - One deer per season is assumed to be shot and eaten by the hunter and his family. (Elk are not included in this analysis because Hanford elk remain on the Fitzner-Eberhardt Arid Land Ecology reserve almost exclusively and rarely travel across Highway 240 to the Columbia River.) The deer is assumed to have a total weight of 45 kilograms of which a 50-percent yield of deer meat is assumed for a total edible meat weight of 22.5 kilograms/deer (Paustenbach 1989). For an individual in the hunter family of four, the intake rate per individual for one 45-kilogram deer is 15 grams/day.
- ◆ **Biota: Upland Game Bird Ingestion** - The upland game birds are assumed to be consumed by the hunter family of four. The weight of meat from each bird is taken to be 0.5 kilogram (50 percent of a 1-kilogram bird). The total weight of upland game birds (25 birds per season) is 12.5 kilograms with consumption by a member of the hunter family of 9 grams/day.
- ◆ **Biota: Waterfowl Ingestion** - The waterfowl are assumed to be consumed by the hunter family of four. The weight of meat from each bird is taken to be 0.5 kilogram (50 percent of a 1-kilogram bird). The total weight of water fowl meat (100 waterfowl per season) is 50 kilograms with consumption by each member of the hunter family of 35 grams/day.

5.1.3.3 Casual Recreational Visitor

This individual is included because many people currently use the Hanford Reach and adjacent wildlife refuge areas. Although there are a variety of year-round recreational activities, one of the most popular is sport fishing. The average angler catches salmon, steelhead, sturgeon and small mouth bass. This individual may fish along the shoreline or from a motorized or non-motorized boat (DOA 1993). Fishing seasons in Washington are regulated by the Washington Department of Fish and Wildlife, and special rules and seasons are provided for trout, salmon, and sturgeon (Washington Department of Fish and Wildlife 1995c). Other activities might include hunting, water skiing, and swimming.

Jet and propeller-driven boats are used along the entire Hanford Reach, while non-motorized boats generally stay in the vicinity of the three primitive river access areas: Vernita Bridge, White Bluffs Ferry Landing (east side only), and Ringold Hatchery. Public access to shorelines and islands is restricted, and no overnight camping is allowed within the Hanford Site. Recreational boating is only a day use activity. Data as to daily fishing and boating stay times per individual have not been determined. However, current parameters as reported in HSRAM indicate that this individual may be potentially exposed 7 days/year averaged over a 70-year lifetime.

For the purposes of this study, the standard HSRAM recreational scenario is used as a baseline. If the Hanford Reach is designated wild and scenic, the access to and use of the Reach would likely increase somewhat, and the 7 days/year exposure frequency for visitors might need to be increased. For the screening assessment, the HSRAM recreational scenario is included with minimal modification.

Inhalation of resuspended soil has been added, for consistency with other scenarios. The screening assessment variations of the HSRAM-specified parameters for this scenario are provided in Table 5.6.

5.1.4 Native American Scenarios

In the CRCIA screening assessment, five Native American scenarios will be assessed for risk: a Subsistence Resident Scenario, Upland Hunter Scenario, River-Focused Hunter and Fisher Scenario, Gatherer of Plant Materials Scenario, and a Columbia River Island User Scenario.

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

This report describes an initial version of a Native American subsistence scenario as well as several habitat-focused activity sets (upland hunting, river-focused hunting and fishing, gathering of plant materials across several habitats, and using Columbia River islands). These scenarios have been specifically developed for Columbia Basin climatic conditions (hot and dry), ecosystems (high desert, river), and indigenous activity patterns (high fish consumption, seasonally active lifestyles). The Subsistence Resident Scenario and the Gatherer of Plant Materials Scenario are composite year-round scenarios that cross all habitats, while the Upland Hunter Scenario focuses on seasonal upland activities and resources, and the River-Focused Hunter and Fisher Scenario includes activities that could occur on or near the river. This habitat approach to human activity patterns was taken because of the potential for these scenarios to be used to answer questions about whether particular areas are safe to use, and therefore it seemed reasonable to combine activities that a person might pursue in different areas into separate scenarios. It should be noted that only the subsistence scenario is an unrestricted use scenario. The other scenarios are partial scenarios for individual activity sets or food sources.

The specific activities presented here reflect several, but not all, treaty-reserved rights (fishing, gathering, hunting, and pasturing). In traditional communities, different people tend to specialize in different activities, and therefore they spend more time at their special activities than a subsistence person would be able to allocate. The Subsistence Resident Scenario is a composite scenario in which a person must divide her/his time throughout a full year among all the specific activities rather than specializing in one or two. The Upland Hunter and River-Focused Hunter and Fisher Scenarios are not year-round scenarios, nor do they include exposure estimates for other site visits (such as visiting cultural sites) or food sources outside of the particular habitat/activity. The result is that the River-Focused Hunter and Fisher Scenario includes fish ingestion but not plant ingestion.

Table 5.6. Exposure Parameters for the Casual Recreational Visitor Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate ^(a) (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration ^(a) (years)	Exposure Duration Range	Other Parameters	Other Parameter Definition
Soil	Ingestion	200 mg (C) 100 mg (A)	100 - 250 10 - 150	7	1 - 8 1 - 8	6 (C) 24 (A)	1 - 6 1 - 64	--	--
	External	8 hr	2 - 12	7	1 - 8	30	1 - 70	1.0	Shielding correction
	Dermal	0.2 mg/cm ²	0.05 - 0.5	7	1 - 8	30	1 - 70	5000 cm ²	Skin surface area
	Inhalation	10 m ³	5 - 15	7	1 - 8	30	1 - 70	50 µg/m ³	Air mass loading
Air	Inhalation	10 m ³	5 - 15	7	1 - 8	30	1 - 70	--	--
Seep/Spring Water	Ingestion	2 L	0 - 3	7	1 - 8	30	1 - 70	--	--
	Dermal	0.17 hr	0 - 1	7	1 - 8	30	1 - 70	20,000 cm ²	Skin surface area
Surface Water	Ingestion	2 L	0 - 3	7	1 - 8	30	1 - 70	--	--
	Dermal	2.6 hr	1 - 8	7	1 - 8	30	1 - 70	20,000 cm ²	Skin surface area
Sediment	Ingestion	200 mg (C) 100 mg (A)	20 - 500 10 - 150	7	1 - 8	6 (C) 24 (A)	1 - 6 1 - 64	--	--
	Dermal	0.2 mg/cm ²	0.05 - 0.5	7	1 - 8	30	1 - 70	5000 cm ²	Skin surface area
Biota	Fish	54 g ^(b)	0 - 100	365	1 - 365	30	1 - 70	0.5	Diet fraction
	Plants	--	--	--	--	--	--	--	--
	Deer	15 g	0 - 90	365	1 - 365	30	1 - 70	--	--
	Waterfowl	--	--	--	--	--	--	--	--

(a) Parameters recommended in EPA (1991a) except as noted
(b) Parameter recommended in WAC (1991) (173-340-730)

C = Child
A = Adult

These scenarios are most likely to be used to answer questions about whether a location is suitable for a particular activity (in other words, "Is it safe to fish here?"), so only those exposures related directly to fishing were included in the scenario (time spent fishing, uptake of contaminants by the fish, amount of fish ingested by the hunter, etc.). It is very important to note, however, that such questions cannot be answered without considering other exposures. The answer to the fishing question might be that it is safe to fish in a particular area only if no other exposures are received elsewhere and if no other activities occur in the same area along with fishing.

There is a tendency to evaluate each exposure as if no other exposures occurred, and each contaminant as if no other contaminants were present, and each source of contamination as if no other sources contributed to the same pool of contamination. Because our goal is to protect entire lifestyles, and not just isolated activities, the role that a particular activity or location plays in the overall lifestyle is an important part of the evaluation. This applies to both the lifestyle of a traditional individual and to the collective community dose or total contaminant burden that a community and its resources bears from all sources.

The overall rationale in developing these scenarios was to ensure that the exposure parameters reflect general traditional activities using native plants and medicines within an active lifestyle that includes higher environmental contact rates than a suburban scenario over a full lifetime of 70 years. While the exact percentile of exposure this represents for traditional tribal members has not been ascertained, this scenario clearly does not represent the highest possible exposure. It was designed to represent average traditional lifestyles or somewhat above average traditional, thus partially satisfying the recommendation of EPA to evaluate average members of the highest exposure groups. It also partially satisfies Executive Order 12898 (59 FR 7629), which requires the evaluation of subsistence lifestyles as part of the evaluation of impacts to human health and the social and economic impacts of federal actions. It is also intended that these scenarios provide approximately the same level of conservatism for a subsistence lifestyle as the conventional residential scenario does for a suburban lifestyle.

The approach to developing these scenarios began with a conventional suburban residential farmer (agricultural) scenario and then was fine tuned on the basis of information provided by a tribal representative to determine which of the exposure parameters should be increased to account for a lifestyle that is more active and in closer contact with the environment. These scenarios were developed using estimates for tribal environmental contact and dietary ingestion rates while specifically avoiding the disclosure of confidential information by tribal staff. The critical data needed by the risk assessor included the number of days per year spent hunting, the amount of plant material in the diet, or other information about the duration and frequency of exposure. The risk assessor did not need to know the particular species of plants because the model does not include species-specific uptake information. In future assessments to avoid revealing proprietary information, tribal technical staff need to determine the complete array of exposure parameters for the Native American scenarios.

From a Native American perspective, it is inherently unsatisfactory to focus on human exposure isolated from environmental effects. Human beings cannot be separated from the environment, and evaluating human health involves much more than making simple mechanistic exposure estimates. The Native American belief is that people in general and Native Americans in particular are not truly healthy

unless the environment is healthy and unless their community is healthy. In fact, traditional tribal communities are so closely associated with their environs that community health and ecological health are essentially synonymous. Thus, the scenarios presented here will help to answer questions about whether particular activities can be safely pursued at particular locations, but they do not answer the full question about how contaminants or other stressors affect eco-cultural systems or overall human-eco-cultural health. They merely provide information about how much exposure a person might receive during particular activities. Further, current models do not take into account the myriad ways that people interact with the environment nor the many ways that people and the environment are mutually interdependent. Any given resource might have ceremonial, material, nutritional, or religious uses. However, since much of this information is confidential and could not be accommodated by current limited models even if the details were known, it may make more sense in some situations to simply incorporate a cultural safety parameter in the exposure assessment to account for these types of recognized but poorly defined pathways.

The Native American tribes involved in CRCIA feel strongly that these scenarios cannot be used by themselves to estimate risk, which would then be used to decide environmental cleanup levels. As explained above, any attempt to set risk-based cleanup levels must consider more than just human exposure. It must include ecological and community quality of life parameters as well. It must also consider a range of health effects (for example, cancer, noncancer, organ toxicity, cumulative population effects) and co-risk parameters (for example, differences in physiological sensitivity and additional expected exposures). In addition, cleanup levels must be temporally apportioned so that both toxicity and environmental persistence are considered, and spatially apportioned so that both the concentration and the total area degraded are considered.

Five semi-quantitative scenarios were constructed to span the range of treaty-reserved activities that are reasonably expected to occur along the Columbia River:

- ◆ Subsistence Resident
- ◆ Upland Hunter
- ◆ River-Focused Hunter and Fisher
- ◆ Gatherer of Plant Materials across all habitats
- ◆ Columbia River Island User (for application to Cobalt-60 particles)

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

The Upland Hunter Scenario is a seasonal, localized scenario that extends for the 70-year lifetime. However, this scenario is included in the screening assessment since upland habitats might be included in future assessments. The Upland Hunter Scenario assumes that a fairly proficient hunter obtains 90 percent of the bag limit for various fowl and game species and some amount of non-game animals. It assumes that the hunter specialist spends 150 days/year hunting, which is more time hunting than the subsistence person could, but assumes that the meat is stored, traded, and eaten year-round. Note that only game is considered in the diet because this scenario was designed to answer habitat-focused questions about hunting and hunting-related activities rather than about a full traditional lifestyle of someone whose primary tribal role is to hunt. It is assumed that the hunter carries spring water with him while hunting.

The River-Focused Hunter and Fisher Scenario is also a seasonal, localized scenario that includes fishing, hunting of waterfowl and waterfowl eggs from the river and the shoreline for a 70-year lifetime. This person is assumed to spend 150 days/year at the river and therefore be in contact with river water and sediment. This scenario was designed to answer questions about whether it might be safe to hunt and fish along the river but is not designed to fully answer whether the river and river corridor are safe for unrestricted use.

The Gatherer of Plant Materials Scenario is a year-round scenario that assumes seasonal gathering of plant materials across relevant habitats for foods, medicines, and crafted goods, as well as their preparation, ingestion and other use. This is a year-round scenario because, while actual gathering is assumed to occur for 270 frost-free days/year, there will be daily cleaning, preparation and ingestion of stored plants, and crafting of plant materials into household goods throughout the year (Harris 1993, 1995). This scenario focuses on plant habitats and does not include game and fish ingestion.

The Columbia River Island User Scenario is a localized scenario intended to specifically address concerns regarding potential exposures to discrete radioactive particles containing cobalt-60. The scenario is based on traditional Native American uses of the islands and shoreline involving extended occupation as a base for fishing and other traditional uses. Pathways evaluated include inhaling a particle, ingesting a particle during incidental ingestion of small amounts of sediments, direct external radiation exposure without contact, and lodging of a particle on the skin.

5.1.4.1 Subsistence Resident

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

- ◆ **Soil: Ingestion** - A person is assumed to continue a child's soil ingestion rate of 200 milligrams/day (EPA 1991a) throughout life. Resuspension of dust with deposition on plants and pasture is included. If soil is contaminated, a soil-plant-animal-human pathway would also exist. If contaminated soil or dust deposits on plants and pasture, an additional exposure route would exist.
- ◆ **Soil: External Radiation Exposure** - Because this scenario assumes full-time residence, the person is assumed to be on site 24 hours/day, and, for this example, the time is not divided among location types (shoreline, boating, and upland). A shielding reduction parameter of 0.8 (a reduction in the dose rate by building walls and other deviations from a uniformly-contaminated, flat surface) is applied per HSRAM (DOE 1995), which assumes that the person is standing on contaminated soil during the entire exposure period.
- ◆ **Soil: Dermal Contact** - Dermal contact is assumed to occur at the rate of one event per day with soil adhering to the skin at a rate of 1 mg/cm^2 per day, which is a multiple of the 0.2 mg/cm^2 default (EPA 1991a) value. The duration of the event is not used because dermal absorption is time-independent. Contact would occur over a skin surface area of $5,000 \text{ cm}^2$. This value represents 25 percent of the total skin surface area (EPA 1991a). The skin absorption fraction is contaminant specific. The increased soil adherence rate needs to be reviewed to ensure that it adequately represents not only initial contact during gathering but also cleaning and preparation.
- ◆ **Soil: Resuspended Soil Inhalation** - Resuspension of soil with subsequent inhalation of the dust in the air is assumed to occur at all times while the person is on site. The amount of resuspension is determined by use of the mass loading approach based on an ambient air mass loading value of $100 \text{ } \mu\text{g/m}^3$, which is twice the EPA recommended value for suburban areas (40 CFR 50.6(b)). The pollutant concentration in the particulate matter is assumed to be the same as the pollutant concentration in the soil. The person is assumed to inhale 30 m^3 of air during the 24 hours s/he is on-site. This is 150 percent of the average value to account for a more active outdoor lifestyle (EPA 1989).
- ◆ **Air: Inhalation** - The person is assumed to inhale 150 percent of the default volume of air per day ($30 \text{ m}^3/\text{day}$) to account for a more active lifestyle (EPA 1989). If there is an airborne radiological plume, immersion of people, plants and animals in that plume is also included.
- ◆ **Seep/Spring Water: Ingestion** - For this scenario, the person is assumed to drink 3 liters/day of seep/spring water, which is assumed to be undiluted groundwater. No decay of radionuclides between withdrawal of seep/spring water and ingestion is assumed, and no filtration of particulate matter is assumed. In other words, the concentration of contaminant in unfiltered groundwater is the appropriate comparison value. In addition, deliberate irrigation of pasture and some amount of domestic crops is assumed to occur, resulting in a pathway from groundwater to plants via direct uptake by the roots of domestic and/or native plants (for example, cattails growing in contaminated seeps). In the present example, game animals are also assumed to drink from the

springs, and groundwater or springs are used as the source of drinking water for pastured animals. If the seeps form a wetland, several of the exposure assumptions will need to be revised to construct a true wetland scenario.

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

- ◆ **Sediment: Ingestion, External Radiation Exposure, Dermal Contact** - The rates used for contact with sediment are similar to soil except the contact is assumed to be 12 hours/day because the individual lives permanently above the high water line. Also the exposure frequency per year is lower (270 days instead of 365 days) because inclement weather, high water, or other activities are assumed to reduce the overall time spent on or near sediments.
- ◆ **Biota: Ingestion** - A fish consumption rate of 540 grams/day was chosen to represent a reasonable maximum intake (CRITFC 1994, DOI 1942, Hunn 1990, CRCIA Team meeting minutes February 6, 1996). Tribal input indicates that fresh fish and dried fish are consumed in roughly equal ratios, so the overall consumption rate was estimated as follows. One quarter of the 540-gram daily consumption (135 grams/day or 3.5 oz.) is assumed to be fresh, and three quarters (405 grams/day) is assumed to be dried. The 405 grams/day that is dried is estimated to lose about two-thirds of its mass during drying, resulting in a dry weight of about 135 grams. Thus, a person is assumed to eat 135 grams/day fresh and 135 grams/day dry, which is equivalent to 540 grams of wet weight.

On the basis of tribal input, the ingestion rate for fruits and vegetables was set at 660 grams/day based on the same principle of 50 percent fresh and 50 percent dried. It will not be useful to investigate specific ingestion rates of roots, fruits, etc. unless uptake parameters to specific plant parts (roots versus leaves) or specific plant species are available. Medicinal and other uses of plant material may provide reason to increase this ingestion rate.

The HSRAM value for meat and game intake is superseded with a single animal protein consumption rate based on tribal input of 75 grams/day of animal protein (which may include flesh, fat, marrow, etc.), of which 50 percent is fresh and 50 percent is dried. Conversion to fresh weight, assuming a wet-to-dry ratio of 3, gives the equivalent fresh weight of 150 grams/day. The waterfowl and upland game bird consumption rates are assumed to be the same for subsistence as they are for the Upland Hunter Scenario. This needs to be reviewed for seasonal take, length of season, and special hunting privileges. Again, since contaminant concentration among animal/fowl species is currently modeled solely on the basis of proportional animal body weight, it will not be useful to determine consumption rates of specific species or animal organs/tissues unless information about contaminant uptake and tissue distribution is available.

The caloric content of fresh salmon is approximately 500 Kcal/275 grams (chinook) or 400 Kcal/275 grams (sockeye). The rate of 540 grams/day therefore represents about 800-1000 Kcal/day depending on the type of salmon. The caloric requirements for moderately active adults is approximately 3000 Kcal/day for males, 2200 Kcal/day for females, with an additional 500 Kcal/day for pregnant or lactating females (or 80,000 Kcal per pregnancy). If the daily protein requirement is about 75 grams for a 75 kilogram male (about 165 pounds) for a sedentary lifestyle and 25 percent more for a moderately active lifestyle, and salmon contains 17 grams protein per 100 grams wet weight, then the salmon would provide close to the required daily amount of protein and one third to one half of the caloric requirement (100 grams = 3 ounces). Hunn (1990) estimated that a traditional diet is composed of 1300 grams/day roots (or 1830 kilocalories/day) plus 1400 grams/day of other vegetation (or 1390 kilocalories/day) plus 500 grams/day salmon

(or 850 kilocalories/day) plus 240 grams/day venison (or 300 kilocalories/day) for a total of 2500 kilocalories/day. This varies somewhat from the estimates used in this report, especially for the amount of venison and the amount versus caloric content of native plants, although the overall caloric estimates are close.

For the screening-level risk assessment, ingestion pathways for milk from locally grazing cattle and for eggs collected from local nests have also been included. However, the values in Table 5.7 are approximations requiring additional tribal staff input.

Organs other than meat are also consumed, such as fish eggs and liver. For this screening scenario, this category is identified as a data gap, and uses as a placeholder value a value equal to one-tenth of the fish ingestion. This is a critical data gap that may be addressed in the future.

- ◆ **Cultural: Inhalation, Dermal** - For the screening level risk assessment, sweat bathing is explicitly added. Based on tribal descriptions, a nominal time of 1 hour/day is assumed to be spent inside a sweat lodge kept at 50 to 80 degrees Centigrade (120 to 180 degrees Fahrenheit). Air inside the sweat lodge is assumed to be saturated with groundwater (equivalent to 0.1 to 0.3 kilogram of water per m^3 of air, and 0.1 to 0.3 L/m^3 of semivolatiles), which are then available for inhalation and dermal absorption over the entire body. During the 1 hour of use, 4 liters of water is used.

Areas for Future Work - Certain limitations were highlighted during the preparation of the Native American scenarios, which are identified here as data gaps. These areas need to be refined and addressed in the future. These gaps apply to the Subsistence Scenario as well as to the subsequent scenarios developed from it.

- ◆ **Children's Scenario** - At present, the only age stratification is to evaluate years 1-6 using a child's body weight, a child's skin surface area, half the adult's drinking water ingestion rate, and half the adult's food ingestion rate. Several parameters are not yet available, such as a child-specific gastrointestinal absorption parameter, or child-specific toxicity parameters.
- ◆ **Mother's Milk** - Another critical data gap is the lack of a mother's milk pathway. For this screening analysis, cow's milk bioconcentration parameters are used.
- ◆ **Elderhood** - The present scenarios extend for 70 years. However, if elderhood is assumed to begin at age 70 and extend for another 20 years, then this would result in additional exposures during a period of increased physiologic sensitivity.
- ◆ **Other Site Activities** - Additional activities, such as restoration activities, ceremonial uses, or teaching activities would increase the number of visits to particular areas/sites. Such activities need to be considered by tribal technical staff in order to evaluate whether the resources in a particular area would cause increased use and exposure.

Table 5.7. Exposure Parameters for the Native American Subsistence Resident Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion ^(a)	200 mg	20 - 500	365	180 - 365	70	1 - 70	--	--
	External	24 hr	12 - 24	365	180 - 365	70	1 - 70	0.8	Shielding parameter
	Dermal	1 mg/cm ²	0.5 - 5	365	180 - 365	70	1 - 70	5000 cm ²	Skin surface area
	Inhalation	30 m ³	20 - 35	365	180 - 365	70	1 - 70	100 µg/m ³	Air mass loading
Air	Inhalation	30 m ³	20 - 35	365	180 - 365	70	1 - 70	--	--
Seep/Spring Water	Ingestion	3 L	2 - 5	365	180 - 365	70	1 - 70	--	--
	External	12 hr	1 - 24	365	180 - 365	70	1 - 70	0.8	Shielding parameter
	Dermal ^(b)	1 hr	0 - 2	365	180 - 365	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(c)	15 m ³	10 - 20	365	180 - 365	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Surface Water	Ingestion	3 L	2 - 5	365	180 - 365	70	1 - 70	--	--
	External	2.6 hr	0.5 - 4	70	30 - 100	70	1 - 70	0.5	Geometry correction
	Dermal ^(d)	2.6 hr	1 - 4	70	30 - 100	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(e)	15 m ³	10 - 20	70	30 - 100	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Sediment	Ingestion	200 mg	20 - 500	270	100 - 365	70	1 - 70	--	--
	External	12 hr	4 - 24	270	100 - 365	70	1 - 70	0.2	Geometry correction
	Dermal	1 mg/cm ²	0.5 - 5	270	100 - 365	70	1 - 70	5000 cm ²	Skin surface area
Biota ^(f)	Fish ^(g)	540 g	100 - 600	365	180 - 365	70	1 - 70	--	--
	Fruit and vegetation	660 g	200 - 800	365	180 - 365	70	1 - 70	--	--
	Animal protein ^(h)	150 g	75 - 200	365	180 - 365	70	1 - 70	--	--
	Other Organs ⁽ⁱ⁾	54 g	1 - 100	365	180 - 365	70	1 - 70	--	--
	Milk	0.6 L	0 - 1	365	180 - 365	70	1 - 70	--	--
	Upland Birds	18 g	5 - 20	365	180 - 365	70	1 - 70	--	--
	Waterfowl	70 g	5 - 100	365	180 - 365	70	1 - 70	--	--
	Wild bird eggs	45 g	5 - 135	365	180 - 365	70	1 - 70	--	--

Table 5.7. (Cont'd)

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Cultural ^(j)	Dermal	1 hr	0.5 - 3	365	180 - 365	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation	1 hr	0.5 - 3	365	180 - 365	70	1 - 70	0.1 - 0.3 L/m ³	Volatilization equivalent
<p>(a) Soil ingestion is typically separated into child (200 mg/d) and adult (100 mg/d) parameters, but considering the activities included in these scenarios, it seems reasonable to assume that the higher rate would persist throughout a lifetime.</p> <p>(b) The dermal parameter for seep/spring water in HSRAM reflects bathing. For this scenario, it is assumed that seep/spring water is encountered regularly while gathering roots.</p> <p>(c) In HSRAM, seep/spring water use is a household scenario where inhalation comes from volatilization during showering and other household use. To the extent that analogous activities occur, this parameter is retained.</p> <p>(d) For surface water, only swimming (2.6 hours/day) is included.</p> <p>(e) As for seep/spring water, exposures may still occur that are the equivalent of suburban household exposures.</p> <p>(f) Foodchain pathways include deposition, soil uptake and seep/spring water uptake, as well as aquatic pathways. There are also additional parameters relevant to human ingestion, such as additional plant parts used or eaten (and multiple parts per plant that rotate through the seasons), medicinal uses (infusions, teas, poultices, etc.), other potential contact with people or their foods (food storage basketry, sleeping mats, extensive contact during basketmaking, use of bones, feathers and sinews), etc.</p> <p>(g) Fish consumption includes multiple species and parts eaten, prepared both fresh and dried. Equivalent fresh weight is given here.</p> <p>(h) The animal protein consumption rate includes meat, fat, and marrow, prepared fresh or dried. The equivalent fresh weight is given here.</p> <p>(i) Approximated as 10 percent of the fish ingestion value.</p> <p>(j) The unique pathway related to volatilization of contaminants from water during sweat bathing is included here. The absolute humidity is based on saturated conditions at a temperature of 50 to 80 degrees Centigrade (120 to 180 degrees Fahrenheit).</p>

- ◆ **Species-Specific Uptake Parameters** - Exposure pathways for key animal and plant species are still rudimentary and do not discriminate among species. Animals are modeled on the basis of body weight in the human exposure models, and by simple trophic levels in some of the ecological models. In the human exposure model, no individual plant species or plant parts (roots versus fruits) are modeled; only a generic soil-to-plant or water-to-plant transfer parameter is used, followed by an estimate of the mass of plant material ingested.
- ◆ **Habitat Specificity** - A wetlands-specific scenario is lacking at present. Although there are relatively few of such areas along the Hanford Reach, they are sought out and used intensively by tribal members. Many species of plants and animals occur in wetlands that include additional food species as well as medicinal and material species. Many species have multiple uses, and could contribute to exposures in multiple ways. Bioaccumulation patterns are likely to be different in wetlands and marshes, and sedimentation patterns are also different. For example, a full assessment for cattails (as food, as baskets for food storage, etc.) throughout various seasonal periods and with a more thorough consideration of sediment and soil exposures could provide both a more accurate estimation of exposure and a better basis for uncertainty analysis.
- ◆ **Community Exposures** - In addition to individual exposure estimates, there is a trade and social network in traditional communities that spreads the total exposure (in other words, the community contaminant burden) much further than the individual. Guidance needs to be developed on how to evaluate exposures to the individual's immediate family and to the extended family network that will also be exposed if contaminated resources are gathered and used. For example, game animals are entirely consumed, so in addition to the amount the hunter might eat, other people eat the rest, so one contaminated deer exposes many people. While the doses to those people may not be as high as the dose to the hunter himself, the total dose to the community will be additive across all contaminated resources. Community quality of life can also be adversely affected by contaminant exposures of the individual, the wider community network, and the environmental and natural resources on which the community depends. In addition, exposure to the collective gene pool needs to be evaluated for appropriate contaminants. The intent of these types of evaluation is much more than deciding whether the dose to the most exposed person is tolerable but also whether the collective dose to the community is tolerable even if no single person is excessively exposed. Evaluating these types of impacts from contaminants is a critical data gap.
- ◆ **Gender Stratification** - Women are most likely to participate in gathering activities, especially women of child-bearing age. This puts the fetus at risk from any contaminants to which the mother is exposed. Women also manage the household, clean and prepare stored foods, and do much of the crafting of household goods.

5.1.4.2 Upland Hunter

This terrestrial scenario is included here for completeness; it is not strictly applicable to the riparian concerns of the CRCIA. The river-based hunting scenarios (water fowl and bird eggs) are included in the

River-Focused Fishing and Hunting Scenario below. The hunting scenario assumes that a fairly proficient hunter obtains 90 percent of the bag limit for various fowl and game species and, in addition, obtains some amount of non-game animals. If there are tribal exceptions to hunting seasons or bag limits, these should be included in future applications of this scenario. The ingestion rate of meat for the hunter is equal to the amount in the subsistence scenario, rather than being scaled proportionally to the number of days spent hunting, because the hunter stores some of the meat for winter use, and what the hunter does not eat, he trades or gives to someone else. Of course, the hunter also eats plant material, but the purpose of this partial scenario is to determine how much exposure a person (plus his trade network) would receive if s/he hunted. It is assumed that hunting results in 150-days/year exposure for hunting for 70 years. Ingestion rates are 150 grams/day animal protein and 18 grams/day upland birds and some additional non-game animal intake, with no fish or vegetation intake. The other parameters remain the same as the subsistence scenario, except that the number of days spent hunting are used to estimate the frequency of soil, air, and water contact. Note that the precision implied by this time distribution is an artifact of the way it was developed; the times are used to represent an average over a 70-year lifetime.

Also to be taken into account is consumption of organs other than meat. Additional parts of the animal besides muscle might be eaten and would result in additional exposures to contaminants that could accumulate in those tissues. For example, lipophilic substances accumulate in fatty tissues (skin, marrow), and many xenobiotics would be found in the liver. The tissue distribution of various materials needs to be reviewed in some detail to develop species-specific parameters for other organs. In addition, other parts of the animal have non-ingestion uses (skin, sinew, horns, etc.) which can result in additional human exposure if the animal is contaminated. These data gaps may be addressed in the future.

Two basic types of exposure might occur: both the hunter and the animal might come in direct contact with contaminated areas, or the animal might be exposed but the hunter might not or vice versa. Without such information as animal home range, it is prudent to assume that both the hunter and animal are exposed. Pasturing might also be an upland activity and is not considered in the hunting scenario. If animals are pastured for consumption, this might involve irrigation as well. This scenario at present does not consider that there is any contact with upland water (ponds, etc.). Except for differences denoted above, the rationale for the exposure parameter values used for the Upland Hunter Scenario (summarized in Table 5.8) is the same as for the values for the Subsistence Resident.

5.1.4.3 River-Focused Hunter and Fisher

This scenario includes river-based food pathways such as fishing, waterfowl hunting, and gathering of waterfowl eggs. Exposure pathways include ingestion of fish, fowl, and eggs, and contact with surface water, sediment, and shoreline contamination. It assumes that a person spends 150 days per year engaged in these activities and assumes that a person eats those items year-round for a lifetime of 70 years. Because this scenario is designed to answer questions about fishing and hunting, it does not include ingestion of plant materials, and, as with the other partial scenarios, does not assume that other river activities or any upland activities occur that result in additional exposures. It is assumed that exposure to groundwater in springs would occur during those 150 days at daily contact rates similar to the subsistence

Table 5.8. Exposure Parameters for the Native American Upland Hunter Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion ^(a)	200 mg	20 - 500	150	100 - 270	70	1 - 70	--	--
	External	24 hr	12 - 24	150	100 - 270	70	1 - 70	0.8	Shielding parameter
	Dermal	1 mg/cm ²	0.5 - 5	150	100 - 270	70	1 - 70	5000 cm ²	Skin surface area
	Inhalation	30 m ³	20 - 35	150	100 - 270	70	1 - 70	100 µg/m ³	Air mass loading
Air	Inhalation	30 m ³	20 - 35	150	100 - 270	70	1 - 70	--	--
Seep/Spring Water	Ingestion	3 L	2 - 5	150	100 - 270	70	1 - 70	--	--
	External	1 hr	1 - 3	150	100 - 270	70	1 - 70	0.8	Shielding parameter
	Dermal ^(b)	1 hr	0 - 2	150	100 - 270	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(c)	1 m ³	0 - 2	150	100 - 270	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Biota	Animal protein ^(d)	150 g	75 - 200	365	180 - 365	70	1 - 70	--	--
	Organs ^(e)	15 g	1 - 100	365	180 - 365	70	1 - 70	--	--
	Upland Birds	18 g	5 - 20	365	180 - 365	70	1 - 70	--	--

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

(b) The dermal parameter for seep/spring water in HSRAM reflects bathing. For this scenario, it is assumed that seep/spring water is encountered regularly while acquiring water.

(c) In HSRAM, seep/spring water use is a household scenario where inhalation comes from volatilization during showering and other household use. For this scenario, volatilization near the spring encountered while collecting water is assumed.

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

(e) Approximated as 10 percent of the meat/fat ingestion value.

scenario. Except for differences denoted above, the rationale for the exposure parameter values used for the River-Focused Hunter and Fisher Scenario (summarized in Table 5.9) is the same as for the values for the Subsistence Resident.

5.1.4.4 Gatherer of Plant Materials

This is a year-round scenario that includes gathering plants for foods, medicines, and crafted goods across all likely habitats (terrestrial, riparian and wetlands), and includes preparation, use and ingestion. The gatherer is assumed to work for 365 days/year for a 70-year lifetime with the same exposure parameters as the Subsistence Resident Scenario but without the fish and game ingestion. The reason that this is a year-round scenario is that while actual gathering might occur for the 270 frost-free days per year, there will be daily cleaning and preparation of stored foods, crafting of materials into households goods, and year-round ingestion of stored foods. As with the Subsistence Scenario, boating and swimming are assumed to occur 70 days per year.

This scenario needs much more consideration before use beyond this screening assessment because of the complex ways that resources are used and recycled back into the environment. This is a particular concern for long-lived radionuclides and other persistent contaminants. Even for a single resource there might be a wide variety of ways for contamination to be transferred to people. The cattail provides an example. In the spring, the shoots are eaten, the roots are consumed, and the fibrous stalks are split, woven or twisted into baskets, mats or cook hole layers. Later in the year, the pollen is used for breads. Each of these activities involves selecting and gathering the plants from marshy areas, sorting, cleaning, stripping, peeling, splitting, chewing, and using various parts of the plant. Cuts on the hands from sharp edges could facilitate dermal absorption, and, in addition to contacting the plant itself, the individual also comes in contact with sediment and water.

This scenario should include all of the ingested plant materials, but several specific pathways must be investigated in more detail, such as the variety of medicinal preparations and ways of administration (concentrated teas, poultices, etc.). The exposure parameter values used for this scenario in the screening assessment are summarized in Table 5.10

5.1.4.5 Columbia River Island User

Discrete radioactive particles, primarily cobalt-60, have been found lodged in the sediments on islands and along the shores of the Columbia River (Sula 1980). These were identified as of interest to the screening assessment (see Section 2.0). This scenario is based on Native American traditional uses of the island involving extended occupation and as a base for fishing or other traditional uses. Within the basic scenario, several pathways are evaluated. These include ingesting a particle during incidental ingestion of small amounts of sediments, direct external radiation exposure without contact, lodging of a particle on the skin (dermal contact), and inhaling a particle. Except for the exposure parameters discussed below, the exposure parameters used for this scenario are per HSRAM (DOE 1995).

Table 5.9. Exposure Parameters for the Native American River-Focused Hunter and Fisher Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion ^(a)	200 mg	20 - 500	150	100 - 270	70	1 - 70	--	--
	External	24 hr	12 - 24	150	100 - 270	70	1 - 70	0.8	Shielding parameter
	Dermal	1 mg/cm ²	0.5 - 5	150	100 - 270	70	1 - 70	5000 cm ²	Skin surface area
	Inhalation	30 m ³	20 - 35	150	100 - 270	70	1 - 70	100 µg/m ³	Air mass loading
Air	Inhalation	30 m ³	20 - 35	150	100 - 270	70	1 - 70	--	--
Seep/Spring Water	Ingestion	3 L	2 - 5	150	100 - 270	70	1 - 70	--	--
	External	12 hr	1 - 24	150	100 - 270	70	1 - 70	0.8	Shielding parameter
	Dermal ^(b)	1 hr	0 - 2	150	100 - 270	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(c)	15 m ³	10 - 20	150	100 - 270	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Surface Water	Ingestion	3 L	2 - 5	150	100 - 270	70	1 - 70	--	--
	External	2.6 hr	0.5 - 4	150	100 - 270	70	1 - 70	0.5	Geometry correction
	Dermal ^(d)	2.6 hr	1 - 4	150	100 - 270	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(e)	15 m ³	10 - 20	150	100 - 270	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Sediment	Ingestion	200 mg	20 - 500	150	100 - 270	70	1 - 70	--	--
	External	12 hr	4 - 24	150	100 - 270	70	1 - 70	0.2	Geometry correction
	Dermal	1 mg/cm ²	0.5 - 5	150	100 - 270	70	1 - 70	5000 cm ²	Skin surface area
Biota ^(f)	Fish ^(g)	540 g	100 - 600	365	180 - 365	70	1 - 70	--	--
	Waterfowl	70 g	5 - 100	365	180 - 365	70	1 - 70	--	--
	Wild bird eggs	45 g	5 - 135	365	180 - 365	70	1 - 70	--	--

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

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

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

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

(e) As for seep/spring water, exposures may still occur that are the equivalent of suburban household exposures.

(f) Foodchain pathways include deposition, soil uptake and seep/spring water uptake, as well as aquatic pathways.

(g) Fish consumption includes multiple species and parts eaten, prepared both fresh and dried. Equivalent fresh weight is given here.

Table 5.10. Exposure Parameters for the Native American Gatherer of Plant Materials Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion ^(a)	200 mg	20 - 500	365	180 - 365	70	1 - 70	--	--
	External	24 hr	12 - 24	365	180 - 365	70	1 - 70	0.8	Shielding parameter
	Dermal	1 mg/cm ²	0.5 - 5	365	180 - 365	70	1 - 70	5000 cm ²	Skin surface area
	Inhalation	30 m ³	20 - 35	365	180 - 365	70	1 - 70	100 µg/m ³	Air mass loading
Air	Inhalation	30 m ³	20 - 35	365	180 - 365	70	1 - 70	--	--
Seep/Spring Water	Ingestion	3 L	2 - 5	365	180 - 365	70	1 - 70	--	--
	External	12 hr	1 - 24	365	180 - 365	70	1 - 70	0.8	Shielding parameter
	Dermal ^(b)	1 hr	0 - 2	365	180 - 365	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(c)	15 m ³	10 - 20	365	180 - 365	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Surface Water	Ingestion	3 L	2 - 5	365	180 - 365	70	1 - 70	--	--
	External	2.6 hr	0.5 - 4	70	30 - 100	70	1 - 70	0.5	Geometry correction
	Dermal ^(d)	2.6 hr	1 - 4	70	30 - 100	70	1 - 70	20,000 cm ²	Skin surface area
	Inhalation ^(e)	15 m ³	10 - 20	70	30 - 100	70	1 - 70	0.1 L/m ³	Volatilization equivalent
Sediment	Ingestion	200 mg	20 - 500	270	100 - 365	70	1 - 70	--	--
	External	12 hr	4 - 24	270	100 - 365	70	1 - 70	0.2	Geometry correction
	Dermal	1 mg/cm ²	0.5 - 5	270	100 - 365	70	1 - 70	5000 cm ²	Skin surface area
Biota ^(f)	Fruit and vegetation	660 g	200 - 800	365	180 - 365	70	1 - 70	--	--

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

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

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

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

(e) As for seep/spring water, exposures may still occur that are the equivalent of suburban household exposures.

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

The time spent on the island is important in calculating the likelihood that a person will interact with a particle. For the screening assessment, a distribution of times is used. The distribution used assumes an individual spends a minimum of 4 hours and a maximum of 40 days on the island every year. The most likely value is 2 days. The rationale for the exposure parameter values summarized in Table 5.11 is as follows:

- ◆ **Sediment: Ingestion** - The individual is assumed to continue a child's ingestion rate of 200 milligrams/day (EPA 1991a) throughout life.
- ◆ **Sediment: External Radiation Exposure** - The individual is assumed to remain on the island during the occupancy period for 24 hours per day. No credit is assumed for shielding from direct irradiation other than that afforded by the distributed nature of the particles in soil.
- ◆ **Sediment: Dermal Contact** - Standard values are provided by HSRAM for uptake of soil onto skin (DOE 1995). Dermal contact of 0.2 mg/cm^2 is used. A distribution of the retention time of the soil on the skin is used. Soil is assumed to remain on the skin from 0 to 48 hours in a triangular distribution with a most likely value of 2 hours. Exposed skin area is assumed to be at least 5000 cm^2 and ranges uniformly up to the total skin area of $20,000 \text{ cm}^2$.
- ◆ **Sediment: Inhalation** - Resuspension of soil with subsequent inhalation of the dust in the air is assumed to occur at all times while the person is on site. The amount of resuspension is determined by use of the mass loading approach based on an ambient air mass loading value of $100 \text{ } \mu\text{g/m}^3$, which is twice the EPA recommended value for suburban areas (40 CFR 50.6b). The pollutant concentration in the particulate matter is assumed to be the same as the pollutant concentration in the soil. The person is assumed to inhale 30 m^3 of air during the 24 hours s/he is on-site. This is 150 percent of the average value to account for a more active outdoor lifestyle (EPA 1989).

A series of equations were established to describe the individual exposure pathways for the Columbia River island user. These equations differ from the more general ones presented in Section 5.2.1 and so are presented here.

For the possibility of ingestion of a particle, the equation is

$$\begin{aligned} &(\text{Ingestion rate}) * (\text{Concentration}) * (\text{Time on island}) * (\text{Ingestion slope parameter}) \\ &\quad * (\text{Decay integral}) \end{aligned}$$

The scenario is established for a lifetime of exposure, so the annual exposures are multiplied by the integral of the activity over a 70-year lifetime.

For external irradiation without direct contact, the equation is

$$(\text{Time spent on island}) * (\text{Particle density}) * (\text{Slope parameter}) * (\text{Decay integral})$$

Table 5.11. Exposure Parameters for the Native American Columbia River Island User Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency (days/year)	Exposure Frequency Range	Exposure Duration (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Sediment	Ingestion	200 mg	20 - 500	2	0.2 - 40	70	1 - 70	3.77 mrem/ μ Ci	Dose conversion parameter for Co-60 particles
	External	24 hr	8 - 24	2	0.2 - 40	70	1 - 70	1.0	No shielding parameter
	Inhalation	30 m ³	10 - 30	2	0.2 - 40	70	1 - 70	100 μ g/m ³	Air mass loading
	Dermal	2 hr	0 - 48 hr	2	0.2 - 40	70	1 - 70	20,000 cm ² 0.2 mg/cm ²	Skin surface area Dermal contact per skin surface area

The decay integral is required in this calculation because the slope parameter is defined for constant exposure over a lifetime. Thus, the scenario assumes that the individual is exposed every year of her/his life. Because cobalt-60 has a 5.27-year half-life, the exposures decrease rapidly. This must be accounted for in the exposure estimate.

For the likelihood of being subjected to a skin lesion/beta particle burn, the equation is

$$\begin{aligned} & (\text{Probability of picking up a particle on the skin/day}) * (\text{Number of days on the island/year}) \\ & * (\text{Particle activity}) * (\text{Time on the skin}) \end{aligned}$$

For inhalation, the equation is based on lodging of a discrete particle in the nose, as

$$\begin{aligned} & (\text{Inhalation rate}) * (\text{Time on island}) * (\text{Particle density}) * (\text{Particle activity}) \\ & * (\text{Retention time in nose}) \end{aligned}$$

The possibility of inhaling a discrete radioactive particle was addressed by Durham and Soldat in the appendix of Cooper and Woodruff (1993). They found the physical size of the particles was such that it was not possible to inhale one into the lungs. At worst, the particles would lodge in the anterior portion of the nose. Durham used the specific activity of hot particles commonly found in the commercial nuclear industry in his calculation (60,000 Ci/cm³). This specific activity relates to relatively young particles. Those found in the Columbia River from plutonium production activities are at least 25 years old and so older than those studied by Durham. Thus, for the same particle activity, the particles would physically be much larger than assumed by Durham. He based his calculations on a 10-micron particle. The typical size found by Sula (1980) is 0.1 mm (100 microns). Therefore, the nasal retention used by Durham (1 to 2 days) is considerably longer than what would occur with this size particle. Nevertheless, a retention of up to 2 days has been used in this analysis. Durham's dose conversion parameter for cobalt-60 particles of 3.77 millirem/microcurie has also been used for this scenario.

5.1.5 General Population Scenarios

In the CRCIA screening assessment, two general population scenarios will be assessed for risk: a Resident Scenario and an Agricultural Resident Scenario. Except for the differences denoted below, the parameters used for both of these scenarios are from HSRAM (DOE 1995).

5.1.5.1 Resident

Residential land use of the Hanford Site does not currently occur, and it does not appear likely in the foreseeable future (DOE 1990). However, because residences are currently located downwind, down river, and in the vicinity of the site, the Resident Scenario is included in the screening assessment. Current residential exposures are primarily limited to contaminant levels measured in off-site air, water, and sediment and in some biota such as fish or wildlife. If residential use occurs in the future, onsite receptors would also have the potential for exposure to soil and seep/spring water.

A residential scenario was developed in HSRAM (DOE 1995) to evaluate the risks associated with common residential activities. In the residential scenario, individuals reside year round at the specified location with concurrent exposure to contaminants in soil and sediment, and exposures through incidental ingestion of soil, sediment, and water. The individual also catches fish from the river and tends a small garden that provides limited supplies of fruit and vegetables.

All parameters in the scenario have been adapted from the HSRAM (DOE 1995) tables but made internally consistent. For example, the breathing rates have been standardized at 20 m³/day and the drinking of river and spring water standardized at 2 liters/day. Ingestion and dermal exposures to sediment have been established to correspond with the time spent swimming in the river (EPA 1992). The volatilization equivalent for inhalation of seep/spring and surface water are based on Andelman (1990). The parameters for this scenario are provided in Table 5.12.

5.1.5.2 Agricultural Resident

The Columbia Basin area is extensively farmed. The HSRAM (DOE 1995) established an agricultural resident scenario to account for potentially increased exposures as a result of living on a farm affected by Hanford contaminants. The Agricultural Resident Scenario is very similar to the Residential Scenario with increases in the quantity of locally produced food and animal products.

All parameters in the scenario have been adapted from the HSRAM (DOE 1995) tables but made internally consistent. For example, the breathing rates have been standardized at 20 m³/day and the drinking of river and spring water standardized at 2 liters/day. Ingestion and dermal exposures to sediment have been established to correspond with the time spent swimming in the river (EPA 1992). The volatilization equivalent for inhalation of seep/spring and surface water are based on Andelman (1990). The parameters for this scenario are provided in Table 5.13.

Table 5.12. Exposure Parameters for the Resident Scenario

Pathway		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate ^(a) (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency ^(b) (days/year)	Exposure Frequency Range	Exposure Duration ^(a) (year)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion	200 mg (C) 100 mg (A)	20 - 500 10 - 150	365	270 - 365	6 (C) 24 (A)	1 - 6 1 - 64	--	--
	External	24 hr	8 - 24	365	270 - 365	30	1 - 70	0.8	Shielding parameter
	Dermal	0.2 mg/cm ²	0.05 - 0.5	180	100 - 365	30	1 - 70	5000 cm ²	Skin surface area
Air	Inhalation	20 m ³	15 - 30	365	270 - 365	30	1 - 70	--	--
Seep/Spring Water	Ingestion	2 L ^(b)	0 - 3	365	270 - 365	30	1 - 70	--	--
	Dermal	0.17 hr	0 - 1	365	270 - 365	30	1 - 70	20,000 cm ²	Skin surface area
	Inhalation	15 m ^{3(c)}	10 - 20	365	270 - 365	30	1 - 70	0.1 L/m ³	Volatilization equivalent
Surface Water	Ingestion	2 L ^(b)	0 - 3	365	270 - 365	30	1 - 70	--	--
	Dermal/showering	0.17 hr	0.1 - 1	365	270 - 365	30	1 - 70	20,000 cm ²	Skin surface area
	Dermal/swimming	2.6 hr	0 - 8	7	1 - 20	30	1 - 70	20,000 cm ²	Skin surface area
	Inhalation	15 m ^{3(c)}	10 - 20	365	270 - 365	30	1 - 70	0.1 L/m ³	Volatilization equivalent
Sediment	Ingestion	200 mg (C) 100 mg (A)	20 - 500 10 - 150	7	1 - 20	6 (C) 24 (A)	1 - 6 1 - 64	--	--
	Dermal	0.2 mg/cm ²	0.05 - 0.5	7	1 - 20	30	1 - 70	5000 cm ²	Skin surface area
Biota	Fish	54 g ^(d)	0 - 100	365	270 - 365	30	1 - 70	0.5	Diet fraction
	Fruit	42 g ^(e)	0 - 100	365	270 - 365	30	1 - 70	--	--
	Vegetable	80 g ^(e)	0 - 200	365	270 - 365	30	1 - 70	--	--

(a) Parameters recommended in EPA (1991a) except as noted.

(b) Parameters recommended in WAC (1991) (sects.720, 740, 750, Method B) except as noted.

(c) Indoor inhalation rate (EPA 1991a).

(d) Parameter recommended in WAC (1991) (sect. 730).

(e) Based on wet weight (EPA 1991a).

C = Child

A = Adult

Table 5.13. Exposure Parameters for the Agricultural Resident Scenario

Pathways		Exposure Parameters							
Media	Exposure Route	Intake/Contact Rate ^(a) (per day)	Intake/Contact Rate Range Min - Max	Exposure Frequency ^(b) (days/year)	Exposure Frequency Range	Exposure Duration ^(a) (years)	Exposure Duration Range	Other Parameters	Other Parameter Definitions
Soil	Ingestion	200 mg (C) 100 mg (A)	20 - 500 10 - 150	365	270 - 365	6 (C) 24 (A)	1 - 6 1 - 64	--	--
	External	24 hr	8 - 24	365	270 - 365	30	1 - 70	0.8	Shielding parameter
	Dermal	0.2 mg/cm ²	0.05 - 0.5	180	100 - 365	30	1 - 70	5000 cm ²	Skin surface area
Air	Inhalation	20 m ³	15 - 30	365	270 - 365	30	1 - 70	--	--
Seep/Spring Water	Ingestion	2 L ^(b)	0 - 3	365	270 - 365	30	1 - 70	--	--
	Dermal	0.17 hr	0 - 1	365	270 - 365	30	1 - 70	20,000 cm ²	Skin surface area
	Inhalation	15 m ^{3(c)}	10 - 20	365	270 - 365	30	1 - 70	0.1 L/m ³	Volatilization equivalent
Surface Water	Ingestion	2 L ^(b)	0 - 3	365	270 - 365	30	1 - 70	--	--
	Dermal/showering	0.17 hr	0.1 - 1	365	270 - 365	30	1 - 70	20,000 cm ²	Skin surface area
	Dermal/swimming	2.6 hr	0 - 8	7	1 - 20	30	1 - 70	20,000 cm ²	Skin surface area
	Inhalation	15 m ^{3(c)}	10 - 20	365	270 - 365	30	1 - 70	0.1 L/m ³	Volatilization equivalent
Sediment	Ingestion	200 mg (C) 100 mg (A)	20 - 500 10 - 150	7	1 - 20	6 (C) 24 (A)	1 - 6 1 - 64	--	--
	Dermal	0.2 mg/cm ²	0.05 - 0.5	7	1 - 20	30	1 - 70	5,000 cm ²	Skin surface area
Biota	Fish	54 g ^(d)	0 - 100	365	270 - 365	30	1 - 70	0.5	--
	Fruit	42 g ^(e)	0 - 200	365	270 - 365	30	1 - 70	--	--
	Vegetable	80 g ^(e)	0 - 300	365	270 - 365	30	1 - 70	--	--
	Deer	15 g ^(f)	0 - 100	365	270 - 365	30	1 - 70	0.19	--
	Beef	75 g	0 - 150	365	270 - 365	30	1 - 70	--	--
	Dairy	300 g	100 - 1000	365	270 - 365	30	1 - 70	--	--

(a) Parameters recommended in EPA (1991a) except as noted.
 (b) Parameters recommended in WAC (1991a) (sects. 720, 740, 750, Method B) except as noted.
 (c) Indoor inhalation rate (EPA 1991).
 (d) Parameters recommended in WAC (1991a) (173-340-730.)
 (e) Based on wet weight (EPA 1991a).
 (f) Intake adjusted for upperbound hunter success rate of 19 percent for game management unit 370.

C = Child
A = Adult

5.2 Results: Human Risk Screening Assessment

To estimate the potential risk to human health, we put the data described in Section 3.0, the ecological risk results described in Section 4.2, and the parameters for the scenarios described in Section 5.1 into a computer model. The computer model consisted of a series of equations that estimated risk. In this section, we describe how the information from the three sources was used in the equations and what the results of the equations are. The results are the possible risk to humans from the Columbia River.

The results of the screening assessment of human risk were estimated by putting the monitoring data (Section 3.0), the results of the ecological screening assessment (Section 4.2), and the parameters of the human scenarios (Section 5.1) into a computer model. This section provides the calculations used in the model and the resulting estimated risk to humans.

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

5.2.1 Exposure Equations

The exposure equations described in this section were used to assess human risk at a screening level. The parameters in the various scenarios were used in these equations. The equations were based on the exposure routes: external radiation, dermal, inhalation, and ingestion. These exposure equations were adapted and expanded from those in Appendix D of the Hanford Site Risk Assessment Methodology (HSRAM)(DOE 1995). The same notation and terminology were used for consistency with HSRAM. Additions (described in Section 5.1) were made to the equations to make them more directly applicable to the CRCIA screening assessment scenarios. In addition, the equations were revised so that the risk from each of the media to which people might be exposed could be reported separately. Therefore, the equations are presented in two forms here: the first in conventional pathway analysis format, the second in a media analysis format. The presentations are equivalent in that the theory and results are the same. The first presentation is for review by persons interested in the overall exposure. The second is for review by persons interested in the details of the presentation of the assessment.

We first calculated what the exposure to contaminants would be. Contaminants reach us via four pathways: contact with the skin, ingestion, inhalation, and from external radiation. External radiation is different from contact with the skin in that with external radiation the contaminant need not actually come into contact with the human body. In the exposure equations, we used the concentrations of contaminants in sediment, seep water, surface water, food products, and cultural materials.

5.2.1.1 Human Exposure Equations Derived by Pathway

The following equations represent the total exposure of a person to radionuclides or chemicals. These equations describe just the exposure or intake not the dose or risk from those exposures. The risk is included in the revised equations in Section 5.2.1.3.

External Radiation Exposure

$$\text{Dose}_{\text{ext}} = [(C_{\text{soil}} * ET_{\text{soil}} * RF_{\text{soil}} * EF_{\text{soil}} + C_{\text{sed}} * ET_{\text{sed}} * EF_{\text{sed}}) * DF1 + C_{\text{river}} * ET_{\text{swim}} * EF_{\text{swim}} * DF2 + C_{\text{river}} * ET_{\text{boat}} * EF_{\text{boat}} * DF3] * ED \quad (5.1)$$

where

C_{river}	=	radionuclide concentration in river water (pCi/L)
C_{sed}	=	radionuclide concentration in sediment (pCi/g)
C_{soil}	=	radionuclide concentration in soil (pCi/g)
$DF1$	=	dose conversion factor for soil and sediment (rem/hr per pCi/g)
$DF2$	=	dose conversion factor for swimming (rem/hr per pCi/L)
$DF3$	=	dose conversion factor for boating (rem/hr per pCi/L)
Dose_{ext}	=	dose from external radionuclides (rem)
ED	=	exposure duration (year)
EF_{boat}	=	exposure frequency for boating (days/year)
EF_{sed}	=	exposure frequency for sediment (days/year)
EF_{soil}	=	exposure frequency for soil (days/year)
EF_{swim}	=	exposure frequency for swimming (days/year)
ET_{boat}	=	exposure time for boating (hours/day)
ET_{sed}	=	exposure time for sediment (hours/day)
ET_{soil}	=	exposure time for soil (hours/day)
ET_{swim}	=	exposure time for swimming (hours/day)
RF_{soil}	=	soil shielding factor (dimensionless)

Dermal Exposure (Carcinogenic, Non-Carcinogenic, Non-Radioactive)

$$\begin{aligned} \text{DAD} = & [C_{\text{soil}} * AF_{\text{soil}} * ABS * SA_{\text{soil}} * EF_{\text{soil}} * CF1 + \\ & C_{\text{sed}} * AF_{\text{sed}} * ABS * SA_{\text{sed}} * EF_{\text{sed}} * CF1 + \\ & (C_{\text{other}} * K_p * SA_{\text{other}} * ET_{\text{other}} * EF_{\text{other}} + \\ & C_{\text{seep}} * K_p * SA_{\text{seep}} * ET_{\text{seep}} * EF_{\text{seep}}) * CF3 + \\ & C_{\text{river}} * K_p * SA_{\text{river}} * ET_{\text{river}} * EF_{\text{river}} * CF3] * ED / (BW * AT) \end{aligned} \quad (5.2)$$

where

ABS	=	material-specific absorption factor (unitless)
AF_{sed}	=	adherence factor for sediment (mg/cm ² per day)
AF_{soil}	=	adherence factor for soil (mg/cm ² per day)
AT	=	averaging time (year x 365 days/year)
BW	=	body weight (kg)
C_{other}	=	contaminant concentration in cultural materials (defined in the scenarios as seep water used in sweat lodges) (mg/L)
C_{river}	=	contaminant concentration in river water (mg/L)
C_{sed}	=	contaminant concentration in sediment (mg/kg)
C_{seep}	=	contaminant concentration in seep/spring water (mg/L)
C_{soil}	=	contaminant concentration in soil (mg/kg)

CF1	=	unit conversion factor (1E-6 kg/mg)
CF3	=	unit conversion factor (1E-3 L/cm ³)
DAD	=	dose from dermal absorption (mg/kg per day)
ED	=	exposure duration (year)
EF _{other}	=	exposure frequency to cultural activities (sweat lodge) (days/year)
EF _{river}	=	exposure frequency to river water (days/year)
EF _{sed}	=	exposure frequency to sediment (days/year)
EF _{seep}	=	exposure frequency to seep/spring water (days/year)
EF _{soil}	=	exposure frequency to soil (days/year)
ET _{other}	=	exposure time to cultural activities (sweat lodge) (hours/day)
ET _{river}	=	exposure time to river water (hours/day)
ET _{seep}	=	exposure time to seep/spring water (hours/day)
K _p	=	permeability coefficient for a chemical in water through skin (cm/hour)
SA _{other}	=	body surface area exposed during cultural activities (sweat lodge) (cm ²)
SA _{river}	=	body surface area exposed to river water (cm ²)
SA _{sed}	=	body surface area exposed to sediment (cm ²)
SA _{seep}	=	body surface area exposed to seep/spring water (cm ²)
SA _{soil}	=	body surface area exposed to soil (cm ²)

Inhalation Exposure (Non-Radioactive)

$$\begin{aligned}
 \text{INH} = & (C_{\text{soil}} * \text{ML} * \text{ET}_{\text{soil}} * \text{EF}_{\text{soil}} + C_{\text{seep}} * \text{VF} * \text{ET}_{\text{seep}} * \text{EF}_{\text{seep}} + \\
 & C_{\text{river}} * \text{VF} * \text{ET}_{\text{river}} * \text{EF}_{\text{river}} + C_{\text{other}} * \text{CF}_{\text{other}} * \text{ET}_{\text{other}} * \text{EF}_{\text{other}}) * \\
 & \text{ED} * \text{BR} / (\text{BW} * \text{AT} * \text{CF4})
 \end{aligned} \tag{5.3}$$

where

AT	=	averaging time (year x 365 days/year)
BW	=	body weight (kg)
C _{other}	=	contaminant concentration in cultural materials made airborne (defined in the scenarios as volatilized seep water used in sweat lodges) (mg/L)
C _{river}	=	contaminant concentration in river water (mg/L)
C _{seep}	=	contaminant concentration in seep/spring water (mg/L)
C _{soil}	=	contaminant concentration in soil (mg/kg)
CF4	=	unit conversion factor (24 hours/day)
CF _{other}	=	factor relating cultural materials to air concentration (defined in the scenarios as volatilized seep water used in sweat lodges) (L/m ³)
ED	=	exposure duration (year)
EF _{other}	=	exposure frequency to materials resuspended from cultural activities (day/year)
EF _{river}	=	exposure frequency to volatilized river water (day/year)
EF _{seep}	=	exposure frequency to volatilized seep/spring water (day/year)
EF _{soil}	=	exposure frequency to resuspended dusts (day/year)
ET _{other}	=	exposure time for breathing materials suspended from cultural activities (hours/day)
ET _{river}	=	exposure time for breathing volatilized river water (hours/day)
ET _{seep}	=	exposure time for breathing volatilized seep/spring water (hours/day)

ET_{soil} = exposure time for breathing resuspended dusts (hours/day)
 INH = chronic daily inhalation intake (mg/kg per day)
 BR = inhalation (Breathing) rate (m^3/day)
 ML = mass loading of soil in air (kg/m^3)
 VF = volatilization factor (L/m^3)

Inhalation Exposure (Radioactive)

$$Dose_{inh} = (C_{soil} * ML * ET_{soil} * EF_{soil} * CF5 + C_{seep} * VF * ET_{seep} * EF_{seep} + C_{river} * VF * ET_{river} * EF_{river} + C_{other} * CF_{other} * ET_{other} * EF_{other} * CF5) * ED * BR * DF5/CF4 \quad (5.4)$$

where

C_{other} = radionuclide concentration in cultural materials made airborne (defined in the scenarios as volatilized seep water used in sweat lodges) (pCi/g)
 C_{river} = radionuclide concentration in river water (pCi/L)
 C_{seep} = radionuclide concentration in seep/spring water (pCi/L)
 C_{soil} = radionuclide concentration in soil (pCi/g)
 $CF4$ = unit conversion factor (24 hours/day)
 $CF5$ = unit conversion factor (1000 g/kg)
 CF_{other} = factor relating cultural materials to air concentration (defined in the scenarios as volatilized seep water used in sweat lodges) (L/m^3)
 $DF5$ = dose conversion factor for inhalation (rem/pCi)
 $Dose_{inh}$ = dose from inhalation of radionuclides (rem)
 ED = Exposure duration (year)
 EF_{other} = exposure frequency to materials resuspended during cultural activities (days/year)
 EF_{river} = exposure frequency to volatilized river water (days/year)
 EF_{seep} = exposure frequency to volatilized seep/spring water (days/year)
 EF_{soil} = exposure frequency to resuspended dusts (days/year)
 ET_{other} = exposure time for breathing materials suspended during cultural activities (hours/day)
 ET_{river} = exposure time for breathing volatilized river water (hours/day)
 ET_{seep} = exposure time for breathing volatilized seep/spring water (hours/day)
 ET_{soil} = exposure time for breathing resuspended dusts (hours/day)
 BR = inhalation rate (m^3/day)
 ML = mass loading of soil in air (kg/m^3)
 VF = volatilization factor (L/m^3)

Ingestion Exposure (Non-Radioactive)

$$ING = (C_{soil} * IR_{soil} + C_{sed} * IR_{sed} + C_{river} * IR_{river} + C_{seep} * IR_{seep} + C_{fish} * IR_{fish} + C_{leafy} * IR_{leafy} + C_{root} * IR_{root} + C_{meat} * IR_{meat} + C_{bird} * IR_{bird}) * EF * ED / (AT * BW) \quad (5.5)$$

where

AT	=	averaging time (year x 365 days/yr)
BW	=	body weight (kg)
C _{bird}	=	contaminant concentration in domestic and wild birds (mg/kg)
C _{fish}	=	contaminant concentration in fish (mg/kg)
C _{leafy}	=	contaminant concentration in above-ground vegetation (mg/kg)
C _{meat}	=	contaminant concentration in meat (mg/kg)
C _{river}	=	contaminant concentration in river water (mg/kg)
C _{root}	=	contaminant concentration in root vegetables (mg/kg)
C _{sed}	=	contaminant concentration in sediment (mg/kg)
C _{seep}	=	contaminant concentration in seep/spring water (mg/kg)
C _{soil}	=	contaminant concentration in soil (mg/kg)
ED	=	exposure duration (year)
EF	=	exposure frequency (days/year)
ING	=	chronic daily ingestion rate (mg/kg per day)
IR _{bird}	=	ingestion rate of domestic and wild birds (kg/day)
IR _{fish}	=	ingestion rate of fish (kg/day)
IR _{leafy}	=	ingestion rate of above-ground vegetation (kg/day)
IR _{meat}	=	ingestion rate of meat (kg/day)
IR _{river}	=	ingestion rate of river water (kg/day)
IR _{root}	=	ingestion rate of root vegetables (kg/day)
IR _{sed}	=	ingestion rate of sediment (kg/day)
IR _{seep}	=	ingestion rate of seep/spring water (kg/day)
IR _{soil}	=	ingestion rate of soil (kg/day)

Ingestion Exposure (Radioactive)

$$\text{Dose}_{\text{ing}} = (C_{\text{soil}} * \text{IR}_{\text{soil}} + C_{\text{sed}} * \text{IR}_{\text{sed}} + C_{\text{river}} * \text{IR}_{\text{river}} + C_{\text{seep}} * \text{IR}_{\text{seep}} + C_{\text{fish}} * \text{IR}_{\text{fish}} + C_{\text{leafy}} * \text{IR}_{\text{leafy}} + C_{\text{root}} * \text{IR}_{\text{root}} + C_{\text{meat}} * \text{IR}_{\text{meat}} + C_{\text{bird}} * \text{IR}_{\text{bird}}) * \text{EF} * \text{ED} * \text{CF5} * \text{DF6} \quad (5.6)$$

where

C _{bird}	=	radionuclide concentration in domestic and wild birds (pCi/g)
C _{fish}	=	radionuclide concentration in fish (pCi/g)
C _{leafy}	=	radionuclide concentration in above-ground vegetation (pCi/g)
C _{meat}	=	radionuclide concentration in meat (pCi/g)
C _{river}	=	radionuclide concentration in river water (pCi/g)
C _{root}	=	radionuclide concentration in root vegetables (pCi/g)
C _{sed}	=	radionuclide concentration in sediment (pCi/g)
C _{seep}	=	radionuclide concentration in seep/spring water (pCi/g)
C _{soil}	=	radionuclide concentration in soil (pCi/g)
CF5	=	unit conversion factor (1000 g/kg)
DF6	=	dose conversion factor for ingestion (rem/pCi)
Dose _{ing}	=	dose from ingestion (rem)

ED	=	exposure duration (year)
EF	=	exposure frequency (days/year)
IR _{bird}	=	ingestion rate of domestic and wild birds (kg/day)
IR _{fish}	=	ingestion rate of fish (kg/day)
IR _{leafy}	=	ingestion rate of above-ground vegetation (kg/day)
IR _{meat}	=	ingestion rate of meat (kg/day)
IR _{river}	=	ingestion rate of river water (kg/day)
IR _{root}	=	ingestion rate of root vegetables (kg/day)
IR _{sed}	=	ingestion rate of sediment (kg/day)
IR _{seep}	=	ingestion rate of seep/spring water (kg/day)
IR _{soil}	=	ingestion rate of soil (kg/day)

5.2.1.2 Estimate of Environmental Concentrations of Contaminants

The equations defined in Section 5.2.1.1 required both the concentrations of contaminants in the measured media (sediment, seep water, surface water) and also in food products, such as fish, birds, meat, and vegetables that become contaminated through contact with these media. The human exposure model used the data (Section 3.0) for the contaminant concentrations in the media and the results of the ecological model (Section 4.2), summarized as transfer coefficients, to determine the concentrations in vegetation. The same transfer coefficients were assumed to apply to all terrestrial vegetation, therefore, concentrations estimated for riparian vegetation were assumed to be the same as those estimated for food products. In this way, the human and ecological models were directly connected and thus consistent. The estimate of concentrations in these food products is described here.

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

$$C_{\text{fish}} = C_{\text{river}} * \text{BIO}_{\text{fish}} \quad (5.7)$$

where:

C_{fish}	=	analyte concentration in fish (pCi or $\mu\text{g/kg}$)
C_{river}	=	analyte concentration in river water (pCi or $\mu\text{g/L}$)
BIO_{fish}	=	analyte-specific bioaccumulation factor derived from the CRCIA ecosystem model results (L/kg)

Foods. The contaminant concentrations in terrestrial foods were related to the concentrations of analytes in sediment.

$$\begin{aligned} C_{\text{leafy}} &= C_{\text{sed}} * \text{CR}_{\text{veg}} \\ C_{\text{root}} &= C_{\text{sed}} * \text{CR}_{\text{veg}} = C_{\text{leafy}} \\ C_{\text{meat}} &= C_{\text{leafy}} * \text{TF}_{\text{deer}} = C_{\text{sed}} * \text{CR}_{\text{veg}} * \text{TF}_{\text{deer}} \\ C_{\text{bird}} &= C_{\text{leafy}} * \text{TF}_{\text{bird}} = C_{\text{sed}} * \text{CR}_{\text{veg}} * \text{TF}_{\text{bird}} \end{aligned} \quad (5.8)$$

where:

C_{bird}	=	analyte concentration in wild bird flesh (pCi or $\mu\text{g/kg}$)
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C_{leafy}	=	analyte concentration in leafy vegetables (pCi or $\mu\text{g/kg}$)
C_{meat}	=	analyte concentration in animal protein (pCi or $\mu\text{g/kg}$)
C_{root}	=	analyte concentration in root vegetables (pCi or $\mu\text{g/kg}$)
C_{sed}	=	analyte concentration in sediment (pCi or $\mu\text{g/kg}$)
CR_{veg}	=	sediment-to-vegetation concentration ratio derived from ecosystem model
TF_{bird}	=	feed-to-wild-bird transfer factor derived from ecosystem model
TF_{deer}	=	feed-to-animal-protein transfer factor derived from ecosystem model

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

$$C_{\text{other}} = C_{\text{seep}} \quad (5.9)$$

5.2.1.3 Human Exposure Equations Derived by Media

To provide the maximum amount of information to the CRCIA decision makers, the equations defined in Sections 5.2.1.1 and 5.2.1.2 were rearranged to provide risk as a function of exposure medium (sediment, seep water, or surface water) or external radiation exposure. These equations used the same parameter definitions as in Section 5.2.1.1 but were broken out by contaminant type (radionuclide, carcinogenic chemical, or toxic chemical) and measured initiating medium. Note that groundwater, although used extensively as a surrogate measure for concentration as defined in Section 3.0, was not an initiating medium in the scenarios. Without repeating the same parameter definitions again, the equations used in the actual analysis are given here.

Radionuclides

$$\begin{aligned} \text{Risk(SD)} = & \{ [C_{\text{sed}} * (IR_{\text{sedchild}} * ED_{\text{child}} + IR_{\text{sedadult}} * ED_{\text{adult}}) * EF_{\text{sed}}] \\ & + \{ C_{\text{leafy}} * IR_{\text{leafy}} + C_{\text{root}} * IR_{\text{root}} + C_{\text{meat}} * IR_{\text{meat}} + C_{\text{bird}} * IR_{\text{bird}} \} \\ & * EF * ED \} * CF5 * DF6 * \text{DOSE2RISK} \end{aligned} \quad (5.10)$$

where

Risk(SD)	=	risk from sediment
IR_{sedchild}	=	ingestion rate of sediment by a child (kg/day)
ED_{child}	=	exposure duration of a child (year)
IR_{sedadult}	=	ingestion rate of sediment by an adult (kg/day)
ED_{adult}	=	exposure duration of an adult (year)
DOSE2RISK	=	factor converting accumulated radiation dose to risk (risk/rem)

Note: C_{leafy} , C_{root} , C_{meat} , C_{bird} are all derived from C_{sed} as described in Section 5.2.1.2.

$$\begin{aligned} \text{Risk(SW)} = & [C_{\text{river}} * ET_{\text{swim}} * EF_{\text{swim}} * ED * DF2 + C_{\text{river}} * ET_{\text{boat}} * EF_{\text{boat}} \\ & * ED * DF3 + C_{\text{river}} * VF * ET_{\text{river}} * EF_{\text{river}} * ED * BR * DF5/CF4 + \\ & (C_{\text{fish}} * IR_{\text{fish}} + C_{\text{river}} * IR_{\text{river}}) * EF * ED * CF5 * DF6] * \text{DOSE2RISK} \end{aligned} \quad (5.11)$$

where

Risk(SW) = risk from surface water

Note: C_{fish} is derived from C_{river}

$$\begin{aligned} \text{Risk(SP)} = & [(C_{seep} * VF * ET_{seep} * EF_{seep} + C_{other} * CF_{other} * ET_{other} * EF_{other}) \\ & * ED * BR * DF5/CF4 + C_{seep} * IR_{seep} * EF_{seep} * ED * CF5 * DF6] \\ & * \text{DOSE2RISK} \end{aligned} \quad (5.12)$$

where

Risk(SP) = risk from seeps

Two cases were evaluated for external irradiation: where direct thermoluminescent dosimetry measurements were available and where they were not. For the cases where measurements were available, the measurements were used directly. To use the measurements, which record all radiation exposure including background and Hanford Site contribution, a background value was subtracted. For the region around the Hanford Site, a regional value of 0.2 mrad/day (8 μ R/hour) was subtracted.

$$\text{Risk(ER)} = \text{MAX}[(\text{ER}-0.2), 0] * ET_{sed} * EF_{sed} * ED * \text{DOSE2RISK}/(CF4 * CF6) \quad (5.13)$$

where

Risk(ER) = risk from external radiation

MAX = functional relationship, taking the larger of the measured exposure rate minus background or zero

ER = measured exposure rate in a segment (mrad/day)

CF6 = unit conversion factor, 0.001 rem/mrad

When measured values were not available, the dose rates were estimated from the sediment concentrations.

$$\text{Risk(ER)} = C_{sed} * ET_{sed} * EF_{sed} * RF_{sed} * ED * DF1 * \text{DOSE2RISK} \quad (5.14)$$

Carcinogenic Chemicals

$$\begin{aligned} \text{Risk(SD)} = & [C_{sed} * AF_{sed} * ABS * SA_{sed} * EF_{sed} * CF1 * ED/(BW_{adult} * AT) + \\ & \{C_{sed} * (IR_{sedchild} * ED_{child}/BW_{child} + IR_{sedadult} * ED_{adult}/BW_{adult}) + \\ & C_{leafy} * IR_{leafy} * ED/BW_{adult} + C_{root} * IR_{root} * ED/BW_{adult} + C_{meat} * \\ & IR_{meat} * ED/BW_{adult} + C_{bird} * IR_{bird} * ED/BW_{adult}\} * EF/AT] * \\ & CPF_{ing} * CF7 \end{aligned} \quad (5.15)$$

where

BW_{adult} = body weight of an adult (kg)

BW_{child} = body weight of a child (kg)

CPF_{ing} = cancer potency factor for ingestion, risk per mg/(kg/day)

CF7 = unit conversion factor, 0.001 mg/ μ g

Note: C_{leafy} , C_{root} , C_{meat} , C_{bird} are all derived from C_{sed} as described in Section 5.2.1.2.

$$\begin{aligned} \text{Risk(SW)} = & \{[(C_{river} * IR_{river} + C_{fish} * IR_{fish}) * EF + (C_{river} * K_p * SA_{river} * \\ & ET_{swim} * EF_{swim} * CF3)] * ED / (AT * BW_{adult}) * CPF_{ing} + \\ & C_{river} * VF * ET_{river} * EF_{river} * ED * BR / (BW_{adult} * AT * \\ & CF4) * CPF_{inh}\} * CF7 \end{aligned} \quad (5.16)$$

where

$$CPF_{inh} = \text{cancer potency factor for inhalation, risk per mg/(kg/day)}$$

Note: C_{fish} is derived from C_{river} as described in Section 5.2.1.2.

$$\begin{aligned} \text{Risk(SP)} = & [(C_{seep} * K_p * SA_{seep} * ET_{seep} * EF_{seep} * CF3 + C_{other} * K_p * \\ & SA_{other} * ET_{other} * EF_{other} * CF3) * ED / (BW_{adult} * AT) * CPF_{ing} + \\ & (C_{seep} * VF * ET_{seep} * EF_{seep} + C_{other} * CF_{other} * ET_{other} * EF_{other}) * \\ & ED * BR / (BW_{adult} * AT * CF4) * CPF_{inh} + C_{seep} * IR_{seep} * EF * \\ & ED / (BW_{adult} * AT) * CPF_{ing}] * CF7 \end{aligned} \quad (5.17)$$

Toxic Chemicals

The difference in the equations between those for carcinogenic chemicals and toxic chemicals was that CPF_{ing} and CPF_{inh} were replaced with $1/RfD_{ing}$ and $1/RfD_{inh}$, respectively.

$$\begin{aligned} \text{Risk(SD)} = & [C_{sed} * AF_{sed} * ABS * SA_{sed} * EF_{sed} * CF1 * ED / (BW_{adult} * AT) + \\ & \{C_{sed} * (IR_{sedchild} * ED_{child} / BW_{child} + IR_{sedadult} * ED_{adult} / BW_{adult}) + \\ & C_{leafy} * IR_{leafy} * ED / BW_{adult} + C_{root} * IR_{root} * ED / BW_{adult} + C_{meat} * \\ & IR_{meat} * ED / BW_{adult} + C_{bird} * IR_{bird} * ED / BW_{adult}\} * EF / AT / RfD_{ing}] * CF7 \end{aligned} \quad (5.18)$$

where

$$RfD_{ing} = \text{reference dose for ingestion, mg/(kg day)}$$

Note: C_{leafy} , C_{root} , C_{meat} , C_{bird} were all derived from C_{sed} as described in Section 5.2.1.2.

$$\begin{aligned} \text{Risk(SW)} = & \{[(C_{river} * IR_{river} + C_{fish} * IR_{fish}) * EF + (C_{river} * K_p * SA_{river} * \\ & ET_{swim} * EF_{swim} * CF3)] * ED / (AT * BW_{adult}) / RfD_{ing} + C_{river} * \\ & VF * ET_{river} * EF_{river} * ED * BR / (BW_{adult} * AT * CF4) / RfD_{inh}\} * CF7 \end{aligned} \quad (5.19)$$

where

$$RfD_{inh} = \text{reference dose for inhalation, mg/(kg day)}$$

Note: C_{fish} was derived from C_{river} as described in Section 5.2.1.2.

$$\text{Risk(SP)} = [(C_{\text{seep}} * K_p * SA_{\text{seep}} * ET_{\text{seep}} * EF_{\text{seep}} * CF3 + C_{\text{other}} * K_p * SA_{\text{other}} * ET_{\text{other}} * EF_{\text{other}} * CF3) * ED / (BW_{\text{adult}} * AT) / RfD_{\text{ing}} + (C_{\text{seep}} * VF * ET_{\text{seep}} * EF_{\text{seep}} + C_{\text{other}} * CF_{\text{other}} * ET_{\text{other}} * EF_{\text{other}}) * ED * BR / (BW_{\text{adult}} * AT * CF4) / RfD_{\text{inh}} + C_{\text{seep}} * IR_{\text{seep}} * EF * ED / (BW_{\text{adult}} * AT) / RfD_{\text{ing}}] * CF7 \quad (5.20)$$

5.2.2 Parameters

A large number of parameters were required by the equations defined in the preceding sections in addition to those that describe the human activities in the scenarios (Section 5.1). The parameters fall into the categories of environmental transfer factors, radiation dose conversion factors, chemical risk and reference doses, dermal absorption rate constants, and miscellaneous other parameters. Each parameter used in the assessment is defined here and its source given. Most parameters were treated stochastically, which means that they have a range of uncertainty. This uncertainty range is also provided here with notes as to how it was selected.

As you noticed in the previous section, each equation contains numerous parameters. Each parameter defines a particular aspect that affects risk to human health. For instance, one parameter is denoted as C_{leafy} in the equations. C_{leafy} is the amount of contaminant in leafy vegetables. We calculated C_{leafy} for each of the contaminants (28) in each of the areas (27 segments) along the Columbia River. In this section, we describe the parameters used in the equations and where we obtained our information for each parameter. We organized the descriptions of the parameters according to type of parameter: environmental transfer factors, radiation dose conversion factors, chemical risk and reference dose factors, dermal absorption rate constants, or other types of parameters.

5.2.2.1 Common Parameters with the Ecological Model

The equations described in Section 5.2.1.2 for estimating potential contaminant concentrations in fish, birds, meat, and vegetation (plants consumed by humans or animals) require parameters that relate the ratios of a contaminant in one medium to that in another. The ratios used in the human health risk assessment were developed by running the ecological risk model described in Section 4.2. The ecological model was run in a deterministic fashion for each of the 27 river segments. The results of these runs were analyzed to develop the distributions of transfer functions needed for the human risk model. The results are presented in Table 5.14. The transfer functions for fish (averaged over several species of food fish), birds (an average of ducks), meat (defined as deer in the ecological model), and vegetation are given. The minima and maxima presented in Table 5.14 are those that came from the ecological model. The deterministic value is the average from that model's results.

An exception is the bioaccumulation factors for Columbia River fish. The ecological model was unable in several instances to provide information for several contaminants because the measurements of these contaminants in river water were not available. Therefore, to ensure completeness and consistency, bioaccumulation factors for fish were taken from a standard reference (IAEA1994). The minima and maxima presented in Table 5.14 are those that came from the IAEA handbook. The deterministic value is the best estimate from the IAEA reference.

A number of transfer factors can be seen to be set to zero in Table 5.14. For most contaminants for which this is true, the ecological modeling indicated that plants or animals did not take up these chemical

Table 5.14. Parameters in the Human Health Risk Assessment Coordinated with the Ecosystem Models

	BIO _{fish} ^(a)			Cr _{veg}			TF _{deer}			TF _{bird}			Kd	
	(pCi/kg per pCi/L)			(pCi/kg per pCi/kg)			(pCi/kg per pCi/kg)			(pCi/kg per pCi/kg)			Hanford-Specific Values	
	(µg/kg per µg/L)			(µg/kg per µg/kg)			(µg/kg per µg/kg)			(µg/kg per µg/kg)			(ml/g)	
Analyte	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Distr.
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	30	Fixed
Benzene	0	0	0	0	0	0	0.00E+00	0.009	0.009	0.00E+00	0.157	0.157	19	Fixed
Carbon-14	0	0	0	0.9	0.9	0.9	4.624	4.624	4.624	8.114	8.114	8.114	4	Fixed
Cesium-137	2000	30	3000	0.045	0.001	35.1	1.801	1.748	2.6	2.254	1.54	12.842	1360	Fixed
Chromium	200	40	1000	0.024	0.004	0.18	0.07	0.069	0.079	0.014	0.009	0.116	0	Fixed
Cobalt-60	300	10	300	0.045	0.007	0.5	0.124	0.093	0.184	20.747	0.579	50.144	200	Fixed
Copper	200	50	200	0.225	0.03	9.5	1.751	1.751	1.751	10.318	7.541	12.853	40	Fixed
Cyanide	0	0	0	0	0	0	0	0	0	0	0	0	0	Fixed
Diesel	0	0	0	0	0	0	0	0	0	0	0	0	4464	Fixed
Europium-152	50	10	200	0.003	0.001	0.01	0.416	0.345	3.213	9.018	7.454	76.707	500	Fixed
Europium-154	50	10	200	0.003	0.001	0.01	0.416	0.345	3.213	9.018	7.454	76.707	500	Fixed
Iodine-129	0	0	0	0.23	0.03	13.1	0	0	0	0	0	0	3	Fixed
Kerosene	0	0	0	0	0	0	0	0	0	0	0	0	4464	Fixed
Lead	300	100	300	0.038	0.0001	0.25	0.107	0.107	0.109	0.033	0.03	0.074	1000	Fixed
Mercury	1000	1000	1000	0.55	0.04	0.9	0.363	0.363	0.363	14.42	14.42	14.42	500	Fixed
Neptunium-237	0	0	0	0.02	0.00004	0.19	0	0	0	0	0	0	25	Fixed
Nickel	100	100	100	0.145	0.06	5.72	0.003	0.003	0.003	0.006	0.006	0.006	40	Fixed
Nitrate	0	0	0	30	30	30	0	0	0	0	0	0	0	Fixed
Nitrite	0	0	0	30	30	30	0	0	0	0	0	0	0	Fixed
Phosphate	0	0	0	3.5	3.5	3.5	0	0	0	0	0	0	50	Fixed
Strontium-90	60	1	1000	0.744	0.005	85.3	0.556	0.554	1.014	2.418	2.35	12.082	42	Fixed
Sulfate	0	0	0	1.5	1.5	1.5	0	0	0	0	0	0	0	Fixed
Technetium-99	20	2	80	185	1.5	881	0.085	0.085	0.087	0.173	0.159	0.176	1	Fixed
Tritium (H-3)	1	1	1	0.9	0.9	0.9	0	0	0	0	0	0	0	Fixed
Uranium-234	10	2	50	0.017	0.00016	45	0.331	0.322	0.458	1.621	1.229	6.995	10	Fixed
Uranium-238	10	2	50	0.017	0.00016	45	0.331	0.322	0.458	1.621	1.229	6.995	10	Fixed
Xylene	0	0	0	0	0	0	0	0	0	0	0	0	1122	Fixed
Zinc	1000	100	3000	0.33	0.05	4.16	1.08	1.08	1.08	4.367	2.973	506.61	40	Fixed
(a) IAEA 1994

compounds without first breaking them down to other biological components (for example, nitrates are metabolized to other forms of nitrogen, sulfates to sulfur, etc.).

5.2.2.2 Radiation Dose Conversion Factors

The translation of radionuclide concentration in sediment, soil, or water to radiation dose rate was performed using dose rate conversion factors (see Table 5.15). Such factors are available from a number of sources and are very similar regardless of the source. Those used in this analysis were taken from the Federal Guidance Report No. 12 (Eckerman and Ryman 1993).

Soil and sediment factors relate concentration in soil and sediment in picocuries/kilogram to the external dose rate above a large, flat contaminated area in rem/hour. These factors apply to very large sources, therefore, the geometry correction factor defined for each scenario is used to adjust these to fit the smaller geometry of the riparian zone. Uncertainties in these factors are fairly small. A range of one-half to twice the tabulated values was selected for all of these dose conversion factors in a uniform distribution following the logic of Snyder et al. (1994).

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

Dose conversion factors for boating were derived from those for swimming. It can be shown that the dose rate at the surface of a body of contaminated water is exactly half that of a point immersed within the water (see, for example, Morgan and Turner 1973). For this analysis, that fact was used with no additional modifications (such as shielding from the boat, distance above the water line, etc.). A small range of a factor of 2 uniformly above and below the calculated dose rate conversion factor was also used.

Dose conversion factors for ingestion and inhalation were taken from Federal Guidance Report No. 11 (Eckerman et al. 1988). These factors relate the amount of a radionuclide in rem/picocurie taken in to the body to the ultimate expressed dose over a period of 50 years following the intake. Internal doses such as these are more variable between individuals than are the external doses discussed above. Individual radiation doses depend on the amount of a radionuclide taken in to the body and absorbed in the bloodstream, in which organs the contaminants accumulate and how long they remain there, and on the masses of the individual's organs as well as the age and sex of the individual. These parameters vary in every person. Research on the variability of these parameters indicates that the resulting variability can be quite large (see, for example, Dunning and Schwarz 1981). Following the example of Snyder et al. (1994), a loguniform distribution was selected with a geometric standard deviation of 2. This provided an overall range of about a factor of 25 between the 1st and 99th percentiles of the distribution.

Table 5.15. Radiation Dose Conversion Factors

Analyte	Uniform Distributions									Lognormal Distributions, GSD = 2.0								
	Soil and Sediment			Swimming			Boating			Ingestion			Inhalation			Sweat Lodge Pathway = Inhalation		
	(rem/hr per pCi/kg)			(rem/hr per pCi/L)			(rem/hr per pCi/L)			(rem/pCi)			(rem/pCi)			(rem/pCi)		
	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Min.	Max.	Deterministic	Min.	Max.
Carbon-14	9.60E-16	4.8E-16	1.92E-15	5.80E-15	2.9E-15	1.16E-14	2.9E-15	1.45E-15	5.8E-15	2.10E-09	4.2E-10	1.05E-08	2.10E-09	4.2E-10	1.05E-08	2.10E-09	4.2E-10	1.05E-08
Cesium-137	2.30E-10	1.15E-10	4.6E-10	8.30E-10	4.15E-10	1.66E-09	4.15E-10	2.075E-10	8.3E-10	5.00E-08	0.00000001	0.00000025	3.20E-08	6.4E-09	0.00000016	3.20E-08	6.4E-09	0.00000016
Cobalt-60	9.70E-10	4.85E-10	1.94E-09	3.60E-09	1.8E-09	7.2E-09	1.8E-09	9E-10	3.6E-09	2.70E-08	5.4E-09	0.000000135	3.30E-08	6.6E-09	0.000000165	3.30E-08	6.6E-09	0.000000165
Europium-152	4.30E-10	2.15E-10	8.6E-10	1.60E-09	8E-10	3.2E-09	8E-10	4E-10	1.6E-09	6.50E-09	1.3E-09	3.25E-08	2.20E-07	0.000000044	0.00000011	2.20E-07	0.000000044	0.00000011
Europium-154	4.70E-10	2.35E-10	9.4E-10	1.80E-09	9E-10	3.6E-09	9E-10	4.5E-10	1.8E-09	9.60E-09	1.92E-09	0.000000048	2.90E-07	0.000000058	0.00000145	2.90E-07	0.000000058	0.00000145
Iodine-129	9.20E-13	4.6E-13	1.84E-12	1.20E-11	6E-12	2.4E-11	6E-12	3E-12	1.2E-11	2.80E-07	0.000000056	0.00000014	1.70E-07	0.000000034	0.00000085	1.70E-07	0.000000034	0.00000085
Neptunium-237	5.50E-09	2.70E-09	0.000000011	3.10E-11	1.60E-11	6.2E-11	1.60E-11	7.85E-12	3.10E-11	2.40E-06	0.000000048	0.00000012	2.90E-04	0.00000058	0.00145	2.90E-04	0.00000058	0.00145
Strontium-90	5.00E-14	2.5E-14	1E-13	1.90E-13	9.5E-14	3.8E-13	9.5E-14	4.75E-14	1.9E-13	1.40E-07	0.000000028	0.00000007	2.40E-07	0.000000048	0.00000012	2.40E-07	0.000000048	0.00000012
Technetium-99	8.90E-15	4.45E-15	1.78E-14	4.20E-14	2.1E-14	8.4E-14	2.1E-14	1.05E-14	4.2E-14	1.50E-09	3E-10	7.5E-09	1.00E-09	2E-10	0.000000005	1.00E-09	2E-10	0.000000005
Tritium (H-3)	0	0	0	0	0	0	0	0	0	6.40E-11	1.28E-11	3.2E-10	6.40E-11	1.28E-11	3.2E-10	6.40E-11	1.28E-11	3.2E-10
Uranium-234	2.80E-14	1.4E-14	5.6E-14	2.30E-13	1.15E-13	4.6E-13	1.15E-13	5.75E-14	2.3E-13	2.80E-07	0.000000056	0.00000014	2.70E-06	0.000000054	0.00000135	2.70E-06	0.000000054	0.00000135
Uranium-238	7.40E-15	3.7E-15	1.48E-14	1.10E-13	5.5E-14	2.2E-13	5.5E-14	2.75E-14	1.1E-13	2.50E-07	0.000000005	0.000000125	2.40E-06	0.000000048	0.00000012	2.40E-06	0.000000048	0.00000012
References:	External dose factors from Eckerman and Ryan 1993																	
	Internal dose factors from Eckerman et al. 1988																	
Notes:	External dose factors are fairly well defined.																	
	Following example of Snyder et al. 1994, external varied two times over tabulated values, uniform distribution Soil and sediment to account for surface roughness, shielding, and potentially closer exposures Swimming/boating to account for non-uniformities and potential lesser degrees of immersion Boating equals half of swimming.																	
	Internal dose factors are more individual specific. Following the example of Snyder et al. 1994, the Geometric Standard Deviation of 2.0 is assigned to all internal dose factors (for example, Dunning and Schwarz 1981, Snyder et al. 1994). This gives a range of a factor of 25 from 1st to 99th percentiles.

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

5.2.2.3 Chemical Exposure Risk Factors

The calculations outlined in Sections 5.2.1.1 and 5.2.1.3 require a large number of input parameters for every chemical. Distributions of parameter values for the cancer potency factor, reference dose, skin absorption factor, and skin permeability coefficient are presented in Table 5.16 for the non-radioactive chemicals of interest in this scoping assessment. The information in Table 5.16 is derived from several sources. The preferred source is EPA's Integrated Risk Information System (IRIS) (EPA 1996, 1992b). IRIS is a database available through EPA's Environmental Criteria Assessment Office in Cincinnati, Ohio, and from various commercial electronic sources. The preferred secondary source is EPA's Health Effects Assessment Summary Tables (HEAST) (EPA 1995). HEAST, prepared by EPA's Office of Solid Waste and Emergency Response, is a compilation of toxicity values published in health effects documents issued by EPA. It is intended for use in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) programs.

Periodically, EPA announces changes in toxicity factors for individual chemicals as new information becomes available. In some instances, reference doses or other factors listed in IRIS or HEAST for some chemicals are withdrawn. For some of the chemicals in Table 5.16, older references were used to approximate the potential health risk because specific values are no longer included in IRIS or HEAST.

The range of uncertainty about the various health effect indicators or transfer factors can be quite large because the estimated values are often based on studies in animals or studies based on conditions quite unlike those typically encountered in routine human exposures. Many of the values include a safety factor used to account for uncertainty inherent in differences in response between humans and animals, variations in susceptibility among individuals in a human population, and use of data from a limited time to estimate chronic effects. In establishing the outer limits of the uncertainty bounds for this analysis, these safety factors have been considered.

For benzene, the ingestion cancer potency factor was taken from IRIS (EPA 1996) and the inhalation cancer potency factor, which has the same numerical value, was taken from HEAST (EPA 1995). The cancer potency factor is described in IRIS as being the geometric mean of a series of well-defined measurements spanning about one order of magnitude. Therefore, the uncertainty assigned to these values is set to span a factor of 10 with a lognormal distribution.

The inhalation cancer potency factor for chromium is from HEAST. Neither HEAST nor IRIS provides an ingestion factor, so the ingestion factor is assumed to be the same as the inhalation factor. The studies that support this value have potentials for both over- and under-estimation, therefore, the uncertainty band could be a factor of 10 higher or lower on a lognormal scale.

Table 5.16. Chemical Exposure Risk Factors

Carcinogenic Chemical						Carcinogenic Chemical					
Inhalation Cancer Potency Factor						Ingestion Cancer Potency Factor					
Risk/(mg/kg per day)						Risk/(mg/kg per day)					
	Deterministic	Minimum	Maximum	Distribution	Reference		Deterministic	Minimum	Maximum	Distribution	Reference
Benzene	0.029	0.009	0.09	lognormal	Heast 95		0.029	0.009	0.09	lognormal	IRIS 96
Chromium	42	4	400	lognormal	IRIS 96		42	4	400	lognormal	= Inhalation
Toxic Chemical						Toxic Chemical					
Inhalation Reference Dose						Ingestion Reference Dose					
(mg/kg per day)						(mg/kg per day)					
	Deterministic	Minimum	Maximum	Distribution	Reference		Deterministic	Minimum	Maximum	Distribution	Reference
Ammonia	0.029	0.01	0.87	triangular	EPA 1996		0.97	0.3	3	triangular	EPA 1995
Chromium	0.005	1.00E-03	0.015	triangular	= ingestion		0.005	0.002	2.5	triangular	EPA 1996
Copper	0.01	0.002	0.05	triangular	EPA 1984a		0.003	0.0006	0.015	triangular	EPA 1992b
Cyanide	0.02	0.004	2	triangular	= ingestion		0.02	0.007	2	triangular	EPA 1996
Diesel	0.36	0.06	1.8	triangular	= ingestion		0.36	0.07	1.8	triangular	NIOSH 1996
Kerosene	0.7	0.14	3.5	triangular	ACGH 1987		0.7	0.14	3.5	triangular	= inhalation
Lead	0.00043	0.00008	0.002	triangular	EPA 1984b		0.0014	0.0003	0.007	triangular	EPA 1986
Mercury	8.60E-05	2.80E-05	2.60E-03	triangular	EPA 1996		3.00E-04	1.00E-07	3.00E-01	triangular	EPA 1995
Nickel	0.02	0.007	0.06	triangular	= ingestion		0.02	7.00E-03	6	triangular	EPA 1996
Nitrate	1.6	0.3	8	triangular	= ingestion		1.6	0.5	4.8	triangular	EPA 1996
Nitrite	0.1	0.02	0.5	triangular	= ingestion		0.1	0.03	0.3	triangular	EPA 1996
Phosphate	0.007	0.0014	0.035	triangular	NIOSH 1996		0.46	0.09	2.3	triangular	NIOSH 1996
Sulfate	71	14	350	triangular	= ingestion		71	14	350	triangular	40 CFR 143.3
Xylene	2	0.4	10	triangular	= ingestion		2	0.7	200	triangular	EPA 1996
Zinc	0.3	0.06	1.5	triangular	= ingestion		0.3	0.1	0.9	triangular	EPA 1996
NOTE: Distribution maxima based on safety factor where available											
ABS						Kp					
Skin Absorption Factor						Skin Permeability Coefficient					
(unitless)						(cm/hr)					
	Deterministic	Minimum	Maximum	Distribution	Reference		Deterministic	Minimum	Maximum	Distribution	Reference
Ammonia	0.01	0.03	0.3	loguniform	EPA 1992a		0.001	1.00E-04	1.00E-02	loguniform	default
Benzene	0.01	0.03	0.3	loguniform	McKone 1990		0.11	0.05	0.2	loguniform	EPA 1992a
Chromium	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	0.0003	0.003	loguniform	EPA 1992a
Copper	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	1.00E-04	1.00E-02	loguniform	default
Cyanide	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	1.00E-04	1.00E-02	loguniform	default
Diesel	0.01	3.00E-03	3.00E-02	loguniform	benzene analogy		0.1	3.00E-02	3.00E-01	loguniform	benzene analogy
Kerosene	0.01	3.00E-03	3.00E-02	loguniform	benzene analogy		0.1	3.00E-02	3.00E-01	loguniform	benzene analogy
Lead	0.001	1.00E-04	1.00E-02	loguniform	default		4.00E-06	2.00E-06	8.00E-06	loguniform	EPA 1992a
Mercury	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	5.00E-04	2.00E-03	loguniform	EPA 1992a
Nickel	0.001	1.00E-04	1.00E-02	loguniform	default		3.00E-05	1.00E-05	1.00E-04	loguniform	EPA 1992a
Nitrate	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	1.00E-04	1.00E-02	loguniform	default
Nitrite	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	1.00E-04	1.00E-02	loguniform	default
Phosphate	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	1.00E-04	1.00E-02	loguniform	default
Sulfate	0.001	1.00E-04	1.00E-02	loguniform	default		0.001	1.00E-04	1.00E-02	loguniform	default
Xylene	0.05	1.70E-02	1.50E-01	loguniform	EPA 1992a		0.08	4.00E-02	1.60E-01	loguniform	EPA 1992a
Zinc	0.001	1.00E-04	1.00E-02	loguniform	default		6.00E-04	3.00E-04	1.20E-03	loguniform	EPA 1992a

The inhalation and ingestion reference doses for ammonia are the same from HEAST or IRIS. IRIS states that reference doses are generally certain to within a factor of about 3. The ammonia inhalation reference dose also includes a safety factor of 30. Therefore, the ingestion range is defined by a factor of 3 up or down, and the inhalation range is defined by a factor of 3 up and a factor of 30 down in triangular distributions.

IRIS provides an ingestion reference dose for chromium (assumed here to be soluble chromium VI). The inhalation value is assumed to be equal. The ingestion reference dose for chromium includes a safety factor of 500, which has been used to establish the upper bound for the ingestion uncertainty range.

The human toxicity of copper is equivocal. Recent versions of IRIS and HEAST have not provided values of reference dose. However, in 1992 IRIS did provide a value for ingestion, and EPA (1984a) has older documents that discuss the inhalation toxicity. Because these older references are under reevaluation, a wider range of a factor of 5 was used to set the uncertainty bounds for copper toxicity.

A reference dose value for oral uptake of cyanide is provided in IRIS. Because various forms of cyanide readily disassociate in body fluid to free cyanide, the ingestion value is used here for inhalation as well. A safety factor of 100 is included in the IRIS reference dose, which was accounted for in setting the upper value of the uncertainty range.

Reference doses are not provided by EPA for diesel fuel. An effective reference dose was estimated from the acute toxicity data available in the Registry of Toxic Effects of Chemical Substances (RTECS) published by the National Institute for Occupational Safety and Health (NIOSH 1996). An effective reference dose was evaluated using the equation (Streng and Peterson 1989)

$$RfD = LD_{50} \times 4 \times 10^{-5} \quad (5.21)$$

where

RfD = reference dose

LD_{50} = acute lethal dose to 50 percent of animals (mg/kg)

4×10^{-5} = empirical conversion factor (mg/kg/day per mg/kg)

based on a study by Layton et al. (1987) in which data for chemicals having known reference doses and LD_{50} s were compared. The conversion factor represents the median value of the reported ratios of reference dose to LD_{50} values. Because this approach was used, a range of a factor of 25 from low to high was used to bound the uncertainty.

A difficulty similar to that for diesel fuel was encountered for kerosene. A slightly different approach was used, based on the Threshold Limit Value (TLV) defined by the American Conference of Government Industrial Hygienists (ACGIH 1987) to estimate an effective reference dose for inhalation. The TLV values represent air concentrations that are not to be exceeded in the work environment. They represent concentrations that are assumed to be protective of workers exposed 8 hours/day, 5 days/week for a 50-year career. By adjusting for differences in exposure time, breathing rate, and a safety factor, the TLVs can be converted to a value representative of continuous exposure by a member of the public. This approach is

preferable to that using the LD₅₀ values because it is based on a reference directly relating to human exposures. This inhalation value was then also used for ingestion. Because of this approach, a range of a factor of 25 from low to high was used to bound the uncertainty.

Values of the reference dose for lead were taken from EPA documents (EPA 1984b, EPA 1986). Because these are older references, a range of a factor of 25 from low to high was used to bound the uncertainty.

The reference dose for inhalation of mercury is from IRIS, the reference dose for ingestion of mercury is from HEAST. The IRIS reference dose for inhalation contains a safety factor of 30. The HEAST reference dose for ingestion contains a safety factor of 1000. These were used in defining the overall ranges of uncertainties.

For nickel, IRIS presents an ingestion reference dose associated with a safety factor of 300. The reference dose for inhalation is assumed to be the same as that for ingestion, but because of the pathway extrapolation, the safety factor was not used in defining the uncertainty range.

For nitrate and nitrite ions, reference doses are presented in IRIS for ingestion. In keeping with the general guidance that IRIS reference doses are accurate to within about a factor of 3, this was used to set the uncertainty bounds on the ingestion ranges. The same values were assumed for the inhalation route, but a factor of 5 was used to expand the range of uncertainty because of the pathway extrapolation.

Reference doses are not available for phosphate ion. The same technique based on RTECS LD₅₀ data as used for diesel fuel was used for phosphate.

The estimate for reference dose for sulfate inhalation is based on TLV using the same technique as described for diesel fuel. For ingestion, rather than assume the same value as derived for inhalation, an estimate was made using EPA's Secondary Drinking Water Standard (40 CFR 143). The drinking water standard for sulfates is 250 milligrams/liter. Because the secondary standards are based on aesthetics rather than human health risk, the value thus derived was increased by a factor of 10. A factor of 5 was included in the uncertainty range for this extrapolated set of estimates.

The IRIS database provides an ingestion reference dose for xylenes, which includes a safety factor of 100. The ingestion value was assumed to also apply to inhalation. An uncertainty range of 5 was used on the inhalation value to determine the uncertainty bounds.

Zinc is listed in the IRIS database for ingestion with a safety factor of 3. The ingestion value was assumed to also apply to inhalation. An uncertainty range of 5 was used on the inhalation value to determine the uncertainty bounds.

Values for the skin absorption coefficient ABS are difficult to obtain because very few measurements have been made. A metal, cadmium, has been evaluated (Wester et al. 1991), and the organics, benzene

(Skowronski et al. 1988) and xylene (Skowronski et al. 1990), in experiments that are not completely consistent with exposure conditions in the environment. For cadmium applied at 20 and 40 mg/cm² to the skin of the abdomen for 16 hours, between 0.08 and 0.2 percent of the applied dose was absorbed. The average of twelve samples was 0.1 percent. EPA recommends an upper range of 0.1 to 1.0 percent (EPA 1992a).

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

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

5.2.2.4. Miscellaneous Parameters

Additional parameters unrelated to the individual exposure scenarios used in the human health risk calculations are presented in Table 5.17. The risk from exposure to radiation and radioactive materials are estimated from the radiation doses, using a range of the dose-to-risk conversion factor. Lifetime averaging time and body weights are standard values.

Organic chemicals are assumed to be volatile. For simplicity, the chemicals ammonia, benzene, diesel, kerosene, and xylene are assumed to be related to the volatilization of water as described in the individual exposure scenarios in Section 5.1. All others are assumed to be non-volatile.

5.2.3 Overall Risk

Each of the contaminants identified in Section 2.0 has been evaluated for each of the scenarios identified in Section 5.1. While the resulting number of calculations provides a detailed database from which to draw inferences, it also provides a voluminous amount of information. Therefore, the majority of the resulting information can be found in Appendix I-E. A summary of the nature of the results and an interpretation are provided in this section.

Table 5.17. Miscellaneous Parameters

Dose-to-Risk Conversion, risk/rem				
8.00E-04	Deterministic			
2.00E-04	Minimum			
1.00E-03	Maximum			
	Uniform distribution			
Body weights (kg)				
	Adult	70		
	Child	16		
Averaging Time				
	Days	25550 (70 Years)		
Volatilization Factors (L/m ³)				
	Analyte	Deterministic	Range	Distribution
	Ammonia	0.1	0.001-0.1	loguniform
	Benzene	0.1	0.001-0.1	loguniform
	Diesel	0.1	0.001-0.1	loguniform
	Kerosene	0.1	0.001-0.1	loguniform
	Xylene	0.1	0.001-0.1	loguniform
	All others	0		fixed

5.2.3.1 Risk by Scenario

The equations of Section 5.2.1 provide evaluations of potential human health risk in terms of risk from carcinogenic chemicals, toxic chemicals, and radionuclides. Each of these categories is the linear sum of the risk estimates for all the contaminants in that category. This sum varies for each scenario in each river segment. The intent of the use of multiple scenarios was to provide insight to the range of risk associated with a wide range of potential activities. The range of human health risk associated with each scenario for carcinogenic chemicals is shown in Figure 5.1. The range of risk associated with toxic chemicals is shown in Figure 5.2, and the range associated with radionuclides is shown in Figure 5.3. The figures also show the median estimated risk for each scenario for this segment. The figures show each scenario applied at the location of the N Reactor (Segment 6) because it is one of the areas with higher Hanford-related contamination.

In this section, we discuss the results of the screening assessment of human health. We present the highlights of the results for each scenario in Figures 5.1-5.4 and the full results in Figures E.1-E.9 in Appendix I-E. To show the risk for each scenario, we totaled the risk results for each contaminant according to the type of contaminant: carcinogenic chemical, toxic chemical, or radionuclide. Because the three types of contaminants result in different kinds of risk, the estimates for each type are reported differently:

- ◆ Carcinogenic chemical results reflect the probability of the incidence of cancer.
- ◆ Toxic chemical results reflect the ratio between the dose determined by EPA to be safe (the reference dose) and the dose that has been estimated.
- ◆ Radionuclide results reflect the risk of cancer fatality.

Figure 5.1. Range of Estimated Risk from Carcinogenic Chemicals (Segment 6 - N Reactor)

Figure 5.2. Range of Estimated Risk from Toxic Chemicals (Segment 6 - N Reactor)

Figure 5.3. Range of Estimated Risk from Radionuclides (Segment 6 - N Reactor)

In the calculations, the uncertainties of the measurements, the health parameters, and the individual lifestyles were addressed, and the results are presented as a range of values. The range (from the lower bound for the scenarios of minimal exposure to the upper bound for the scenarios of extensive exposure) can be seen to cover from 5 to 7 orders of magnitude (factors of 100,000 to 10,000,000) for the chemicals and radionuclides. As will be discussed in the following sections, the absolute risk illustrated in Figures 5.1-5.3 is somewhat misleading, but the wide range of different risk levels for the scenarios is very illuminating.

Generally speaking, the scenarios for the Fish Hatchery Worker, Industrial Worker, and Ranger have the lowest exposures and, therefore, are lowest in terms of health risk. As defined in Section 5.1, none of the people involved in these scenarios consume foods grown in the Columbia River riparian zone or drink seep water. Therefore, the exposures are mostly incidental external exposures and inhalation of resuspended materials, although the Fish Hatchery and Industrial Workers also consume a moderate amount of Columbia River water. The risk to workers from these pathways is quite low in comparison to those projected for people potentially exposed in other ways. An initial result, then, is that consumption of Columbia River water is not the major pathway of exposure compared to other pathways.

At the other extreme, people postulated to live along the Columbia River, to eat substantial quantities of foods grown in the riparian zone, to eat fish and wildlife from the river, and to drink seep water have much larger potential exposures and, thus, estimated health risk. This category encompasses nearly all of the remainder of the scenarios described in Section 5.1. From a risk-assessment standpoint, very few differences appear between any of the Native American scenarios and recreational/residential scenarios: all postulate individuals who spend the bulk of their time in the vicinity and consume riparian-zone foods and drink untreated water. The minor differences appear in quantities of each type of food assumed to be eaten.

In Figures 5.1-5-3, we present the range of results for each scenario. For example, our estimated risk from carcinogenic chemicals for fish hatchery workers shows a possible range of less than $1.00\text{E-}05$ (0.00001) to more than $1.00\text{E-}03$ (0.001) with the median just above $1.00\text{E-}04$ (0.0001). The low ends of the range are the results for those fish hatchery workers who have less exposure. The upper ends of the range are the results for those fish hatchery workers who have more exposure. The median is the value for which half the results are greater and half are less.

The Casual Recreational Visitor Scenario appears to fall in between these two sets. However, it actually has much more in common with the upper-end scenarios than with the worker scenarios. The main pathways of exposure for the Casual Recreational Visitor are consumption of food and seep water. The key difference between the Casual Recreational Visitor Scenario and the Native American or recreational/residential scenarios is in the number of exposure days per year. The Casual Recreational Visitor Scenario assumes that the individual visits the Hanford Reach of the Columbia River only 7 days per year. If the Casual Recreational Visitor were to increase the frequency of visits, ultimately the exposures and risk would parallel those of the residential scenarios. To a limited extent, this argument also applies to the Avid Recreational Visitor and, to a lesser extent, Native American Upland Hunter scenarios. In the Avid Recreational Visitor Scenario, the individual visits less frequently but is assumed to consume foods associated with the Columbia River nearly to the extent a resident does.

Figures 5.1-5.3 show each scenario applied at the location of the N Reactor. While this is one of the river segments with higher Hanford-related contamination, it is not the highest for all contaminants. However, the statements made above regarding the scenarios are generally true. This is illustrated in Figure 5.4. Figure 5.4 shows the relationship of each scenario, normalized to the scenario of highest exposure, which is the Native American Subsistence Resident Scenario. In this figure, the ratio of the total carcinogenic, toxic, and radionuclide health risk at each segment for each scenario is shown relative to the estimated risk for the Native American Subsistence Resident Scenario. Thus, the Native American Subsistence Resident Scenario is always assigned a value of 1.0, and the other scenarios are plotted against it. In this figure, the Industrial Worker and Fish Hatchery Worker are indistinguishable (the Fish Hatchery Worker symbols cover up those of the Industrial Worker), and the Ranger is generally very close to these two. The remainder of the scenarios cluster together in a generally decreasing band, with the exception of the Casual Recreational Visitor Scenario, which lies in between the two groups. As mentioned above, the Casual Recreational Visitor Scenario follows the patterns of the higher-exposure scenarios but at only a fraction of the total exposure because of the assumed limited duration.

Because the differences between the upper exposure scenarios and the lower exposure scenarios are distinct and the differences between scenarios within either group are less distinct, the Ranger Scenario has been selected as representative of the lower risk group and the Native American Subsistence Resident

Figure 5.4. Comparison of Risk Results for All Scenarios

Scenario has been selected as representative of the higher group. These representative scenarios are used in the following detailed discussions of exposure pathways and contaminants.

5.2.3.2 Risk by River Segment

The calculations described in Section 5.2.1.3 provide total risk, that is, the sum of the potential carcinogenic chemical, toxic chemical, and radionuclide risk for each river segment. The risk is illustrated for Segment 6 for each scenario in Figures 5.1-5.3. The variability of total risk by segment of the Columbia River is illustrated in Figure 5.5 for the Ranger Scenario and in Figure 5.6 for the Native American Subsistence Resident Scenario.

The upper portion of Figure 5.5 shows the lifetime risk of cancer incidence from exposure to carcinogenic chemicals estimated for the Ranger Scenario in each of the 27 river segments. This particular calculation is dominated in all segments by the metal chromium in sediment, and the pathway is inadvertent ingestion of sediment. The deterministic calculations (performed as described in Section 5.2.2 with the highest measured contaminant concentrations in each segment and with reasonable maximum individual exposure parameters) can be seen to vary between an estimated lifetime risk of 10^{-4} to 10^{-3} . Overall, the deterministic values fall at about the 75th percentile of the stochastic range. For all segments, the estimated risk is within about a factor of 3 of the background risk estimated for Segment 1.

The center portion of Figure 5.5 shows the hazard index value calculated for the Ranger Scenario at all river segments. The hazard index implies contaminant concentrations of potential risk when the hazard index value is greater than 1.0. The maximum values of hazard index for the Ranger Scenario are 1 to 3 percent of the indicator value of 1.0 with little discernable difference between the upstream background in Segment 1 and any of the downstream segments. The risk reflected in this portion of the figure predominantly represents the presence of the metals (lead, copper, and chromium), which together make up over 90 percent of the total risk. The apparent dips in the curves at Segments 6 and 13 reflect the lack of measurements for lead at these locations.

The lower portion of Figure 5.5 illustrates the lifetime risk of death from cancer caused by radionuclides. The risk illustrated in this portion of the figure is largely from external irradiation. The somewhat jagged nature of the curve is the result of using two different approaches for this part of the calculation. The higher portions of the curve were calculated using radiation dose rates measured along the Columbia River shoreline with an approximate correction for background. The lower portions of the curve were calculated from the measured concentrations of radionuclides and dose conversion factors. In the calculations done with the measured dose rates, an attempt was made to correct for terrestrial and cosmic ray background by subtracting 0.2 mrem/day from the measured values. Because background has small local fluctuations, this is an imprecise approach, and because any measured dose rate in excess of 0.2 mrem/day was considered to be a result of Hanford contributions, some background values are probably reflected in the upper portions of the curve. The calculations based on the radionuclide concentration measurements in the environment are all lower than the background-corrected, measured dose rates by factors of greater than 10. It is probable that the bulk of the risk reported in this portion of the figure is attributable to natural sources. The peak at Segment 6, however, is due to the documented increase in dose rate caused by radiation from facilities in the 100-N Area. In this case, the use of the

Figure 5.5. Human Health Risk Estimate for the Ranger Scenario

Figure 5.6. Human Health Risk Estimate for the Native American Subsistence Resident Scenario

measured dose rates has indicated a known problem, but one which would not have been evident from the samples of water or sediment because the source is the facilities themselves. The radionuclide average upper risk estimates of about 10^{-4} shown in Figure 5.5 correspond to a lifetime dose of about 125 millirem (about 2 millirem per year above the natural background rate of about 100 millirem/year).

The upper portion of Figure 5.6 shows the lifetime risk of cancer incidence from exposure to carcinogenic chemicals estimated for the Native American Subsistence Resident Scenario in each of the 27 river segments. This particular calculation is dominated in all segments by the metal chromium, but this scenario exemplifies the complexity of the contamination at Hanford. The primary medium causing exposure in Segments 1, 2, 6, 7, 13, 18, 19, 20, 21, and 22 is surface water with the primary pathway being ingestion of fish. The primary medium in Segments 5, 8, 9, and 10 is seep water with the primary pathway being ingestion of the seep water itself. For the remaining segments, the primary medium is sediment, and the primary pathway is consumption of food grown in sediment. Generally, if the chromium has been measured in the surface water (meaning in the river itself), the risk estimates are highest. If the main measurements are of seep water, the risk estimates are intermediate, and if the measurements are only of sediment, the risk estimates are lower. This result indicates that the estimated risk is highly dependent on the data available and on how well the data actually characterize the environment.

The center portion of Figure 5.6 shows the hazard index value calculated for the Native American Subsistence Resident Scenario at all river segments. Recall that the definition of the hazard index implies contaminant concentrations of potential risk when the hazard index value is greater than 1.0. The deterministic and the median stochastic calculated hazard indices exceed the value of 1.0 at all segments. However, for only one-third of the 27 segments is the estimated median greater than that estimated for Segment 1 and for only 4 of the 27 segments for the deterministic calculation and never by more than a factor of two. The primary contributor to the high values of hazard index is copper. Over half the total hazard index is attributable to copper in nearly all segments. Other major contributors in Segment 1 are mercury (nearly 20 percent) and lead (over 15 percent). The primary medium is sediment with a large contribution also from surface water. As is discussed in subsequent sections, the high background of these metals makes discernment of a Hanford contribution to risk difficult to detect.

The lower portion of Figure 5.6 illustrates the lifetime risk of death from cancer caused by radionuclides. The median risk of about 10^{-3} results from estimated doses of about 20 millirem/year. The risk illustrated in this portion of the figure has a significant component from external irradiation, up to about half of the total in some segments. The external doses vary as described above for the Ranger Scenario. The second major contributor is ingestion of cesium-137 from surface water via fish. There are 8 segments with measurements of cesium-137 in surface water (see Table 3.9 in Section 3.0). The others are all surrogates. However, the measured concentrations are very similar in all measured segments. The concentrations in the river water are mostly attributable to global fallout. In certain segments, other sources stand out: strontium-90 in seeps and sediment in Segment 6, strontium-90 in surface water in Segment 7 (perhaps as a result of the releases in Segment 6), tritium (hydrogen-3) in seeps in Segments 4 and 17, and uranium in seeps in Segment 20.

Figures presenting the results of the other nine scenarios in the format of Figures 5.5 and 5.6 are presented Figures E.1-E.9 in the Results of the Calculations section of Appendix I-E.

The use of the environmentally measured values of the contaminants of interest results in a total potential risk, not one that is solely attributable to Hanford operations. In some cases, the background risk is greater than that estimated for the Hanford-related contaminants. This overshadowing of the Hanford contributions is evident in Figures 5.5 and 5.6 where, for example, the bulk of the hazard index is from metals such as copper and lead or a substantial fraction of the radionuclide risk is from cesium-137. Without careful evaluation, this background contribution to the results could be misunderstood as the Hanford Site contribution, and resources could be directed to mitigation of problems that do not exist. Therefore, efforts were undertaken to identify and compensate for contaminants that occur in the Hanford environs but that are not the result of Hanford past practices.

The background values cannot simply be subtracted from the measurements. The background concentration itself is distribution that must be compared with the distributions of the measurements. Therefore, sophisticated statistical techniques are required. These are described in Section 5.2.4.

5.2.3.3 Uncertainties in the Risk Calculations

Figures 5.5 and 5.6 show the human health risk calculated for the Ranger and Native American Subsistence Resident scenarios using the available monitoring data and the other parameters described in Section 5.2.2. The results are presented as both the deterministic estimate and a stochastic range. The input to the model were selected to cover a wide range of possibilities. The various ranges consider the uncertainty of the measured data, the degree to which the data adequately characterize the real situation, the range of potential exposures within each scenario as defined, the uncertainties of the processes modeled, and the uncertainties of the response of humans to those exposures. Each of these ranges contributes to the overall uncertainty of the calculated answers.

The deterministic calculations use the largest measured environmental concentrations of each contaminant in each segment and reasonable maximum individual parameters to describe the behavior of the individual within the scenario. They also use regular defined values of the exposure-to-risk parameters (for example, the dose conversion factors, risk factors, and reference doses). The deterministic result, then, generally represents an exposure and risk as high as would be expected under most circumstances. However, because of the unpredictability of human behavior, the lack of knowledge of the true situation of the contaminant distribution in the environment and the way that real people would respond to it, there is uncertainty in this deterministic answer.

The stochastic calculations are an attempt to quantify these combined uncertainties. As can be seen from Figures 5.5 and 5.6, there is some chance that the exposures and risk could actually be higher than the deterministic estimate. However, it is likely that actual exposures would be less because the deterministic input was designed to reflect a maximum but reasonable case. The median values of the stochastic results represent the central tendency of the risk, which is the value for which half the calculations are greater and half are less. In a sense, this represents a best estimate of what might happen if all of the parameter ranges are correct. Therefore, the median values are used extensively in the discussions in Sections 5.2.4, 5.2.5, and 5.2.7.

Also contributing to uncertainty is the fact that the available data are limited. For many of the contaminants of interest in many locations, measurements were not available for the time period of interest to provide a detailed characterization of the contaminant distributions in each of the river segments used in this screening assessment. For some segments, monitoring has focused on areas of known contamination. The resulting data may overestimate the actual levels of contaminants present within a segment. In other cases, monitoring may have missed hot spots of contamination in the environment. There is no way of estimating where and to what extent this may have happened, and, therefore, this represents an uncertainty that was not modeled in this report. The result of this uncertainty is that the conclusions of this report can highlight areas where the problems are known, but it cannot rule out the possibility of similar problems where no measurements are available.

In a similar fashion, the use of the available data to represent large areas may have tended to artificially homogenize the results. Establishing an estimated risk for a segment does not mean that the risk is uniform within the segment. Some areas may be higher, and some may be lower.

The transfer factors used to relate concentrations of contaminants in water and sediment to those predicted for plant and animal products are also uncertain. As discussed in Section 4.2, there are numerous unknowns in the behavior of chemicals in the Hanford environment. Of key interest is the bioavailability of several of the background metals. If these metals are less bioavailable than assumed in the analysis, the results could mischaracterize the levels of total risk.

Although the individual scenarios include an apparently wide range of parameters, these actually contribute less to the overall uncertainty than do the other uncertainties. Generally speaking, the ranges are narrower than those for the contaminant levels or the risk conversion factors. This is because the scenarios are fairly narrowly defined. The scenarios define a certain set of activities that represent specific lifestyles or habits, and taken together the suite of scenarios covers a wide range of possibilities, but each scenario itself is relatively fixed. In particular, the Native American scenarios defined for this report represent the input of only a few individuals and only include the most obvious pathways of exposure. While the authors expect these pathways to contribute the largest portion of the dose, the existence of other culturally specific pathways tends to increase the overall uncertainty.

As important in estimating actual risk as the levels of contamination are the risk-response functions. The reference doses and cancer potency factors are quite uncertain, and the way that various compounds may interact is even more so. This analysis has attempted to consider the development of the risk factors, but since they are largely based on non-human experiments, the conversion from laboratory results to actual human risk introduces a large potential for error. The risk factors used range in uncertainty from factors of 10 to over factors of 1000.

All of these factors, taken together, explain the wide ranges of the results seen in Figures 5.5 and 5.6 and their companion Figures E.1-E.9 in Appendix I-E.

5.2.4 Evaluation of Background Levels of Contaminants

Although an attempt was made in the scoping calculations of Section 2.0 to account for naturally occurring or globally enhanced levels of contaminants in the environment, even after the contaminants of interest were selected, the Hanford-related portion of the measured concentrations needed to be separated if possible from background levels of the contaminants. For many of the metals, in particular, the abundance in the earth's crust is well within the range of the measurements used in the screening assessment. That means an uncorrected measurement could easily represent the background level rather than a level resulting from Hanford Site operations.

In the screening assessment, we estimated risk from contaminants originating at the Hanford Site. Of the contaminants we studied, some originate from other sources as well as the Hanford Site. Such sources might be those occurring naturally in the environment, those resulting from global fallout, or those from an upstream source. We call the concentrations from such sources "background levels." Because Segment 1 of the Columbia River is upstream from the Hanford Site, we assume the contaminants found in that segment have not originated from the Hanford Site and, therefore, reflect the background levels. In this section, we compare the concentrations of the contaminants measured in Segment 1 against the concentrations of the contaminants measured in the other segments at and downstream from the Hanford Site to indicate what concentrations were contributed by the site. Figures 5.7-5.34 depict these comparisons for each contaminant for the two extreme scenarios: the Ranger Scenario with less risk and the Native American Subsistence Resident Scenario with more risk. Figures 5.36-5.37 and E.10-E.18 denote for each scenario which contaminants have concentrations above background levels, above risk thresholds of 10^{-6} and 10^{-4} , above a hazard index of 0.01 and 1.0.

5.2.4.1 Point-by-Point Comparisons

One way to determine whether the estimated risk presented by a contaminant at a particular segment is an increase over the background level is to compare the risk associated with that contaminant in the particular segment to the risk in a segment unaffected by Hanford Site operations. This can be done with either the deterministic results or the stochastic median results. The deterministic comparison indicates whether the estimated risk at any point is greater than the maximum estimated for the unaffected segment. The stochastic comparison indicates whether the best estimate of the risk in the downstream segment is greater than that in the unaffected segment. Segment 1, the portion of the river upstream of the Hanford Site between Priest Rapids Dam and the Vernita Bridge, can be considered to be relatively unimpacted by Hanford operations.

Although Segment 1 was not originally selected to be free of Hanford-related contamination (see Section 3.2.1), the bulk of Segment 1 is upstream of Hanford and is also generally upwind of Hanford atmospheric emissions. A small portion of Segment 1 is within the Hanford Site, but Segment 1 is upstream of all measured seeps. Two of the three groundwater wells used to characterize Segment 1 may be influenced by a plume of tritium emanating from the 100 B/C Areas. However, of the other contaminants evaluated in the screening assessment, thirteen were undetected in Segment 1 groundwater (ammonia, benzene, cesium-137, cobalt-60, cyanide, europium-152, europium-154, mercury, neptunium-237, nitrite, phosphate, strontium-90, and xylenes). Most of the remaining contaminants are reasonably expected in background samples, so it does not appear that Segment 1 is unsuitable for this type of comparison.

Therefore, an initial comparison of the upstream (Segment 1) and downstream (Segments 2-27) risk estimates was made using the deterministic and stochastic estimates from the various scenarios for each contaminant. The results for each contaminant are presented in Figures 5.7-5.34 as ratios with the one upstream segment (Segment 1). For perspective, the highest estimated values of human health risk in terms of risk from carcinogenic chemicals, hazard index for toxic chemicals, or risk from radioactive carcinogens are provided in Table 5.18. The segment of greatest risk for each contaminant, and the primary contaminated medium, are also identified.

Table 5.18. Maximum Human Health Risk Derived by Contaminant (stochastic median values)

Contaminant	Type ^(a)	Ranger Scenario			Native American Subsistence Scenario		
		Value	Segment	Medium	Value	Segment	Medium
Ammonia	HI	6.6E-6	20	SW	3.6E-3	19	SP
Benzene	CC	1.5E-9	1	SW	2.6E-5	4	SP
Carbon-14	RC	— ^(b)	—	—	2.9E-5	13	SP
Cesium-137	RC	9.6E-8	10	SD	3.1E-5	13	SW
Chromium	CC	2.6E-4	2	SD	2.7E-1	2	SW
Chromium	HI	8.9E-6	2	SD	3.3E-2	4	SW
Cobalt-60	HI	9.0E-9	6	SW	3.0E-6	6	SD
Copper	HI	9.6E-4	27	SD	6.8	27	SW
Cyanide	HI	—	—	—	5.5E-2	20	SP
Europium-152	RC	4.4E-9	12	SD	6.3E-5	13	SP
Europium-154	RC	3.3E-8	18	SW	1.5E-5	21	SP
Iodine-129	RC	6.9E-15	22	SW	2.2E-6	19	SP
Lead	HI	2.0E-3	4	SD	1.2	17	SP
Mercury	HI	3.2E-7	19	SD	8.3E-3	16	SW
Neptunium-237	RC	5.2E-7	9	SD	8.3E-5	9	SD
Nickel	HI	2.0E-6	19	SD	6.8E-3	17	SP
Nitrates	HI	2.2E-6	2	SW	2.4E-1	20	SP
Nitrites	HI	6.3E-7	21	SW	1.1E-2	19	SP
Phosphorus	HI	2.7E-6	18	SW	6.9E-1	21	SW
Strontium-90	RC	5.4E-8	6	SD	7.7E-4	6	SD
Sulfates	HI	1.0E-6	27	SW	1.2E-2	7	SP
Technetium-99	RC	6.3E-11	8	SD	3.1E-6	10	SP
Tritium (H-3)	RC	—	—	—	2.1E-4	17	SP
Uranium-234	RC	6.5E-8	20	SD	9.9E-4	20	SP
Uranium-238	RC	7.7E-8	20	SD	9.2E-4	20	SP
Xylenes	HI	2.7E-10	14	SD	1.8E-4	13	SP
Zinc	HI	1.1E-4	21	SD	3.7E-1	12	SP

(a) HI = hazard index of toxic chemicals; CC = lifetime risk of carcinogenic chemicals; RC = lifetime risk of radionuclides.
(b) A dash (—) indicates no exposure to this contaminant via this scenario.

Figure 5.7. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Ammonia

Ammonia. The ratios of the risk estimated for ammonia using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.7. The major differences in these scenarios are apparent in the two parts of this figure. The results for the Ranger Scenario are controlled by measurements in Columbia River water. As a result, the lack of detection of ammonia in most Hanford Site segments results in a low to zero estimated risk. Ammonia, however, is detected at downstream segments, but the amounts are not more than 2.5 times that detected upstream. The results for the Native American Subsistence Resident Scenario are largely controlled by the contribution of ammonia through seep water (frequently substituted by groundwater). The large risk ratios seen in Segments 2, 6, 8, 13, 18, 19, and 20 result from postulated exposures via seep water. These indicate definite points of Hanford Site contribution to the Columbia River via groundwater. The minor increases in Segments 22-27 are, as for the Ranger Scenario, the result of surface water detections. The highest risk from ammonia via the Ranger Scenario is from surface water in Segment 20 with a hazard index of 6.6×10^{-6} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 20 with a hazard index of 3.6×10^{-3} .

Figure 5.8. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Benzene

Benzene. The ratios of the risk estimated for benzene using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.8. Benzene is assumed to be a tracer/analog (as is xylene, discussed below) for more complex hydrocarbon mixtures such as diesel fuel or other petroleum products. The key differences in the exposure scenario assumptions are also apparent in the two parts of this figure. The results for the Ranger Scenario are controlled by surface water measurements. For surface water, data for a segment are used if available, and if not, data from an upstream segment are substituted. This is seen in the first five segments for the Ranger Scenario where a measurement made in Segment 1 is repeated until a new measurement (which happened to be below detection) is applied at Segment 6. No downstream surface water measurements exceed the one made in Segment 1. The Native American Subsistence Resident Scenario, on the other hand, has components controlled by ingestion of seep water. River Segments 5 and 13 have higher inputs via seep water (substituted with groundwater). These suggest Hanford Site contributions from the groundwater to the Columbia River. The highest risk from benzene via the Ranger Scenario is from surface water in Segment 1 with a lifetime risk of 1.5×10^{-9} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 13 with a risk of 2.6×10^{-5} .

Figure 5.9. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Carbon-14

Carbon-14. The ratios of the risk estimated for carbon-14 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.9. Carbon-14 is not detected in surface water, and so there is no contribution to risk in the Ranger Scenario from carbon-14. The Native American Subsistence Resident Scenario is uniformly controlled by ingestion of carbon-14 derived from seep water. Seep water is surrogated with groundwater in almost all segments along the Hanford Site. A single particularly high value in Segment 4 is evident in the deterministic data. This point also influences the stochastic result in Segment 4. A lesser input is also evident in Segment 6. There is no risk from carbon-14 via the Ranger Scenario because the decay energy of carbon-14 is so low that external exposure is immaterial. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 4 with a lifetime risk of 2.9×10^{-5} .

Figure 5.10. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Cesium-137

Cesium-137. The ratios of the risk estimated for cesium-137 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.10. Cesium-137 is present in the world environment from global fallout, making its Hanford-related detection difficult. The deterministic Ranger Scenario implies a somewhat higher than normal concentration in sediment in Segment 10. The Native American Subsistence Resident Scenario peak concentration (deterministic) calculations do not indicate any enhancement downstream, but the stochastic calculations do because they compare the median upstream value, rather than the peak, to those estimated for downstream locations. The results for Segments 4-20 are controlled by surface water concentrations, but most of these are surrogates taken primarily from Segment 8. Cesium-137 in surface water was not detected in Segment 17, resulting in the dip in the figure. The highest risk from cesium-137 via the Ranger Scenario is from sediment in Segment 10 with a lifetime risk of 9.6×10^{-8} . The highest risk via the Native American Subsistence Resident Scenario is from surface water in Segment 13 with a risk of 3.1×10^{-5} .

Figure 5.11. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Chromium Treated as a Carcinogenic Chemical

Figure 5.12. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Chromium Treated as a Toxic Chemical

Chromium. The ratios of the risk estimated for chromium, as both a carcinogenic and toxic chemical, using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figures 5.11 and 5.12. The ratios in these two figures can be seen to be essentially identical, as would be expected since both sets of calculations use the same monitoring data. Generally speaking, the results indicate fluctuations around the background value. The highest values indicated by the Ranger Scenario are caused by sediment at Segments 2, 14, and 19. The highest indicated by the Native American Subsistence Resident Scenario is at Segment 2, although here it is in surface water. The highest risk from chromium via the Ranger Scenario is from sediment in Segment 2 with a lifetime risk of 2.6×10^{-4} and a hazard index of 8.9×10^{-6} . The highest risk via the Native American Subsistence Resident Scenario is from surface water in Segments 2 and 4 with a lifetime risk of 0.27 and a hazard index of 3.3×10^{-2} . Chromium exemplifies the difficulty of determining the Hanford Site contribution above background. Chromium is known to enter the Columbia River via groundwater at several Hanford Site locations and yet the results do not show dramatic increases in human risk at these known locations. The condensing of data from several locations to represent an entire river segment does result in some dilution of the contaminant level from selected hot spots. The results do represent some reality of potential human exposures since people would not be expected to continually remain at one point. Because of this difficulty, a more detailed statistical technique for evaluating whether contaminants are present in elevated concentrations was also developed. It is presented in the subsequent section.

Figure 5.13. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Cobalt-60

Cobalt-60. The ratios of the risk estimated for cobalt-60 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.13. Cobalt-60 has an obvious Hanford Site origin and is present in elevated quantities throughout the Hanford Reach. In the Ranger Scenario, the primary exposure media is surface water. In the Native American Subsistence Resident Scenario, the dominant medium varies between surface water, sediment, and seep water in various segments. The noticeable drop in the ratio in the downstream Segments 21-27 is the result of a single surface water measurement in Segment 21 being used as a surrogate in subsequent downstream segments. The highest risk from cobalt-60 via the Ranger Scenario is from surface water in Segment 6 with a lifetime risk of 9.0×10^{-9} . The highest risk via the Native American Subsistence Resident Scenario is from sediment in Segment 6 with a risk of 3.0×10^{-6} .

Figure 5.14. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Copper

Copper. The ratios of the risk estimated for copper using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.14. The controlling media vary with location between sediment (for example, Segment 14) and surface water (for example, Segments 23-27). Generally, the variations appear to be minor fluctuations around the background concentration. An apparent increase in copper concentration in surface water in Segments 23-27 may be related to the influx of Yakima River water or may result from accumulation of fine grained sediment in the slower moving water behind McNary Dam. Concentrations in surface water throughout the Hanford Reach are much lower than below the influx of the Yakima River. The highest risk from copper via the Ranger Scenario is from surface water in Segment 27 with a hazard index of 9.6×10^{-4} . The highest risk via the Native American Subsistence Resident scenario is from surface water in Segment 27 with a hazard index of 6.8. Copper has the largest hazard index of any contaminant evaluated.

Figure 5.15. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Cyanide

Cyanide. The risk estimated for cyanide using the Ranger and Native American Subsistence Resident scenarios for each river segment is presented in Figure 5.15. Cyanide measurements for Segment 1 are all below detection limits, making it impossible to prepare downstream/upstream ratios. Therefore, the absolute value of the estimated hazard index is plotted in this figure. For the four segments for which data are available, all are controlled by seep water data derived from groundwater measurements. The absolute values of the hazard indexes are well below 1.0, and it appears that cyanide at the Hanford Site is not a contaminant of potential toxicity. There is no risk from cyanide via the Ranger Scenario because there are no postulated exposures to seep water in this scenario. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 20 with a hazard index of 5.5×10^{-2} .

Diesel Fuel. This potential contaminant was not detected in any of the media sampled during the time frame of the database. Therefore, it was not analyzed in the screening assessment.

Figure 5.16. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Europium-152

Europium-152. The risk estimated for europium-152 using the Ranger and Native American Subsistence Resident scenarios for each river segment is presented in Figure 5.16. Europium-152 measurements for Segment 1 are all below detection limits, making it impossible to prepare downstream/upstream ratios. Therefore, the absolute value of the estimated radionuclide risk is plotted in this figure. The peaks in the Ranger Scenario results are all controlled by europium-152 measured in sediment. The Native American Subsistence Resident Scenario results generally are well below a risk of 10^{-6} with the exception of a large spike in Segment 13. This spike is caused by a measurement of europium-152 in groundwater which has been used as a surrogate for seep water at this location. The highest risk from europium-152 via the Ranger Scenario is from sediment in Segment 12 with a lifetime risk of 4.4×10^{-9} . The highest risk via the Native American Subsistence Resident scenario is from seep water in Segment 13 with a risk of 6.3×10^{-5} .

Figure 5.17. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Europium-154

Europium-154. The ratios of the risk estimated for europium-154 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.17. Europium-154 is generally considered to be an activation product, and relatively little of it is present in global fallout. Distinctly elevated levels appear in the stochastic calculations for both the Ranger and Native American Subsistence Resident scenarios between Segments 8 and 18. The highest risk from europium-154 via the Ranger Scenario is from surface water in Segment 18, with a lifetime risk of 3.3×10^{-8} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 21 with a risk of 1.5×10^{-5} . Of note is that the surface water measurement for Segment 8 is used as a surrogate through Segment 16. Thus, actual measurements of elevated europium-154 in surface water currently exist only for Segments 8 and 17. The values for the Native American Subsistence Resident Scenario in Segments 20 and 21 result from use of groundwater as a surrogate for seep water in these locations.

Figure 5.18. Absolute and Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Iodine-129

Iodine-129. The ratios of the risk estimated for iodine-129 using the Ranger and Native American Subsistence scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.18. For the Ranger Scenario, the risk is directly dependent on the concentration measured in surface water. Only two such measurements are available, in Segments 1 and 21. The maxima in these two segments are very similar; the median measured value in Segment 1 is much less than that in Segment 21. Both measured concentration values are very small. There is essentially no risk from external exposure to iodine-129, and so the Ranger Scenario is not a good measure of risk from this radionuclide because it postulates only external and dermal exposures. The Native American Subsistence Resident Scenario indicates much higher concentrations of iodine-129 in the seep water of Segments 4, 5, 10, and 19 (each of these were surrogated with seep water data). These segments correspond to the locations of groundwater monitoring wells that are sampled for iodine-129 (Dirkes and Hanf 1996, p. 205). The highest risk from iodine-129 via the Ranger Scenario is from surface water in Segment 22 with a lifetime risk of 6.9×10^{-15} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 19 with a risk of 2.2×10^{-6} .

Kerosene. This potential contaminant was not detected in any of the media sampled during the time frame of the database. Therefore, it was not analysed in the screening assessment.

Figure 5.19. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Lead

Lead. The ratios of the risk estimated for lead using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.19. The deterministic results for neither the Ranger nor Native American Subsistence Resident scenarios indicate deviations much above background, but the stochastic calculations indicate that Segments 4, 12, and 17 may be elevated. In these and the other segments, the controlling medium is sediment. In all cases, the concentrations of lead in sediment are within about a factor of 2 of the upstream value. The highest risk from lead via the Ranger Scenario is in Segment 4 with a hazard index of 2.0×10^{-3} . The highest risk via the Native American Subsistence Resident Scenario is from sediment and seep water together in Segment 17 with a risk of 1.2. Lead has the second highest hazard index calculated.

Figure 5.20. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Mercury

Mercury. The ratios of the risk estimated for mercury using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.20. The Ranger Scenario results are driven by a combination of surface water and sediment measurements. The Native American Subsistence Resident Scenario results also are a mix of these two sources. For both, the surface water measurement in Segment 8 is a surrogate through Segment 16. There appears to be a minor increase in risk throughout the Hanford Reach caused by mercury. However, the source is indeterminate because the surface water value for mercury in Segment 1 is used to estimate its concentration in Segments 2-7, and the higher value from Segment 8 is used in Segments 9-16. Fluctuations in the overall risk in the intervening segments result from the presence or absence of measurements of mercury in sediment. Also, there is no measurement of mercury in sediment in Segment 1. The highest risk from mercury via the Ranger Scenario is from sediment in Segment 19 with a hazard index of 3.2×10^{-7} . The highest risk via the Native American Subsistence Resident scenario is from surface water in Segment 16 with a hazard index of 8.3×10^{-3} .

Figure 5.21. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Neptunium-237

Neptunium-237. The risk estimated for neptunium-237 using the Ranger and Native American Subsistence Resident scenarios for each river segment is presented in Figure 5.21. Neptunium-237 measurements are not available for Segment 1, making it impossible to prepare downstream/upstream ratios. The only positive measurements for neptunium-237 occur in sediment in Segments 8 and 9. The differences in the magnitude of the estimated risk between the Ranger and Native American Subsistence Resident scenarios result from the differences between the external pathway in the Ranger Scenario and the sum of the external and internal exposure pathways in the Native American Subsistence Resident Scenario. The highest risk from neptunium-237 via the Ranger Scenario is from sediment in Segment 9 with a lifetime risk of 5.2×10^{-7} . The highest risk via the Native American Subsistence Resident scenario is from sediment in Segment 9 with a risk of 8.3×10^{-5} .

Figure 5.22. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Nickel

Nickel. The ratios of the risk estimated for nickel using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.22. For both sets of scenarios, the maximum downstream risk estimates are always within 50 percent of the upstream estimates. The highest risk from nickel via the Ranger Scenario is from sediment in Segment 19 with a hazard index of 2.0×10^{-6} . The highest risk via the Native American Subsistence Resident scenario is from seep water in Segment 17 with a hazard index of 6.8×10^{-3} . The upstream and downstream estimates are controlled by measurements in sediment at the respective locations. The dip in the results in Segment 25 is because no sediment measurements are available for this location. Nickel does not appear to be related to releases from the Hanford Site.

Figure 5.23. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Nitrates

Nitrates. The ratios of the risk estimated for nitrates using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.23. The bulk of the downstream Ranger Scenario results are equal to or less than the upstream result, but the risk driven by surface water in Segments 2, 21 and 22 is somewhat higher (surface water in Segment 22 is a surrogate based on Segment 21). The Native American Subsistence Resident Scenario results are increased in Segments 4, 8, 10, 14, 17, and 20. All of these are from the influence of nitrates in seep water measurements. Nitrates are a well known and documented Hanford Site contaminant and are known to discharge to the Columbia River. The highest risk from nitrate via the Native American Subsistence Resident scenario is from seep water in Segment 20 with a hazard index of 0.24. The highest risk via the Ranger Scenario is from surface water in Segment 2 with a hazard index of 2.2×10^{-6} .

Figure 5.24. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Nitrites

Nitrites. The ratios of the risk estimated for nitrites using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.24. Measurements of nitrites are available for most segments, but the concentration of nitrites is generally below detection. Nitrites have been detected in small amounts in surface water in Segments 1 and 21. The use of surrogate surface water is illustrated, in that Segment 22 uses surface water measurements from Segment 21. For the Native American Subsistence Resident Scenario, nitrites are also present in modeled seep water (surrogated by groundwater) in Segments 19 and 21. No other locations have measurements above the detection level for nitrites. The highest risk from nitrite via the Ranger Scenario is from surface water in Segment 21 with a hazard index of 6.3×10^{-7} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 19 with a hazard index of 0.011.

Figure 5.25. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Phosphates

Phosphates. The risk estimated for phosphates using the Ranger and Native American Subsistence Resident scenarios for each river segment is presented in Figure 5.25. Phosphate measurements for Segment 1 are all below detection levels, making it impossible to prepare downstream/upstream ratios. Surface water in Segment 18 for the Ranger Scenario illustrates the only positive measurement for phosphate. This is repeated in the Native American Subsistence Resident Scenario, and two instances of phosphate detection in groundwater used as a surrogate for seep water are shown at Segments 19 and 21. The highest risk from phosphates via the Ranger Scenario is from surface water in Segment 18 with a hazard index of 2.7×10^{-6} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 19 with a deterministic hazard index of 0.69.

Figure 5.26. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Strontium-90

Strontium-90. The ratios of the risk estimated for strontium-90 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.26. Strontium-90 is a component of global radioactive fallout. Results of both the Ranger and Native American Subsistence Resident scenarios indicate that concentrations of strontium-90 are significantly higher in the water and sediment of some segments of the Hanford Reach than elsewhere. For the Ranger Scenario, the increases are the result of strontium-90 concentrations in sediment in the Hanford Reach segments, and below Segment 21 the result of strontium-90 in surface water. Segments downstream from Segment 21 are modeled using the Segment 21 surface water measurement. For the Native American Subsistence Resident Scenario, the primary medium in the Hanford Reach is sediment with a secondary contribution from strontium-90 in seep water (either directly measured or using groundwater as a surrogate). The highest risk from strontium-90 via the Ranger Scenario is from sediment in Segment 6 with a lifetime risk of 5.4×10^{-8} . The highest risk via the Native American Subsistence Resident Scenario is also from sediment in Segment 6 with a risk of 7.7×10^{-4} . It is apparent that strontium-90 is enhanced as a result of Hanford Site operations.

Figure 5.27. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Sulfates

Sulfates. The ratios of the risk estimated for sulfates using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.27. The Ranger Scenario is controlled by a few measurements in surface water. Those made in Segments 1, 6, 13, 17, 18, 20, and 21 are used in the segments that are respectively downstream of these. There is no noticeable difference in surface water concentration throughout the region. The Native American Subsistence Resident Scenario includes the influence of seep water. Minor increases in the estimated risk from sulfates is apparent in segments such as 7, 8, 15, and 20. The largest is almost a doubling of risk in Segment 8 as a result of inflowing sulfates from Hanford groundwater. The highest risk from sulfates via the Ranger Scenario is from surface water in Segment 27 with a hazard index of 1.0×10^{-6} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 7 with a hazard index of 0.012.

Figure 5.28. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Technetium-99

Technetium-99. The ratios of the risk estimated for technetium-99 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.28. The radionuclide technetium-99 is generally of low concentration in global fallout. The patterns in both parts of Figure 5.26 reflect the availability of sediment measurements for technetium-99. The highest risk from technetium-99 via the Ranger Scenario is from sediment in Segment 8 with a lifetime risk of 6.3×10^{-11} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 10 with a risk of 3.1×10^{-6} . Because technetium has a very high bioconcentration factor, it tends to accumulate in plants. The model used to estimate risk uses a bioconcentration factor based on the sediment measurements. When measurements are available, the accumulation in plants is very apparent. Technetium-99 is known to contaminate the groundwater at some Hanford Site locations, one being in the 100-H Area represented by Segment 10. Although technetium-99 has been measured in sediment in the 100-H and other areas, it is not known whether the technetium-99 in the sediment is of Hanford Site origin because no sediment sample measurements for technetium-99 are available upstream of Segment 8 (100-D Area). More sediment samples would be required to unequivocally identify the source of the technetium-99.

Figure 5.29. Absolute and Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Tritium (Hydrogen-3)

Tritium (Hydrogen-3). The risk estimated for tritium (hydrogen-3) using the Ranger Scenario for each river segment and the ratios of the risk estimated using the Native American Subsistence Resident Scenario for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.29. Tritium (hydrogen-3) measurements in sediment are not available for Segment 1, making it impossible to prepare downstream/upstream ratios. There is essentially no risk from external exposure to tritium (hydrogen-3), and so the Ranger Scenario is not a good measure of risk from this radionuclide because it postulates only external and dermal exposures. The Native American Subsistence Resident Scenario indicates that exposures to seep water in Segments 4 and 17 result in risk from tritium (hydrogen-3) that is distinctly elevated above background. There is no risk from tritium via the Ranger Scenario because the low decay energy provides no external exposure. The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 17 with a lifetime risk of 2.1×10^{-4} .

Figure 5.30. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Uranium-234

Uranium-234. The ratios of the risk estimated for uranium-234 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.30. Uranium-234 is a naturally occurring decay product of uranium-238, the form most prevalent in nature. However, in operations involving reactor fuel made of enriched uranium, uranium-234 can also be enhanced in concentration. The results for both the Ranger and Native American Subsistence Resident scenarios indicate that uranium-234 is enhanced in Segment 20 (300 Area). This is quite likely because the 300 Area was used for uranium fuel fabrication. The Ranger Scenario indicates that uranium-234 concentrations are elevated in sediment. The Native American Subsistence Resident Scenario indicates that seep water in the 300 Area also contains elevated concentrations of uranium-234. The highest risk from uranium-234 via the Ranger Scenario is from sediment in Segment 20 with a lifetime risk of 6.5×10^{-8} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 20 with a risk of 9.9×10^{-4} .

Figure 5.31. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Uranium-238

Uranium-238. The ratios of the risk estimated for uranium-238 using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.31. Uranium is a naturally occurring radionuclide, appearing in concentrations of about 1 part per million in igneous rocks (NCRP 1987). As with uranium-234, a peak is apparent in the 300 Area (Segment 20), and a separate peak appears at Segment 10 (100-H Area). The dominant medium in both locations is sediment. The highest risk from uranium-238 via the Ranger Scenario is in Segment 20 with a lifetime risk of 7.7×10^{-8} . The highest risk via the Native American Subsistence Resident Scenario is from sediment and seep water in Segment 20 with a risk of 9.2×10^{-4} .

Figure 5.32. Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Xylenes

Xylenes. The risk estimated for xylenes using the Ranger and Native American Subsistence Resident scenarios for each river segment is presented in Figure 5.32. Xylene measurements for Segment 1 are all below detection limits, making it impossible to prepare downstream/upstream ratios. The peaks in the graph for the Ranger Scenario correspond to measurements of xylenes in sediment in Segments 14, 18, and 22. The graph for the Native American Subsistence Resident Scenario has similar peaks, but they are lost in the scale because of a single measurement of xylenes in groundwater (substituted for seep water) in Segment 13. This large peak in Segment 13 is most likely correlated with the benzene peak in this segment, and both are probably representative of a petroleum hydrocarbon source. The highest risk from xylenes via the Ranger Scenario is from sediment in Segment 14 with a hazard index of 2.7×10^{-10} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 13 with a risk of 1.8×10^{-4} .

Figure 5.33. Downstream/Upstream Ratios of Estimated Risk Results for Ranger and Native American Subsistence Resident Scenarios for Zinc

Zinc. The ratios of the risk estimated for zinc using the Ranger and Native American Subsistence Resident scenarios for each river segment compared to the risk estimated for Segment 1 are presented in Figure 5.33. The highest risk from zinc via the Ranger Scenario is from sediment in Segment 21 with a hazard index of 1.1×10^{-4} . The highest risk via the Native American Subsistence Resident Scenario is from seep water in Segment 12 with a hazard index of 0.37. None of the downstream results differ greatly from the upstream result in Segment 1 for either the Ranger or Native American Subsistence Resident scenarios. Zinc in the environment is not likely to be the result of releases from the Hanford Site.

Figure 5.34. Downstream/Upstream Ratios of Estimated Risk Results for External Doses

External Doses. The ratios of the risk estimated from external radiation, calculated using either thermoluminescent dosimeter data from each river segment or from dose rate calculations based on radionuclide concentrations, are presented in Figure 5.34. The largest deviation from background is apparent in Segment 6, the N-Reactor Area, a dose rate of about 12 millirem/year. This corresponds to a lifetime risk of 6.8×10^{-4} . As discussed above, some of these estimates are based on measurements with a constant background subtracted, and the rest are based on concentrations of radionuclides in soils, sediment, and water.

5.2.4.2 Statistical Evaluation

The comparison of upstream to downstream risk on the basis of the deterministic or median stochastic value does not incorporate all of the information available in the distributions of the measured data. An example of distributions for a contaminant is illustrated in Figure 5.35. In this figure, the distribution of estimated human risk from the radionuclide tritium (hydrogen-3) for the Native American Subsistence Resident Scenario in Segment 1 (the upstream segment) is compared to that for Segment 17 (the old Hanford townsite). In Segment 1, all environmental measurements are below the EPA drinking water standard for tritium (hydrogen-3) of 20,000 picocuries/liter. However, in Segment 17, measurements of seeps and groundwater as high as 169,000 picocuries/liter have been seen. Consumption of groundwater with concentrations of tritium (hydrogen-3) of this magnitude would result in annual doses greater than 4 millirem, and lifetime risk of up to 10^{-3} . The distinct shift of the distributions is indicative of an increase in individual risk that can be attributed to Hanford operations.

Because the distributions hold more information than can be easily used, means of comparing the entire upstream and downstream distributions were developed. These techniques are based on detailed statistical approaches called the Mann-Whitney U Test and the Kruskal-Wallis One-Way Anova Test.

The Mann-Whitney U Test (Gibbons 1971, p. 140) was developed to test whether two independent sets of sample values, called X and Y, were drawn from the same statistical distribution. In this application, both sets of samples come from a two-parameter lognormal distribution by construction. The

Figure 5.35. Comparison of Background and Elevated Distribution of Estimated Lifetime Risk for the Native American Subsistence Resident Scenario for Tritium (Hydrogen-3)

test then addresses whether the two lognormal distributions have the same parameters, that is, $F_Y(t) = F_X(t)$ for all t , where F denotes a cumulative distribution function.

The test procedure combines the two sets of sampled data, and then sorts the combined values into increasing order. The Mann-Whitney U statistic is defined as the number of times a Y_i precedes an X_j in the set of combined, sorted values. The rejection region for the one-sided alternative is $F_Y(t) \leq F_X(t)$ with strict inequality for some t .

If the two sets of values come from the same distribution, they should be randomly interspersed in the combined sorted set. Similarly, if one distribution lies to the left of the other one, the sampled values should be segregated into different areas. Using combinatorial arguments one can derive the statistical distribution of the U statistic under the assumption of equal distributions. Assume that X contains m values, and Y contains n values, then the large sample test statistic

$$Z = \frac{U - mn/2}{\sqrt{mn(m+n+1)/12}} \quad (5.22)$$

has a distribution that is approximately standard normal. The approximation is reasonably accurate for equal sample sizes as small as 6. In the context of this document, both sets of samples have the same number of values: $m = n = 1,000$.

The Mann-Whitney U Test was developed to check for differences between two sets of sampled values. The test can be extended to multiple sets of sampled values (an arbitrarily large number, represented by k) in which case it is then known as the Kruskal-Wallis One-Way Anova Test (Gibbons 1971, p. 198). The null hypothesis for the test is that all of the sets of samples come from the same statistical distribution.

Assume that the i th sample contains n_i values and that the sum of all the n_i is N . The test procedure is to combine all N observations into a single ordered sequence from smallest to largest, keeping track of which observation is from what sample and assign the ranks 1, 2, ..., N to the sequence. Let R_i denote the sum of the ranks associated with the i th sample. The test statistic, K_w , is computed as

$$K_w = \frac{12}{N(N+1)} \sum_{i=1}^k \frac{R_i^2}{n_i} - 3(N+1) \quad (5.23)$$

The large-sample rejection region for the test is $K_w \geq \chi_{\alpha, k-1}^2$ where $\chi_{\alpha, k-1}^2$ denotes a Chi-squared statistic with $k-1$ degrees of freedom. Unfortunately, the form of the test statistic does not yield information as to the nature of differences between the statistical distributions of the sets of sampled values when the null hypothesis is rejected. The only conclusion that can be drawn is that not all of the distributions were the same.

Multiple applications of the Mann-Whitney U Test are not equivalent in a statistical sense to a single application of the Kruskal-Wallis One-Way Anova Test. However, once the Kruskal-Wallis Test has found a difference, multiple applications of the U Test may yield some practical, although not statistically rigorous, insights into the nature of the data.

As with the risk calculations themselves, these statistical tests produce a great deal of numerical output because information for each scenario and each location is provided. Graphical summaries of the results of the statistical evaluation are provided in Figures 5.36 and 5.37 for the Ranger and Native American Subsistence Resident scenarios, respectively. Summaries for the other scenarios (Figures E.10-E.18) are provided in the "Computer Code for the Statistical Analysis of Downstream/Upstream Comparisons and the Results" section of Appendix I-E.

The statistical techniques are very sensitive. They can distinguish very small differences in the shape of the output distributions. In some cases, the difference in shape may be real but not of importance if the absolute magnitude of the estimated risk is very small. This is illustrated using Figures 5.38 and 5.39. Figure 5.38 shows the distributions of estimated human risk from the radionuclide strontium-90 for the Native American Subsistence Resident Scenario in Segment 1 (the upstream segment) as compared to that for Segment 6 (the N Reactor). As in Figure 5.35 for tritium (hydrogen-3), a clear Hanford-related increase in risk is evident, resulting largely in this case from strontium-90 in sediment. Figure 5.39 shows the distributions of estimated human risk from the metal lead for the Native American Subsistence Resident Scenario in Segment 1 (the upstream segment) as compared to that for Segment 17 (the old Hanford townsite). This figure illustrates the largest downstream/upstream difference for lead, and illustrates the difficulty of comparing either the deterministic or median values. The deterministic value

		At or below background																										
		Background																										
		Above background, insignificantly										Based on stochastic output of Ranger Scenario																
		Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
		Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNa
Analyte	Rapids	Area		Area	Trench	Area		Area	Horn	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Casc.	Walla R.	Res.	
Ammonia																												
Benzene																												
C-14																												
Cs-137																												
Cr/Car																												
Cr/Tox																												
Co-60																												
Copper																												
Cyanide																												
Diesel																												
Eu-152																												
Eu-154																												
I-129																												
Kerosene																												
Lead																												
Mercury																												
Np-237																												
Nickel																												
Nitrate																												
Nitrite																												
Phosphate																												
Sr-90																												
Sulfate																												
Te-99																												
Tritium																												
U-234																												
U-238																												
Xylene																												
Zinc																												

Figure 5.36. Statistical Evaluation of the Differences between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Ranger Scenario

	At or below background																										
	Background										Based on stochastic output of Native American Subsistence Resident Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Hom	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Casc.	Walla R.	Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
Bu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
To-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure 5.37. Statistical Evaluation of the Differences between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Native American Subsistence Resident Scenario

Figure 5.38. Comparison of Background and Elevated Distribution of Estimated Lifetime Risk for the Native American Subsistence Resident Scenario for Strontium-90

Figure 5.39. Comparison of Background and Elevated Distribution of Estimated Hazard Index for the Native American Subsistence Resident Scenario for Lead

for lead in Segment 17 is actually lower than that in Segment 1, and the medians differ by less than a factor of 4. The two distributions significantly overlap. There appears to be an increase in the risk in this location resulting from the Hanford Site, however, caused by increased concentrations of lead in seep water. The subtle difference between these two distributions is captured by the statistical tests.

Because the statistical tests are so sensitive, a second screen has been superimposed on the results of the statistical screening. This second screen is based on the size of the estimated risk. For the purposes here of differentiating Hanford-derived contaminants in the Columbia River, a set of risk thresholds have been selected. These risk thresholds are only used in the following discussion to simplify the explanation of the results of the analysis and are not intended to imply definitive levels of importance or neglect. The thresholds are set equal to other accepted regulatory levels to distinguish the differences in the estimated results.

For carcinogenic chemicals and radionuclides, the lower threshold is set at a lifetime risk of 10^{-6} . For toxic chemicals, the lower threshold is set at a hazard index of 0.01 (1 percent of the estimated toxic response level). The upper threshold is set at a lifetime risk of greater than 10^{-4} or a hazard index of 1.0. These values are represented on Figures 5.36 and 5.37 as shadings. Any results greater than the upper threshold are shaded black, results greater than the lower threshold are shaded medium grey. A lighter grey is used to indicate the other segments in which the contaminants were identified as above background but below the lower threshold.

The results illustrated in Figures 5.36 and 5.37 correspond well with the results described in the preceding section. The Columbia River segments identified by the statistical tests as having potential risk results that exceed those of the upstream segment are essentially the same as those identified in Section 5.2.4.1 with several additions. The two techniques compliment each other because the statistical comparison cannot be used if upstream data are missing (for example, as is the case for cyanide and europium-152), and the statistical technique is more sensitive to small variations, for example, tritium (hydrogen-3). Using the observational technique described in Section 5.2.4.1 provides insight to the magnitude of the potential risk for some of the segments identified as being different (for example, nickel in Segments 18, 19, and 20 for the Ranger Scenario).

The superposition of the risk threshold levels (Section 5.2.4.2) on the results of the comparison (Section 5.2.4.1) also provides insight into the most significant potential contaminants. For instance, it indicates that chromium is the largest potential contributor to risk to individuals represented by the Ranger Scenario. It also indicates that while several contaminants of Hanford Site origin, such as europium-154 or cobalt-60, are present in elevated quantities throughout the Hanford Reach they are of lesser risk than other such distributed contaminants as strontium-90 or nitrates.

The combination of observational and statistical techniques identify the same contaminants in the same locations, and the results are generally quite consistent across the numerous exposure scenarios as well.

Although diesel and kerosene were not analyzed because no environmental measurements of their presence are available, benzene and xylene are reasonable surrogates for these. The contaminants

identified as probably not of Hanford Site origin include copper, nickel, and zinc. Those contaminants of probable Hanford Site origin with potential risk in at least one river segment are presented in Table 5.19.

Table 5.19. Maximum Risk Levels in the Native American Subsistence Scenario for Contaminants

Lifetime Risk Levels			Hazard Indices		
>1E-6	>1E-5	>1E-4	>0.01	>0.1	>1.0
Benzene	Benzene		Chromium		
Carbon-14	Carbon-14		Lead	Lead	Lead
Cesium-137	Cesium-137		Nitrate		
Chromium	Chromium	Chromium	Nitrite		
Cobalt-60			Phosphate		
Europium-152			Sulfate		
Europium-154	Europium-154				
Iodine-129					
Neptunium-237	Neptunium-237				
Strontium-90	Strontium-90	Strontium-90			
Technetium-99					
Tritium (H-3)	Tritium (H-3)	Tritium (H-3)			
Uranium-234	Uranium-234	Uranium-234			
Uranium-238	Uranium-238	Uranium-238			

5.2.5 Evaluation of Hanford-Related Contaminants by Scenario

In this section, we describe which contaminants, media, and pathways contribute most to the potential risk for each scenario. For the contaminants of potential risk, we also denote when a contaminant does not appear to be of Hanford origin.

A description is provided of the key pathways of human exposure for each of the contaminants of probable Hanford Site origin for each of the exposure scenarios. This discussion is intended to provide insight to the nature of human exposures, so that plans for possible intervention can be based

on appropriate knowledge of the important contaminant mechanisms. The discussion is based on the scenario specific information in Appendix I-E and the results of Figures 5.5, 5.6, 5.36, 5.37, and E.10-E.18.

5.2.5.1 Industrial Worker, Fish Hatchery Worker, and Ranger Scenarios

The key contaminant for these three scenarios is chromium. The key pathway for the Industrial Worker and Fish Hatchery Worker scenarios is direct consumption of Columbia River water. That for the

Ranger Scenario is incidental consumption of river sediment because the scenario does not postulate her/his drinking the water. Although copper appears to be somewhat elevated in the downstream Segments 23-27, this is entirely due to surface water measurements in Segment 23 (influenced by the influx of the Yakima River) and seems to be unrelated to releases from the Hanford Site. The Fish Hatchery Worker and Industrial Worker scenarios also exhibit a small influence of uranium-238 from consumption of surface water in Segment 19.

5.2.5.2 Avid Recreational Visitor and Casual Recreational Visitor Scenarios

Key contaminants for these two scenarios are chromium, lead, strontium-90, and, uranium for the Avid Recreational Visitor Scenario. Cesium-137 and nitrates are also present at levels just above the lower thresholds. The appearance of zinc in Segment 12 for the Casual Recreation Visitor Scenario results from input via seep water surrogated using groundwater. There is no significant difference in the results for zinc in Segment 12 and the results for zinc in upstream segments in the other media. Although copper appears to be somewhat elevated in the downstream Segments 23-27, this is entirely due to surface water measurements in Segment 23 (influenced by the influx of the Yakima River) and seems to be unrelated to releases from the Hanford Site.

The controlling medium for chromium is surface water. The controlling pathway is consumption of fish caught in the Columbia River. These scenarios do not include any ingestion of native plants, and, because the bioaccumulation factor for chromium is around 200, the fish ingestion outweighs the direct ingestion of drinking water from the river.

The controlling medium for lead is also surface water, and the controlling pathway for lead is also consumption of fish.

The controlling medium for strontium-90 for the casual recreational visitor is seep water, and the controlling pathway is direct consumption. The controlling medium for strontium-90 in the Avid Recreational Visitor Scenario is sediment. The structure of the model is such that the controlling medium becomes consumption of wild birds. The model relates concentrations of strontium-90 in biota to the concentrations in sediment. The transfer factor is large enough that uptake from consumption of resident birds is much higher than that via incidental intake of sediment directly.

For uranium for the Casual Recreational Visitor Scenario, the intake is split between consumption of surface water and seep water. For the Avid Recreational Visitor Scenario, the controlling medium is sediment for modeling reasons similar to those for strontium-90.

5.2.5.3 Native American Scenarios

The four Native American scenarios are all essentially variants on the most complete scenario, that of the Native American Subsistence Resident. The Native American Upland Hunter Scenario includes animal products but omits the vegetable products and surface water exposures, including that of fish consumption. The Native American Hunter/Fisher Scenario uses the same parameters but omits fruit, vegetables, and terrestrial animal products. The Native American Gatherer Scenario includes the vegetable

products but omits birds, fish, and animal products. Because they are all similar, the pathways of exposure are similar for the various contaminants of interest with minor variations discussed below.

The key contaminants for the Native American scenarios are chromium, lead, nitrates, strontium-90, tritium (hydrogen-3), uranium-234, and uranium-238. Benzene, carbon-14, cesium-137, cobalt-60, europium-154, iodine-129, nitrites, sulfates, and technetium-99 also appear at levels somewhat above the lower thresholds.

For chromium, two media are important: surface water and sediment. Both contribute sizable fractions of the total potential exposures. When surface water dominates, the key pathway is consumption of fish. When sediment dominates, the key pathway is consumption of crop plants grown in the riparian zone. Thus, for the Gatherer Scenario, the crops always control, and for the Hunter/Fisher Scenario, the fish always controls. Because the Upland Hunter Scenario is postulated to eat neither of these foods, the pathway of highest exposure for that scenario is the consumption of seep water. All of these pathways contribute to the Native American Subsistence Resident Scenario.

For lead, exposures are primarily dominated by consumption of vegetation grown in sediment (for example in Segments 4, 11, 12, and 17). There are also significant fractions of exposure from consumption of fish caught in surface water (Segments 19 and 20). Of course, fish is not a pathway for the Upland Hunter and Gatherer scenarios, and vegetation is not a pathway for the Upland Hunter and Hunter/Fisher scenarios. For the Upland Hunter, the key pathway (less in magnitude than the others) is the consumption of meat from game animals that are themselves eating food grown in the riparian sediment. As illustrated in Figure 5.39, although the absolute magnitude of the hazard index for lead is relatively large, it is never elevated by more than about a factor of 2 from the upstream segment.

For nitrates, the key medium and pathway for all scenarios is consumption of seep water.

The key medium for strontium-90 is sediment, and the key pathway for those scenarios employing it is consumption of riparian vegetation. A significant secondary pathway is consumption of wild birds that feed on the riparian vegetation. For the scenarios with no consumption of vegetation (Upland Hunter and Hunter/Fisher), the consumption of the wild birds is the controlling pathway.

Tritium (hydrogen-3) is a proven Hanford Site contaminant. It is routinely monitored in surface water, groundwater, and seep water. It is highly ranked in Columbia River Segment 17 in all four of the Native American scenarios and in Segment 4 in the deterministic analyses. The medium causing this high ranking is seep water (surrogated by groundwater), and the pathway is direct ingestion of seep water.

Uranium has more varied exposure routes than the other contaminants. For the two scenarios with substantial intake of crop plants, the Subsistence Resident and Gatherer scenarios, concentrations in sediment in Segment 10 result in exposures. For the scenarios with substantial intake of fish, the Subsistence Resident and Hunter/Fisher scenarios, surface water concentrations in Segment 19 lead to large estimated exposures via fish consumption. For all scenarios, direct ingestion of seep water in Segment 20 is important.

5.2.5.4 Resident and Agricultural Resident Scenarios

These two scenarios differ only by the addition of animal products in the Agricultural Resident Scenario. The key contaminants are chromium, lead, nitrates, strontium-90, and uranium-234 and -238. Other contaminants above the lower threshold include benzene, carbon-14, cesium-137, cobalt-60, and tritium (hydrogen-3).

The controlling medium for chromium is surface water. The controlling pathway is consumption of fish caught in the river.

The controlling medium for lead, unlike the recreational scenarios, is sediment. The difference between these scenarios and those of recreational activities is the addition of vegetation consumption pathways. These pathways result in the potential intake of lead via consumption of food crops grown in the riparian zone.

The controlling medium for nitrates in these scenarios is seep water, and the controlling pathway is direct consumption. Nitrates are not usually detected in sediment, and when they are they typically act as fertilizers. So the addition of the crop consumption pathways does not change the results from the recreational scenarios.

The controlling medium for strontium-90 is sediment. The controlling pathway is ingestion of crop plants. Consumption of meat adds a fraction to the resulting exposure. But it is not as large as the intake from plants directly, and it is modeled as being a secondary pathway to the plant uptake. (The animals eat the plants that are grown in the sediment.) These two scenarios do not have a component for ingestion of wild birds as modeled in the recreational scenarios. Wild birds would add to the exposure via the meat pathways and would also be related to the sediment concentrations.

For the segments where the uranium exposures are above the threshold, the controlling medium for uranium-234 and -238 is seep water, and the controlling pathway is direct consumption. There is also a component via consumption of vegetation grown in the riparian zone sediment, but it never results in exposures greater than the upper threshold.

5.2.6 Radioactive Particles

Surveys of Columbia River islands and shoreline have shown the existence of small, discrete metallic radioactive particles containing microcurie quantities of cobalt-60 (Sula 1980, Cooper and Woodruff 1993, Wade and Wending 1994) beginning in Segment 8 and continuing downstream. This section provides an evaluation of the potential risk to members of the public resulting from these particles based on the scenario developed in Section 5.1.

Various researchers have found particles containing small quantities of cobalt-60 on some of the Columbia River islands and shoreline. D Island has been found to have the highest concentration of these particles. In this section, we evaluate the potential risk from these particles to members of the public. Our evaluation shows that the estimated risk for these cobalt-60 particles is low for D Island. None of the known results are near an integrated exposure of 75 microcurie-hour that would indicate initial harmful effects. The 75 microcurie-hour exposure is a reference dose level set by the National Council on Radiation Protection and Measurements (NCRP 1989).

5.2.6.1 Particle Activity Distribution

The particles were first found by Sula in 1978, who detected 188 particles over a large portion of the Columbia River shoreline. He collected and determined the activity of fourteen particles of which seven were collected from D Island (Sula 1980, p. 37). These particles were barely visible to the naked eye (diameter about 0.1 mm) and contained cobalt-60 activities ranging from 1.7-24 microcuries at that time. The next survey was by Cooper and Woodruff (1993), who also detected particles in the Hanford Reach. Ten of eleven were

found on D Island. Two particles were recovered, with activities of 1.7 and 16 microcuries. In 1993, the upstream end of the island was extensively surveyed, and 103 particles were found and recovered of which activities were determined for 47 (Wade and Wending 1994).

To obtain a statistical description of the likely distribution of particle activities, the activities of the particles found by Sula, Cooper, and Woodruff were decayed to 1996, and the total set analyzed. Table 5.20 lists the 1996 cobalt-60 activities of the 61 particles and shows that the activities are lognormally distributed with a mean value of about 1.9 microcuries, a median value of 1.1 microcuries, and a geometric standard deviation of about 2.4-2.6. This indicates that there is a 95 percent probability that any additional particles found should be in the range of 0.2 to 20 microcuries.

5.2.6.2 Areal Density of Particles

Sula (1980) performed a detailed survey to obtain information on the distribution and density of the radioactive particles on D Island. From this data, Wells (appendix to letter from J.L. Erickson, Washington State Department of Health, to L.E. Gadbois, EPA, January 3, 1995) derived a density of particles in rocky surfaces of 0.037 particles/m³. In Sula's survey, fourteen 100-square-foot areas were selected at random along the north shore of the island, some near the water line and some 20-30 feet inland. Each plot was carefully surveyed. A total of seven particles were located in the fourteen areas, yielding a density of 0.054 particles per square meter (0.005 particles per square foot). Since all of these particles were found within the top 15 centimeters, this provides a volume density estimate of 0.36 particles/m³ in 1978/1979.

The survey documented by Wade and Wending (1994) on D Island may also be used to estimate the density of particles in sediment. For this survey, thirteen areas of approximately 65 meters by 65 meters (200 feet by 200 feet) were established, and transects were made every 3 meters (10 feet) in two perpendicular directions. The survey thus covered approximately 30 kilometers (nearly 20 miles). If a detector window about a third of a meter wide (1 foot) is assumed to a depth of 15 centimeters (6 inches), then a total of 1470 m³ (52,000 ft³) were surveyed in which 103 particles were found. This provides a particle density estimate of 0.07 particles/m³. It is notable in this survey that Sula's assumption the

particles would be within 6-9 meters (20-30 feet) of the waterline was not confirmed. The particles were distributed across the entire island.

The particles are located in the sediment between the rocks on the island. If the rocks were spheres, the smallest volume that could be occupied by sediment would be 26 percent. Hexagonal close-packed spheres occupy 74 percent of the available volume (Rosenbaum 1970). For non-spherical rocks, the solid fraction may be even higher. Values as high as 90 percent could be conceivable. Thus, the density of particles in sediment (as opposed to in the mixture of rocks and sediment) could approach or exceed 1.0 particle/m³ in the rocky areas.

The sandier, downstream end of the island has not received a detailed survey for discrete radioactive particles. Although, Cooper and Woodruff describe a survey track consisting of two survey lines 20 meters (approximately 20 yards) apart, walked on the island in 1993, which found eight particles on the upstream end and three particles on the downstream end. This information is insufficient to defensibly conclude particle densities on the downstream end of the island. However, numerous measurements of the direct gamma ray exposure rates have been performed which provide sufficient information to set an upper bound on the number of particles that may exist there. Sula describes the particles as approximately 0.1 millimeter (0.04 inch) in diameter with a composition similar to the metal alloy stellite. Stellite has a density of about 8 grams/cm³ (28 ounces), making the particles considerably denser than the other sands in the area. This could provide a partial explanation of the observed behavior of the particles, which are like gold flakes trapped in cracks and settling into low spots rather than distributing uniformly throughout the sediment or accumulating in sandy spots.

An early aerial radiological survey was performed in 1973-1974 soon after the last once-through cooled production reactor was shut down. This survey could clearly distinguish radioactive contamination on the banks, islands, and sloughs of the Columbia River far downstream from the reactors (EG&G 1975). During the fly-overs of D Island,

Table 5.20. Measured Cobalt-60 Particle Activities in 1996

Number	Sula 1980	Cooper and Woodruff 1993	Wade and Wendling 1994	Decay to 1996
1	16			1.71
2	14			1.50
3	1.7			0.18
4	6.6			0.71
5	23			2.46
6	21			2.25
7	9.9			1.06
8	13			1.39
9	12			1.28
10	6.5			0.70
11	2.5			0.27
12	9.7			1.04
13	1.7			0.18
14	24			2.57
15		16		9.46
16		1.7		1.00
17			2.3	1.77
18			2.3	1.77
19			4	3.08
20			1.3	1.00
21			1.2	0.92
22			22	16.91
23			2.2	1.69
24			2.4	1.85
25			0.28	0.22
26			1.7	1.31
27			1.9	1.46
28			3.4	2.61
29			4.1	3.15
30			0.13	0.10
31			0.66	0.51
32			3.9	3.00
33			2.7	2.08
34			0.45	0.35
35			1.9	1.46
36			1.7	1.31
37			1.1	0.85
38			0.52	0.40
39			0.98	0.75
40			0.99	0.76
41			1.5	1.15
42			1.5	1.15
43			1.2	0.92
44			1.5	1.15
45			1.7	1.31
46			18.6	14.30
47			3.3	2.54
48			0.58	0.45
49			1.1	0.85
50			0.39	0.45
51			2.6	2.00
52			0.67	0.52
53			2.6	2.00
54			0.96	0.74
55			0.41	0.32
56			1.5	1.15
57			4.04	3.11
58			0.8	0.62
59			0.78	0.60
60			2.36	1.81
61			0.5	0.38
			Average	1.88
			Geo.Mean	1.12
			Median	1.15
	Sula age	17 yr		
	Cooper age	4 yr		
	Wendling ag	2 yr

this survey found the highest exposure rates near the middle of the island (approximately 5.6 to 8.8 microrentgen/hour above background) and the lower exposure rates at each end (<1 microrentgen/hour). The background rate was about 10 microrentgen/hour. A repeat aerial survey in 1988 during low water in April/May found the highest radiation near the upstream end of the island. The measurements were near the limit of detection of the instrumentation and no exposure rates are provided (EG&G 1990). During the 1978 survey, Sula et al. (1980, Appendix D) found an average exposure rate on the island of 9 microrentgen/hour with a maximum of 125 microrentgen/hour near the vent pipes. No particular elevation in exposure rates was noted at the downstream end. Cooper and Woodruff (1993) also walked the upstream and downstream ends of the island. For the upstream end, the maximum, average, and median exposure rate was 10 microrentgen/hour, and for the downstream end, the maximum was 11, average 10.1, and median 10.0 microrentgen/hour. In addition, the average soil concentration of cobalt-60 in sediment was determined to be 0.91 picocuries/gram on the upstream end and 0.36 picocuries/gram on the downstream end of the island (Cooper and Woodruff 1993, p. B.4 and Figure 4.19). Cooper (1995, p. 3.2) states that the normal background rate in the Hanford Reach is 9.8 microrentgen/hour. The 1993 Hanford Site annual report provides the exposure rate at the site of the single thermoluminescent dosimeter permanently located on the island near the vent pipes at 10.8 microrentgen/hour (Bisping 1994, p. 205). Finally, a recent survey to determine gamma ray spectra performed in June of 1995 found a hint of cobalt-60 spectra on the downstream end of Island but no noticeably elevated exposure rates (personal communication between E.J. Antonio and B.A. Napier, June 1995).

A distributed source of cobalt-60 in soil to an infinite depth has a dose rate conversion factor of about 1 microrentgen/hour per microcurie/m³ (Eckerman and Ryman 1993). In the rocky areas, the particle densities of 0.1 to 0.3 particle/m³ of rocky soil with average particle activities of about 1.9 microcuries, would lead to exposure rates of 0.2 to 0.7 microrentgen/hour, which would be essentially undetectable above background. If it is assumed that the exposure rate should have to be as high as 10 microrentgen/hour above background to be reliably detected, then the soil would have to contain 4 particles/m³. This is a potential increase of factors of about 10 to 50 above what is seen in the rocky areas, although only about 4 times what is seen in the sediment of the rocky areas.

5.2.6.3 Effects of Particles

The possibility of inhaling a discrete radioactive particle was addressed by Durham and Soldat in the appendix of Cooper and Woodruff (1993). They found that the physical size of the particles was such that it was not possible to inhale one into the lungs, but that they would at worst lodge in the anterior portion of the nose. Durham used the specific activity of hot particles commonly found in the commercial nuclear industry in his calculation (60,000 curies/cm³). This specific activity relates to relatively young particles. Those found in the Columbia River from plutonium production activities are at least 25 years old. Thus, for the same particle activity, the particles would physically be much larger than assumed by Durham. (He based his calculations on a 10-micron particle.) The typical size found by Sula is 0.1 millimeter (100 microns). Thus, the nasal retention used by Durham (1 to 2 days) is considerably longer than what would occur with this size particle. (However, a retention of up to 2 days has been used in this analysis.)

For direct contact with the particles, no effect is seen below a limit of 75 microcuries-hour (NCRP 1989).

5.2.6.4 Results for Cobalt-60 Particles

The detailed deterministic calculations for the four pathways in each of the rocky and sandy areas are summarized in Table 5.21. It is apparent from the differences between the median and 99.9 percentile values shown in Table 5.21 that there is a wide difference between the expected and most extreme exposures that could occur. The worst case exposures are factors of up to 100 times greater than the median exposures. This indicates that the exposure distributions are generally lognormally distributed.

The pathway of highest risk is lifetime cancer risk from external exposure to cobalt-60 radiations in the sandy areas. It is unlikely that exposures of this magnitude could occur (besides being at the 99.9% of the distribution) because the calculation is based on an assumed upper level of contamination that could exist without having been detected via aerial and foot surveys.

It can be seen that the estimated risk for cobalt-60 particles is low for D Island, the point of highest known concentration of particles. None of the risk approaches the 75 microcurie-hour value for which the NCRP (1989) indicates initial harmful effects could occur. It is assumed that the risk is lower at other downstream locations. This conclusion is supported by a recent re-survey and risk analysis of D Island by the Washington State Department of Health (Danielson and Jaquish 1996).

Table 5.21. Summary of Cobalt-60 Calculation Results

Exposure Pathway	Units	Median in Rocky Area	Median in Sandy Area	99.9% in Rocky Area	99.9% in Sandy Area
Skin exposure	$\mu\text{Ci-hr}$	1.2×10^{-4}	2.1×10^{-4}	9.9×10^{-3}	1.8×10^{-2}
Direct external	Risk	1.6×10^{-7}	3.2×10^{-6}	1.2×10^{-6}	2.4×10^{-5}
Ingestion	Risk	4.9×10^{-11}	1.8×10^{-10}	2.7×10^{-9}	9.8×10^{-9}
Inhalation	$\mu\text{Ci-hr}$	1.6×10^{-7}	4.3×10^{-7}	2.0×10^{-5}	4.0×10^{-5}

5.2.7 Evaluation of Hanford-Related Contaminants by Segment

The Hanford Site is very large, and many different operations occurred at various places during its history. The distribution of possible contaminants is not uniform and varies in the surface water, sediment, and groundwater. In addition, not all possible contaminants have been measured for in each location.

For those readers more interested in the risk at a particular location rather than risk for a particular scenario, we discuss the estimated risk for each segment of the Columbia River in this section. Where possible, we have denoted the Hanford operations in the segment that contributed the contaminants found.

The following sections discuss the nature and extent of possible contamination in each segment of the Columbia River. The discussions relate the key contaminants identified as possibly important in each of the human exposure scenarios to those identified as possibly important in each segment.

5.2.7.1 Segment 1: Priest Rapids Dam

This river segment is upstream of the Hanford Site reactors and generally upgradient for groundwater movement. For the purposes of this assessment, the concentrations of contaminants measured in this segment have been considered to represent natural or background levels. The background risk to humans estimated using the scenarios developed for this report ranges from a stochastic median low for the Ranger Scenario of 1×10^{-4} lifetime risk and 2.2×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 6.6×10^{-2} lifetime risk and 3.8 hazard index. The cancer risk values are dominated by chromium and the hazard index is primarily driven by copper. While the upper background risk seems large in absolute terms, the various limitations of the modeling must be kept in mind (discussed more extensively in Section 6.0). The values are best considered to be screening indicators of the various potential problems that may exist along the Columbia River today.

5.2.7.2 Segment 2: 100-B/C Area

This first river segment within the bounds of the Hanford Site initiated many of the contaminants that are associated with past Hanford operations. Distinctly identified above background in this segment are ammonia, cesium-137, chromium, cobalt-60 (diffuse), strontium-90, sulfates, technetium-99, and tritium (hydrogen-3). The radionuclides are easily attributed to past reactor operations. Sodium dichromate was used in large amounts for decades as a water conditioner for the reactor cooling water. The ammonia and sulfates could be associated with other process chemicals (for example, sulfuric acid).

The contaminant that stands out as being significant in this segment is chromium in almost all scenarios. Chromium is present in sediment and surface water. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137, cobalt-60, and strontium-90 in surface water, and tritium (hydrogen-3) in seep water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 2.7×10^{-4} lifetime risk and 1.2×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.27 lifetime risk and 1.9 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.3 Segment 3: Between 100-B/C and K Areas

As might be expected for a river segment not adjacent to a Hanford Site operating area, fewer contaminants are identified in Segment 3. Ammonia, cesium-137, cobalt-60, strontium-90, technetium-99, and tritium (hydrogen-3) are present in concentrations above the upstream background. The risk from several contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 and cobalt-60 in surface water (extrapolated from upstream), strontium-90 in sediment, and technetium-99 in seep water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and

1.1×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.026 lifetime risk and 2.4 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.4 Segment 4: K Reactor Area

Segment 4 represents the next Hanford Site operating area downstream. The number of contaminants identified increases, and the relative risk is also higher here than in Segment 3. The contaminants identified as present above background levels include ammonia, carbon-14, cesium-137, chromium, cobalt-60 (diffuse), cyanide, lead, mercury, nitrates, strontium-90, tritium (hydrogen-3), and uranium-238. Chromium risk exceeds the upper threshold value. In this segment, chromium is elevated in seeps and sediment with which they are associated. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include carbon-14, nitrates, and tritium (hydrogen-3) in seep water; cesium-137, cobalt-60, and strontium-90 in surface water (extrapolated from upstream); and lead and uranium-238 in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 2.1×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.11 lifetime risk and 4.2 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.5 Segment 5: K Reactor (Mile-Long Trench)

The region between the 100-K Area and the 100-N Area is outside the official boundaries of these operating areas, but it did contain a large crib for disposal of waste water from the 100-K reactors. Thus, contaminants identified in this segment are similar to those in Segment 4, although generally in slightly lower concentrations. Those contaminants identified as existing above upstream background levels are ammonia, benzene, carbon-14, cesium-137, chromium, cobalt-60 (diffuse), cyanide, europium-152 and -154, iodine-129, lead, strontium-90, sulfates, and technetium-99. Those sufficiently elevated to be above the upper threshold are chromium and strontium-90. Those above the lower threshold include benzene in seep water (surrogated by groundwater), cesium-137 and cobalt-60 in surface water (extrapolated from upstream), and lead in sediment. Chromium is present in sediment and the associated seeps. Strontium-90 is present in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 2.1×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.11 lifetime risk and 4.2 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.6 Segment 6: N Area

The 100-N Area is the location of the most recently operating Hanford Site reactor, the N Reactor, which was shut down in 1987. This area contains not only environmentally dispersed contaminants but also a large concentration of recently operating facilities. This is apparent in the large component of external radiation risk estimated for scenarios in this location. The source of the majority of the radiation

is the 1325-N and 1301-N Liquid Waste Disposal Facilities, and the 1304-N Emergency Dump Tank (Thatcher 1995). Each of these facilities contains substantial inventories of gamma-emitting radionuclides. As stated by the Washington State Department of Health, "free release scenarios involving access to the 100-N Area could not occur without a remediation of the highly contaminated areas" (Thatcher 1995, p. 23).

Other contaminants were identified as being in the environment in the 100-N Area in this analysis. These include ammonia, carbon-14, cesium-137, chromium, cobalt-60 (diffuse), europium-152 and -154, iodine-129, strontium-90, and tritium (hydrogen-3). The contaminants above the upper threshold, along with the direct radiation, are chromium and strontium-90. The chromium is indicated as being in surface water by the Industrial Worker, Fish Hatchery Worker, and Avid Recreational Visitor scenarios. It is not indicated as being elevated for the other scenarios. The strontium-90 exposure primarily results from sediment, although it is likely that the sediment is associated with riverside. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include carbon-14, europium-154, and tritium (hydrogen-3) in seep water; cesium-137 in surface water, and cobalt-60 in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 4×10^{-4} lifetime risk and 4.7×10^{-4} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.042 lifetime risk and 2.0 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.7 Segment 7: Upstream of D Area

This segment is also between operating areas, and the levels of the various contaminants of interest are lower than in the preceding segment. Contaminants noted to statistically be elevated above the background level include carbon-14, cesium-137, chromium, cobalt-60 (diffuse), europium-152, sulfates, and tritium (hydrogen-3). The chromium and sulfates are sufficiently elevated to be above the upper threshold. Chromium is elevated in surface water for the Industrial Worker and Fish Hatchery Worker scenarios and in sediment for the Ranger and Native American Subsistence Resident scenarios. Sulfates are present in groundwater (substituted for seep water) and contribute to risk primarily via the direct ingestion portions of the scenarios. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 in surface water (extrapolated from upstream), cobalt-60 and europium-152 in sediment, and sulfates in seep water (surrogated with groundwater).

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.6×10^{-4} lifetime risk and 1.8×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.066 lifetime risk and 2.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.8 Segment 8: D Area

Segment 8 houses the D and DR Reactors in the 100-D Area. This area is the apparent source of the discrete radioactive particles discussed in Section 5.2.6. Based on the discussion of Section 5.2.6, these

particles do not present a major human health risk, and although they have been detected downstream of this location, they are not discussed further. Other contaminants identified as existing in concentrations elevated above the upstream background are ammonia, cesium-137, chromium, cobalt-60 (diffuse), europium- and -154, mercury, strontium-90, sulfates, technetium-99, and tritium (hydrogen-3). Chromium is elevated sufficiently to be above the upper threshold. Chromium is present in surface water, seeps, and sediment at this location. This condition has been reported regularly (for example, Dirkes and Hanf 1996). The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 and cobalt-60 in surface water; europium-154, strontium-90, and tritium (hydrogen-3) in seep water; and technetium-99 in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 6.2×10^{-5} lifetime risk and 1.6×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.087 lifetime risk and 2.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.9 Segment 9: The Horn

This segment is relatively far from the upstream operating reactors and relatively distant from the direction of groundwater flow common to the remainder of the Hanford Site, but some contaminants still are statistically evident above background levels. These include cesium-137, chromium, cobalt-60, europium-152 and -154, mercury, neptunium-237, strontium-90, sulfates, technetium-99, and tritium (hydrogen-3). Present in sufficiently high concentrations to exceed the upper reporting threshold is chromium. Chromium is present in seeps and sediment in Segment 9. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 (extrapolated from upstream), cobalt-60 (extrapolated from upstream), and strontium-90 in surface water; neptunium-237 and technetium-99 in sediment; and tritium (hydrogen-3) in seep water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.0×10^{-4} lifetime risk and 2.1×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.069 lifetime risk and 3.2 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.10 Segment 10: H Area

Reactor operations in the 100-H Area ceased over 30 years ago in 1965. However, the 100-H Area was subsequently used for other waste handling operations, some of which resulted in a substantial legacy of soil and groundwater contamination in the vicinity. Contaminants potentially relating to human health risk discerned to be above background levels in or near the Columbia River in this area include carbon-14, cesium-137, chromium, cobalt-60 (diffuse), europium-152 and -154, iodine-129, mercury, neptunium-237, nitrates, strontium-90, technetium-99, uranium-234, and uranium-238. Those resulting in risk above the upper threshold values in at least one of the scenarios are chromium, strontium-90, and uranium-238. Chromium is elevated in seep water and sediment. The primary medium for strontium-90 and uranium-238 is sediment. The risk from several other contaminants falls in the range between the lower and upper

reporting threshold. These include cesium-137 and cobalt-60 in surface water (extrapolated from upstream), neptunium-237 in sediment, and nitrate and technetium-99 in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.4×10^{-4} lifetime risk and 2.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.061 lifetime risk and 3.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.11 Segment 11: Between the H Area and White Bluffs Slough

Relatively few measurements are available for this segment. It is difficult to state which contaminants are not present in this segment. The limited information available does indicate that Hanford-related contaminants common in the other areas are also present in concentrations above background. These include cesium-137, cobalt-60 (diffuse), europium-152 and -154, mercury, technetium-99, tritium (hydrogen-3), and uranium-234 and -238. Through agreement with the CRCIA Team, only minimal analyses were performed for this river segment.

5.2.7.12 Segment 12: White Bluffs Slough

The sloughs are backwater areas, relatively distant from the operating areas and presumed release points, where fine-grained sediment and whatever is attracted to sediment can settle. The detected Hanford-related contaminants are fewer here, and the concentrations are generally also lower. However, benzene, cesium-137, cobalt-60, europium-152 and -154, mercury, nitrates, strontium-90, technetium-99, uranium-234, and uranium-238 are identified as being present in concentrations above background. None of the estimated risk exceeds the upper reporting threshold. The risk from several contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137, cobalt-60, and strontium-90 in surface water (extrapolated from upstream); strontium-90 in sediment; and uranium-234 and -238 in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.025 lifetime risk and 3.8 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.13 Segment 13: F Area

The reactor in 100-F Area was also shut down in 1965. Although some biological research continued in that area for several years, now almost all of the facilities have been removed and the waste sites stabilized. Concentrations of Hanford-related contaminants are relatively low. Contaminants identified as remaining above the background levels include ammonia, benzene (an indicator of petroleum hydrocarbons), cesium-137, chromium, diffuse cobalt-60, europium-152 and -154, mercury, strontium-90, technetium-99, and xylenes (probably also indicators of petroleum). Chromium remains in sufficient concentrations to exceed the upper risk threshold. Chromium appears in measurements of surface water. The risk from several other contaminants falls in the range between the lower and upper reporting

threshold. These include cesium-137 in surface water (extrapolated from upstream); strontium-90 in sediment; and cobalt-60, europium-152 and -154, benzene, and xylene in seep water. The benzene and xylene are both surrogated using groundwater measurements, strengthening their probable association.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 8.0×10^{-5} lifetime risk and 4.9×10^{-4} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.054 lifetime risk and 2.0 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.14 Segment 14: F Slough

The sloughs are backwater areas, relatively distant from the operating areas and presumed release points, where fine-grained sediment and whatever is attracted to them can settle. The detected Hanford-related contaminants are fewer here, and the concentrations are generally also lower. However, benzene, cesium-137, cobalt-60, europium-152 and -154, mercury, nitrates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), uranium-234, and uranium-238 are identified as being present in concentrations above background levels. No contaminants are present in concentrations sufficient to exceed the upper risk threshold. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 and cobalt-60 in surface water (extrapolated from upstream), and nitrates, uranium-234, and -238 in seep water. Nitrates are present in groundwater and provide a potential risk through drinking of seep water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.3×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.037 lifetime risk and 4.5 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.15 Segment 15: Between the F Area and Hanford Sloughs

This river segment is downstream of all the reactor areas and behind Gable Mountain in relation to the operations in the 200 Areas. Contaminants identified as above the background levels are cesium-137, cobalt-60, europium-152 and -154, mercury, strontium-90, sulfates, and technetium-99. None of the contaminants is present in concentrations sufficient to exceed the upper threshold. The risk from several other contaminants falls in the ranges between the lower and upper reporting threshold. These include cesium-137 and cobalt-60 in surface water (extrapolated from upstream). Strontium-90 is somewhat elevated in sediment in this segment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 7.6×10^{-5} lifetime risk and 1.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.011 lifetime risk and 2.1 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.16 Segment 16: Hanford Slough

The sloughs are backwater areas, relatively distant from the operating areas and presumed release points, where fine-grained sediment and whatever is attracted to them can settle. The detected Hanford-related contaminants are fewer here, and the concentrations are generally also lower. However, benzene, cesium-137, cobalt-60, europium-152 and -154, mercury, strontium-90, and technetium-99 are identified as being present in concentrations above background. None of the contaminants are present in concentrations resulting in estimated risk above the upper threshold. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 and cobalt-60 in surface water extrapolated from upstream, and strontium-90 in surface water measured in this location.

The total risk in this segment to humans estimated using the scenarios developed for this report ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and 2.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.013 lifetime risk and 3.4 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.17 Segment 17: Old Hanford Townsite

Although no nuclear production operations occurred in this segment, it is the original site of the town of Hanford, which began as a farming community and was later taken over as temporary housing for thousands of Hanford construction workers. Groundwater contaminated with contaminants from the 200 Areas is known to discharge into the Columbia River in this region. Contaminants identified as being above background levels in this segment are diffuse cobalt-60, europium-152 and -154, lead, mercury, nitrates, strontium-90, technetium-99, tritium (hydrogen-3), uranium-234, and uranium-238. The lead and tritium (hydrogen-3) are present in concentrations resulting in estimated risk above the upper threshold. Lead is present in sediment at this location at levels about twice as high as background. The primary increase is in groundwater. This may be due to historical releases in this region or may be the result of natural fluctuations. Tritium (hydrogen-3) is present in groundwater and is measured in seep water in this segment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include europium-154 in surface water; cobalt-60, nitrates, technetium-99, and uranium-234 in seep water; and uranium-238 in sediment.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and 2.9×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.012 lifetime risk and 5.4 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.18 Segment 18: Washington Public Power Supply System

A commercial nuclear electric generating station operates in this segment, withdrawing makeup water from the Columbia River and returning blowdown water from the cooling tower. Relatively few measurements are available for this segment. It is difficult to state which contaminants are not present in this segment. The limited information available does indicate that Hanford-related contaminants common

in the other areas are also present in concentrations above background. However, the water and shoreline of the Columbia River are not noticeably different here from other Hanford-influenced areas.

Contaminants identified as being above background include those seen in the other areas upstream: benzene, cesium-137, chromium, diffuse cobalt-60, europium-152, europium-154, mercury, phosphates, strontium-90, tritium (hydrogen-3), and xylene. Through agreement with the CRCIA Team, only minimal analyses were performed for this river segment.

5.2.7.19 Segment 19: Between the Supply System and 300 Area

This segment is relatively far downstream of the Hanford Site operating reactors but is still within the zone of groundwater discharge from the 200 Areas. Contaminants identified as above background levels include ammonia, benzene, cesium-137, chromium, diffuse cobalt-60, iodine-129, lead, mercury, nitrites, technetium-99, tritium (hydrogen-3), and uranium-238. That of greatest interest from a risk perspective is chromium. Chromium contributes to risk via sediment in this segment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137 (extrapolated from upstream), cobalt-60 (extrapolated from upstream), technetium-99, and uranium-238 in surface water; and iodine-129, nitrites, and tritium (hydrogen-3) in seep water. This is one of the few areas with positive measurements of either iodine-129 or nitrites in groundwater, which was used as a surrogate for seep water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 2.6×10^{-4} lifetime risk and 2.5×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.11 lifetime risk and 4.3 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.20 Segment 20: 300 Area

The 300 Area was used for research and development and also for manufacturing the uranium fuel elements used in the Hanford Site plutonium production reactors. Several well documented environmental releases of uranium have occurred in this area. Contaminants identified as above background levels include ammonia, cesium-137, chromium, diffuse cobalt-60, europium-154, iodine-129, lead, mercury, nitrates, phosphates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), uranium-234, and uranium-238. Those of particular interest are chromium, uranium-234, and uranium-238. Chromium is present in sediment. Uranium-234 is a decay product of uranium-238. They generally occur together in nature. Both are found in elevated quantities here in seep water and associated sediment. The risk from several other contaminants falls in the range between the lower and upper reporting threshold. These include lead and strontium-90 in surface water, and europium-154, nitrates, and tritium (hydrogen-3) in seep water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.7×10^{-4} lifetime risk and 2.2×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.073 lifetime risk and 3.9 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.21 Segment 21: 1100 Area to the Richland Pumphouse

This segment downstream of the 300 Area includes portions of the inhabited part of the City of Richland. This segment marks the southern boundaries of known groundwater plumes from Hanford Site sources. Contaminants identified here as above background include ammonia, cesium-137, cobalt-60, cyanide, europium-154, iodine-129, nitrates, nitrites, strontium-90, technetium-99, tritium (hydrogen-3), and uranium-238. None of the contaminants is present in sufficient concentration to result in estimated risk in excess of the upper threshold. The risk from several contaminants falls in the range between the lower and upper reporting threshold. These include cesium-137, cobalt-60, and europium-154 in seep water (surrogated with groundwater); and strontium-90 in surface water.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.3×10^{-4} lifetime risk and 2.1×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.042 lifetime risk and 4.1 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.22 Segment 22: Richland Pumphouse to Columbia Point

This segment comprises most of the City of Richland. This segment is downstream of all Hanford Site production operations and groundwater plumes. Any contaminants found here related to Hanford Site operations would have to be transported via the Columbia River itself. Contaminants identified as being above background include ammonia, benzene, cesium-137, cobalt-60, europium-154, iodine-129, lead, nitrates, nitrites, technetium-99, tritium (hydrogen-3), uranium-238, and xylene. Only the lead is present in sediment in concentrations sufficient to exceed even the calculated lower risk threshold. It is within 50 percent of the background concentration.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.4×10^{-4} lifetime risk and 2.2×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.04 lifetime risk and 3.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.23 Segment 23: Yakima River Influence

This segment was established between the Yakima River and Snake River entrances to the Columbia River. Thus it includes most of the cities of Pasco and Kennewick. Contaminants tentatively identified here above background levels are ammonia, cesium-137, cobalt-60, europium-154, iodine-129, nitrates, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. None of the contaminants is present in sufficient quantity to score above the risk thresholds.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.1×10^{-4} lifetime risk and 1.5×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.012 lifetime risk and 7.1 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.24 Segment 24: Snake River Influence

In this segment, the Snake River joins the Columbia River. Contaminants tentatively identified here above background levels are ammonia, benzene, cesium-137, cobalt-60, europium-152 and -154, iodine-129, mercury, nitrates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. Strontium-90 is present in sufficient quantity to score above the lower risk threshold, but the calculated result is dominated by a surface water estimate calculated with concentrations extrapolated from Segment 21.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 2.7×10^{-5} lifetime risk and 7.7×10^{-4} hazard index to a median high for the Native American Subsistence Resident Scenario of 3.3×10^{-3} lifetime risk and 4.6 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.25 Segment 25: Boise Cascade

This segment of the Columbia River includes the oxbow lakes of the Columbia River National Wildlife Refuge and is affected by a large paper pulp plant. This segment is not noticeably different from the one above it in terms of identified contaminants. Contaminants tentatively identified here above background levels are ammonia, cesium-137, cobalt-60, europium-154, iodine-129, nitrates, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. None of the contaminants is present in sufficient quantity to score above the risk thresholds.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 6×10^{-5} lifetime risk and 1.3×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 7.1×10^{-3} lifetime risk and 6.5 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.26 Segment 26: Walla Walla River Influence

This segment corresponds with the influx of the Walla Walla River into the Columbia River. This segment is not noticeably different from the one above it in terms of identified contaminants. Contaminants tentatively identified here above background levels are ammonia, cesium-137, cobalt-60, europium-154, iodine-129, nitrates, strontium-90, sulfates, technetium-99, tritium (hydrogen-3), and uranium-238. Strontium-90 is present in sufficient quantity to score above the lower risk threshold, but the calculated result is dominated by a surface water estimate calculated with concentrations extrapolated from Segment 21. As in Segment 24, this indication is likely a statistical variation near the background level.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 5.6×10^{-5} lifetime risk and

1.4×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 6.7×10^{-3} lifetime risk and 5.7 hazard index. These results are controlled by chromium and copper, respectively.

5.2.7.27 Segment 27: McNary Dam and Reservoir

This segment includes the McNary Reservoir between the influx of the Walla Walla River and McNary Dam. This segment is not noticeably different from the one above it in terms of identified contaminants. Contaminants tentatively identified here above upstream background are ammonia, cesium-137, chromium, cobalt-60, europium-152 and -154, nitrates, strontium-90, sulfates, technetium-99, and uranium-238. Chromium appears above the upper reporting threshold in this segment but only for the Ranger Scenario. This seems to be a statistical artifact. Strontium-90 is present in sufficient quantity to score above the lower risk threshold, but the calculated result is dominated by a surface water estimate calculated with concentrations extrapolated from Segment 21. As in Segments 24 and 26, this indication is likely a statistical variation near the background level.

The total risk in this segment to humans estimated using the scenarios developed for the screening assessment ranges from a stochastic median low for the Ranger Scenario of 1.5×10^{-4} lifetime risk and 2.3×10^{-3} hazard index to a median high for the Native American Subsistence Resident Scenario of 0.016 lifetime risk and 7.8 hazard index. These results are controlled by chromium and copper, respectively.

6.0 Synthesis of Results

The objective of the screening assessment was to identify areas where the greatest potential exists for adverse effects on humans or the environment under current conditions. This required determining what contaminants are elevated because of past or ongoing Hanford Site operations, and, if those contaminants are elevated, what is the measure of potential risk to both humans and the ecosystem.

With the above in mind, the following assessment questions were established:

- ◆ Do current levels of contaminants in Columbia River water, sediment, and riparian zone materials pose a potential risk to ecological resources?
- ◆ Do current levels of contaminants in Columbia River water, sediment, and riparian zone materials pose a potential risk to humans who might be exposed to them?

If the answers to either of these questions were yes, then answers for the following sub-set of questions were sought:

- ◆ What contaminants contribute to risk? (For answer, see Figure 6.1 and Table 6.1.)
- ◆ Where in the study area are these contaminants located? (For answer, see Figure 6.1 and Table 6.1.)
- ◆ In what media are these contaminants concentrated? (For answer, see Table 6.1.)
- ◆ Which organisms or groups of organisms have the greatest likelihood of being adversely affected? (For answer, see discussion below in Section 6.3 and Table 4.22 in Section 4.2.)
- ◆ Humans in which economic or cultural categories have the greatest likelihood of being adversely affected? (For answer, see discussion below in Section 6.3 and Figure 5.4 in Section 5.2.)

6.1 Assessment Context

By agreement with the Tri-Parties and the CRCIA Management Team, this screening assessment addressed the current potential for ecological and human risk, resulting from known levels of contaminants in the Columbia River or in its immediate vicinity. The screening assessment does not address inventories currently moving towards the river from distant locations or other inventories that may be left by future remediation activities at other Hanford Site locations.

The contaminants that could possibly be associated with past Hanford Site operations were evaluated. This contaminant identification process, described in Section 2.2, was based on a preliminary review of easily available records, environmental measurements, and process knowledge. The initial list contained nearly 100 possible environmental contaminants. Although a considerable effort was expended to compile this list, its use was to focus the remaining data gathering on only those contaminants of greatest interest. The data and parameters used in the selection of contaminants for study were not the ones used in the remainder of the screening assessment because the data and parameters used for the risk assessment could only be determined once the contaminants were selected.

		Minimal risk																										
		Ecological risk above threshold defined in Section 6.3																										
		Human risk above threshold (>IE-6 lifetime risk >0.01 hazard index)																										
		Above both ecological and human risk thresholds																										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakma	Snake	Boise	Wata	McNa
Analyte		Rapids	Area		Area	Trench	Area		Area	Hom	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Casc.	Wata R	Res
Ammonia																												
Benzene																												
C-14																												
Cs-137																												
Cr/Car																												
Co-60																												
Copper																												
Cyanide																												
Diesel																												
Eu-152																												
Eu-154																												
I-129																												
Kerosene																												
Lead																												
Mercury																												
Np-237																												
Nickel																												
Nitrate																												
Nitrite																												
Phosphate																												
Sr-90																												
Sulfate																												
Tc-99																												
Tritium																												
U-234																												
U-238																												
Xylene																												
Zinc																												

Figure 6.1. Summary of the Screening Assessment of Risk to the Ecosystem and Human Health (The reporting thresholds in this figure identify potentially hazardous contaminants, chronic and acute effects to all plants and animals, and toxic and carcinogenic impacts on human health for all scenarios considered in this report.)

Table 6.1. Potentially Hazardous Contaminants Identified by River Segment and Contaminating Media
(This table presents the contaminants by river segment and media and the estimated range of human risk.)

Contaminant	Ecological Risk		Human Risk					
	River Segment	Medium	River Segment	Medium	Ranger Scenario		Native American Sc.	
					Haz. Index	Risk	Haz. Index	Life Risk
Benzene			5	SP				2.60E-05
			13	SP				2.60E-05
Carbon-14			4	SP				2.90E-05
			6	SP				1.20E-05
Cesium-137			2	SW				7.01E-06
			3	SW(2)				7.46E-06
			4	SW(2)				1.06E-05
			5	SW(2)				1.32E-05
			6	SW				1.76E-05
	7	SD	7	SW(6)				2.16E-05
			8	SW				2.78E-05
			9	SW(8)				2.81E-05
	10	SD	10	SW(8)				3.06E-05
			11	SW(8)				2.94E-05
	12	SD	12	SW(8)				2.92E-05
			13	SW(8)				3.32E-05
			14	SW(8)				2.43E-05
			15	SW(8)				2.39E-05
			16	SW(8)				2.63E-05
			18	SW				1.34E-05
			19	SW(18)				2.05E-05
			21	SP(GW)				1.59E-05
Chromium	2	SD+SP	2	SW+SD		2.60E-04	2.32E-02	2.58E-01
	4	SD+SP	4	SD+SP		2.10E-04	3.30E-02	1.09E-01
	5	SD+SP	5	SD		2.10E-04	1.43E-02	6.30E-02
			6	SW		5.90E-05		4.23E-02
			7	SD		1.50E-04		6.94E-02
			8	SW+SP		5.60E-05	1.35E-02	8.66E-02
	9	SD+SP	9	SD+SP		1.00E-04	2.46E-02	6.72E-02
	10	SD+SP	10	SD+SP		1.40E-04	1.71E-02	5.90E-02
			13	SD		7.20E-05		5.28E-02
			18	SD		1.90E-04		3.89E-02
			19	SD		2.50E-04		1.05E-01
			20	SD		1.60E-04		7.03E-02
			27	SD		1.50E-04		1.64E-02
Cobalt-60 (Diffuse)			2	SD				3.54E-06
			3	SW(2)				2.22E-06
			4	SW(2)				2.96E-06

Table 6.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River Segment	Medium	River Segment	Medium	Ranger Scenario		Native American Sc.	
					Haz. Index	Risk	Haz. Index	Life Risk
			5	SW(2)				2.71E-06
	6	SD	6	SD				1.08E-05
	7	SD	7	SD				2.58E-06
	8	SD	8	SW				3.71E-06
	9	SD	9	SD				2.49E-06
			10	SW(8)				1.86E-06
			11	SW(8)				2.16E-06
	12	SD	12	SW(8)				2.04E-06
	13	SD	13	SP(GW)				6.61E-06
			14	SW(8)				1.55E-06
			15	SW(8)				2.08E-06
			16	SW(8)				2.08E-06
			17	SP				2.15E-06
			18	SW				3.49E-06
			19	SW(18)				8.46E-06
			21	SP(GW)				2.89E-06
Copper	4	SP	4	SD			2.35E+00	
			11	SD			2.57E+00	
			14	SD			2.79E+00	
			17	SD			2.51E+00	
	20	SP						
			23	SW			6.51E+00	
			24	SW(23)			4.28E+00	
			25	SW(23)			6.32E+00	
			26	SW(23)			5.30E+00	
			27	SW(23)			6.90E+00	
Cyanide	20	SP(GW)						
	21	SP(GW)						
Europium-152			13	SP(GW)				6.30E-05
Europium-154			6	SP				2.92E-06
			8	SP				9.23E-06
			13	SP(GW)				1.26E-05
			17	SW				3.13E-06
			18	SW(17)				3.15E-06
			20	SP				1.68E-06
			21	SP(GW)				1.47E-05
Iodine-129			19	SP(GW)				2.20E-06

Table 6.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River Segment	Medium	River Segment	Medium	Ranger Scenario		Native American Sc.	
					Haz. Index	Risk	Haz. Index	Life Risk
Lead	2	SD+SP						
	3	SD+SP						
			4	SD			4.30E-01	
	5	SD+SP	5	SD			3.65E-01	
	7	SD+SP						
	9	SD+SP						
	13	SD+SP						
	17	SD+SP	17	SD			1.22E+00	
	19	SD+SP	19	SD			6.47E-01	
	20	SD+SP	20	SD			4.74E-01	
	21	SD+SP						
			22	SW(21)			3.78E-01	
Mercury	3	SD						
	4	SD						
	6	SD						
	8	SD						
	9	SD						
	10	SD						
	12	SD						
	13	SD						
	14	SD						
	15	SD						
	16	SD						
	19	SD+SP						
	20	SD+SP						
Neptunium-237			8	SD				6.50E-05
			9	SD				8.30E-05
Nickel	20	SD						
Nitrates			4	SP			1.56E-01	
			10	SP			1.05E-01	
			12	SP(GW)			8.88E-02	
			14	SP			1.42E-01	
			17	SP			1.38E-01	
			20	SP			2.39E-01	
Nitrites			19	SP			1.08E-02

Table 6.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River Segment	Medium	River Segment	Medium	Ranger Scenario		Native American Sc.	
					Haz. Index	Risk	Haz. Index	Life Risk
Strontium-90			2	SD				8.35E-06
			3	SD				6.72E-05
			4	SW(3)				1.07E-05
			5	SD				1.28E-04
			6	SD				6.72E-04
			8	SP				1.79E-05
			9	SW				1.41E-05
			10	SD				1.10E-04
			12	SW(10)				6.43E-06
			13	SD				4.38E-05
			15	SD				5.95E-05
			16	SW				2.97E-05
			20	SW				6.09E-06
			21	SW				5.36E-06
			24	SW(21)				6.45E-06
			26	SW(21)				5.83E-06
			27	SW(21)				6.57E-06
Sulfates			7	SP(GW)			1.14E-02	
Technetium-99			3	SD				2.84E-06
		8	SD	8	SD			1.18E-06
		9	SD	9	SD			9.61E-07
		10	SD	10	SD			2.80E-06
		14	SD					
			17	SD				1.34E-06
		19	SD	19	SD			2.51E-06
Tritium (Hydrogen-3)			2	SP				1.31E-05
			4	SP(GW)				6.70E-06
			6	SP				1.70E-05
			8	SP				5.05E-06
			9	SP				4.31E-06
			17	SP				2.15E-04
			19	SP(GW)				2.38E-05
			20	SP				8.91E-06
Uranium-234			12	SD				4.62E-05
			14	SP				7.34E-05
			17	SP				7.62E-05
			20	SP				9.34E-04

Table 6.1. (Cont'd)

Contaminant	Ecological Risk		Human Risk					
	River Segment	Medium	River Segment	Medium	Ranger Scenario		Native American Sc.	
					Haz. Index	Risk	Haz. Index	Life Risk
Uranium-238			4	SD				5.18E-05
			10	SD				1.51E-04
			11	SD				4.93E-05
			12	SD				4.54E-05
			14	SP				6.49E-05
			17	SD				5.81E-05
			19	SW+SP				1.07E-04
			20	SP+SD				8.67E-04
Zinc	4	SP+SD	4	SD			1.72E-01	
	7	SP+SD						
	8	SP+SD						
			12	SP(GW)			3.78E-01	
			16	SD			1.47E-01	
	17	SP+SD	17	SD			1.59E-01	
			19	SD			2.29E-01	
	20	SP+SD						
GW = Groundwater SP(GW) = Seep water surrogated with groundwater								
SD = Sediment SW = Surface water								
SP = Seep water SW(21) = Surface water extrapolated from upstream Segment 21								
Note: Only human risk values greater than 1.0E-6 or a hazard index of 0.01 are shown.								

The initial list of potential contaminants was screened, using a multi-stage screening process described in Section 2.3, to a manageable number of contaminants likely to produce the greatest risk to the environment or human health. This process was based on a set of simple exposure equations for people and biota. The final list was established to provide reasonable assurance that the preponderance of the risk of either acute toxicity or long-term carcinogenicity of humans and of either acute toxicity or long-term survival of aquatic biota was addressed. Additional considerations were given to known sources of radiation and radioactive materials.

The spatial domain and spatial scale of the analyses were established in consultation with the CRCIA Team. The agreed focus was on the Hanford Reach of the Columbia River and the areas immediately downstream as far as McNary Dam. To best represent the current environmental conditions and state of knowledge relative to contaminant concentrations in the Columbia River, the study area was divided into 27 segments along the river. The segmentation also provides meaningful information associated directly with the site operable units that will be useful in evaluating future remedial actions.

Although the primary focus is on the Columbia River and its associated riparian zone, the potential for influx of contaminants via groundwater through seeps and springs was addressed by relying on additional

measurements of the potential contaminants in groundwater some distance inland from the river shoreline. Depending on the availability of groundwater measurements, this distance varies up to 0.8 kilometer (0.5 mile), the larger distances corresponding to areas with fewer measurements. The segments range in length from less than 1 kilometer to more than 30 kilometers (0.5 to 20 miles). Even the smallest segments are too large to clearly distinguish small areas of highly elevated concentration (in other words, hot spots). Several such areas are known, and other specific studies address them. However, discovery of additional hot spots was not the focus of this assessment.

To gather the data to be used in the screening assessment (a separate process from that to determine which contaminants to study), a detailed search for environmental measurements was made. Hanford and non-Hanford sources were queried, including Hanford contractors, local municipalities, the States of Washington and Oregon, and federal agencies. Data were collected for measurements in the surface water of the Columbia River itself, river sediment, seeps and springs within the Hanford Reach, and Hanford Site groundwater. Only relatively current data were used, defined as being within the period from 1990 to present, in order to avoid evaluating problems that no longer exist. A large database was prepared. However, for many of the contaminants of interest in many locations, measurements were not available for the time period of interest. In these cases, a series of surrogation and extrapolation rules were devised to allow approximation of the local contamination levels. Where use of these approximations has identified a contaminant of potential hazard, the use of the surrogate values is highlighted to indicate the need for further confirmatory measurements. The final database is much larger and better substantiated than that used in the initial selection of contaminants to consider, but it is limited to those that were selected for evaluation.

Concurrently with the data gathering, the CRCIA Team established the indicators that would be used to judge the degree of hazard. For the ecological risk assessment, this consisted of defining a set of indicator species for which comparisons against toxicological benchmarks would be made. The selection of these indicator species has been defined in Section 4.1. For the human risk assessment, a suite of twelve human exposure scenarios was prepared. These have been described in Section 5.1. Individual calculations for each of these scenarios were compared with both toxicity and carcinogenicity indices. The exposure scenarios used cover a wide range of possible behavior patterns, but they are not all-encompassing. Additional possible ways that people could be exposed are easily postulated. Some of the scenarios used have parameters that are not currently possible because of restricted use of the site. These were included because the CRCIA Team wanted to examine whether certain types of possible future land use would pose a risk to such individuals, although they do not represent recommendations about future land uses.

Computational models were developed for all of the ecological species and human scenarios. The computational models include algorithms and input data to produce quantitative results. The computerized models and their parameters have been described in Sections 4.2 and 5.2 and are provided on diskettes in the appendixes. The models were tested and verified prior to their use.

The levels of the contaminants showed variability among and within environmental media and among and within individual river segments. In addition, there is uncertainty in almost all of the parameters used in the ecological and human exposure risk calculations. This implies that there is also considerable variability and uncertainty in the results.

To attempt to quantify the uncertainty, two calculation methods were used: deterministic and stochastic. For the deterministic method, the equations were calculated with single, high values of the parameters to identify potential worst case results. For the stochastic method, the equations were calculated with all possible combinations of parameter values, resulting in an output distribution rather than a single value. For the human risk calculations, both deterministic and stochastic results are available for contaminants in each of the river segments where data or substitute data were available. For the ecological risk analysis, the deterministic calculations were performed for all contaminant-species-segment combinations, but the stochastic calculations were only performed for those combinations for which it appeared that any risk was possible.

A benefit of the stochastic calculations was they enabled the results to be subjected to statistical comparisons. In these comparisons, the concentrations and resulting risk of the contaminants in each Hanford-influenced river segment could be compared to those upstream in Segment 1 that supposedly has not been influenced by releases from the Hanford Site. These comparisons gave insight into the nature and magnitude of the incremental risk posed by Hanford releases.

The ecological risk evaluated is for injury to individual plants or animals. The current state of scientific knowledge does not allow extrapolation to impact on the ecosystem with this level of information. Human risk is limited to individual toxic response or long-term carcinogenicity. The scenarios cannot address cultural impact or multigenerational impact of the exposures.

6.2 Influence of Data Gaps and Potential Future Parameters on the Results

The analyses completed for the screening assessment are based on the currently available data. Information is not available for all of the contaminants studied in all river segments. Where appropriate, data were extrapolated or surrogated to fill some of the data gaps, but other data gaps remain. The final results of the screening assessment, therefore, are limited by the available information. The assessment has indicated that there are portions of the Hanford Reach of the Columbia River in which concentrations of contaminants, particularly in sediment and groundwater, are high enough to warrant additional investigation and possible remediation. These river segments have been identified in this report. However, because of the data gaps, it is not possible to state that the concentrations of some of the contaminants in other locations are not also excessive.

The density of data that were available for the assessment is illustrated in Section 3.0. For some river segments, relatively few data are available. These are areas for which sampling could be advisable. However, the existing sampling schemes were developed with knowledge of past Hanford Site operations and the results of past sampling. In some instances, the lack of data for certain contaminants in certain locations is because those locations never gave cause to warrant sampling for those contaminants during the period 1990 to present. They may have been sampled earlier. Before a recommendation can be made for further sampling, consideration should be given to the results of past sampling not used in this analysis and the likelihood of acquiring useful information with additional sampling. Systematic radiological surveys have been made in the past (for example, Sula et al. 1980, EG&G 1990) that indicate the potential for finding additional, highly radiologically contaminated areas is small.

A further difficulty is that the spatial extent of the river segments as defined for the analysis is large enough to partially mask the presence of hot spots. The risk results tend to average out over segments as much as a few miles long. While it is quite unlikely that individual humans would choose to spend large portions of their time and derive most of their food from single point locations, it is likely that specific biota (particularly plants) could live their entire lives in one spot.

In tandem with the data gaps is the fact that the scenarios used to establish the potential for human exposure, defined in Section 5.1, all have a common starting assumption: the individual described performs all of the described activities within the selected segment and within the river or immediately adjacent riparian zone. In many locations along the riverbanks of the study area, the riparian zone is quite narrow. The likelihood of a person's actually deriving all of her or his food and water from this narrow strip of land has not been included in the scenario definitions. However, to simplify the analyses and provide a common basis for comparison, the same assumptions have been used for all river segments. It is recognized that the screening assessment has been performed with scenarios that include parameters not currently allowed because access to the site is restricted. These parameters are included because the CRCIA Team desired to determine if future potential uses of the land could pose risk to certain types of individuals. Before remedial activities are considered, site-specific considerations should be added to the general results presented here.

The screening assessment was designed to focus attention on those contaminants with the most immediate potential for human and ecological risk. However, some parameters included are future potential parameters. In addition, some data gaps have limited the assessment. Therefore, it is important to take into consideration the focus, the assumptions, and the limitations of this assessment when evaluating the results. Because a contaminant has been identified as potentially posing a risk does not necessarily mean that there is imminent risk to humans or the environment from this contaminant. Just as important, the converse may also be true. Because the risk of a contaminant in certain segments has not been identified does not necessarily mean that a risk does not exist. It just may not have been measured yet.

6.3 Screening Assessment Results and Conclusions

The results of the screening assessment are provided in Section 4.2 for the ecological risk and Section 5.2 for the human risk. These sections show that when taken in the context of the screening assessment the answers to the two main assessment questions are yes. Environmental levels of some contaminants do appear to be elevated as a result of Hanford Site operations as well as resulting from other human activities upstream in the Columbia Basin. Both the ecological modeling and human exposure simulations identify contaminants and locations for which risk to both the environment and humans is evident and for which further analyses or measurements would be worthwhile.

Figure 6.1 is a high-level summary of the findings of the ecological risk and human health risk assessments. The contaminants and affected segments of the Columbia River that pose a potential risk according to the results of either the ecological or human risk assessments are identified. The overlapping results of the two assessments are also identified. For most of the contaminants, segments identified by the ecological risk analysis were also identified by the human health analysis, but sometimes the contaminants were in media that affect biota more directly than humans, so that human risk for those contaminant-segment

combinations is below the reporting threshold. Conversely, segments identified via the human health analysis having indications of increased potential risk are not always identified in the ecological analysis.

The reporting thresholds used in Figure 6.1 to identify potentially hazardous contaminants include consideration of chronic and acute effects on the environment and toxic and carcinogenic impact on humans. For the chronic ecological effects, a contaminant is identified if the number of stochastic simulation results exceeding a chronic toxicity benchmark is more than 5 percent greater than the number estimated in the background segment for that contaminant (denoted by yellow in Figure 4.19 of Section 4.2). For acute ecological effects, a contaminant is identified as potentially hazardous if the sum of acute risk indices across all species for a contaminant is more than twice the equivalent total for the background segment (denoted by red in Figure 4.19 of Section 4.2). For humans, a contaminant is identified as potentially hazardous if the estimated hazard index for a given contaminant for any scenario is greater than 0.01 or if the estimated lifetime risk for any scenario is greater than 10^{-6} .

The contaminants identified in Figure 6.1 as potentially hazardous are listed in Table 6.1 with additional details about the magnitude and sources of the potential risk. Table 6.1 presents the contaminants of highest potential risk identified in either the ecological risk assessment or the human health risk assessment, the segments in which they were identified, the medium or media which provided the dominating component of the risk, and the range of estimated human risk. To demonstrate the range of human risk, the median stochastic values of lifetime risk (carcinogenic chemicals and radionuclides) and hazard index (toxic chemicals) for both the Ranger and Native American Subsistence Resident scenarios are given. Table 6.1 then answers the first three subset questions of which contaminants at what location and in which media are a potential threat.

To answer the fourth sub-set question, the types of organisms most likely to be adversely affected were identified. Terrestrial species that are potentially most affected by contaminants in the study area are swallows, mallards, American coots, harvest mice, Canada geese, and raccoons. However, risk within the study area that is above background levels is limited to only a few locations within the study area (see Figure 4.22). The other species, including bald eagles, have relatively low risk in both absolute and relative (to background) terms. Aquatic species most likely to be affected by acute or chronic toxic effects from contaminants of Hanford Site origin are Columbia pebblesnail, hyalella, daphnia magna, crayfish, Woodhouse's toad, suckers, clams, mussels, and salmon/trout larvae. Most of these aquatic organisms have a benthic life style, spending all or a high proportion of their life in direct contact with sediment or pore water, and the pore water concentrations tend to drive their body burdens. A key pathway of exposure for the terrestrial organisms is predation of the aquatic species with high body burdens, which is also ultimately related to the concentration of contaminants in pore water.

To answer the fifth sub-set question, the categories of humans most likely to be affected were identified. Humans in the region of the Hanford Site may have a wide variety of exposures, from low to high. Generally speaking, the scenarios for the Fish Hatchery Worker, Industrial Worker, and Ranger have the lowest exposures and, therefore, are lowest in terms of health risk. As defined in Section 5.1, none of the people involved in these scenarios consume foods grown in the Columbia River riparian zone or drink seep water. Therefore, the exposures are mostly incidental external exposures and inhalation of resuspended materials, although the Fish Hatchery and Industrial workers also consume a moderate amount of Columbia River

water. The risk to workers from these pathways is quite low in comparison to those projected for people potentially exposed in other ways. At the other extreme, people postulated to live along the Columbia River, to eat substantial quantities of foods grown in the riparian zone, to eat fish and wildlife from the river, and to drink seep water have much larger potential exposures and, thus, estimated health risk. This category encompasses nearly all of the remainder of the scenarios described in Section 5.1. From a risk-assessment standpoint, very few differences appear between any of the Native American scenarios and recreational/residential scenarios. All postulate individuals who spend the bulk of their time in the vicinity and consume riparian-zone foods and drink untreated water.

Through the use of multiple exposure scenarios, the possible activities of people who could come into contact with the contaminants were evaluated. In general, risk to people today is low because of restricted access to the Hanford Site. Casual visitors and even people working in jobs associated with the Columbia River are not at risk unless they frequent limited areas and consume seep or spring water in which high concentrations of contaminants are present. However, potentially increased risk is possible if people were to move onto the Hanford Site and derive large percentages of their daily food intake from crops and animals in the river's riparian zone. In most instances, this higher risk is limited in extent to a few regions of highest contamination. Although there are numerous cultural differences between the general population and Native Americans, the common pathways of food and water consumption could affect both groups. These common pathways are the ones by which most exposure would be received. The key differences come in the source of the water and food products.

Because of scientific uncertainty, the overall potential impact on the riparian ecosystems is not known. There is insufficient knowledge about the distribution of species, their migration patterns, and their interactions over the entire Hanford Reach. It is possible to say that there is a risk to individual members of certain species, those that frequent the locations of highest contamination.

6.3.1 Hanford and Non-Hanford Sources of Contaminants

Contaminants for which a Hanford source appears to be indisputable include ammonia, cesium-137, chromium, cobalt-60, europium-152, europium-154, nitrates, strontium-90, technetium-99, tritium (hydrogen-3), and uranium isotopes. Other contaminants for which the Hanford Site may be a contributor, at least at specific locations, include copper, cyanide, lead, mercury, and zinc. The analyses indicate relatively high potential risk from these latter contaminants. However, the upstream risk from these contaminants is also high, and the Hanford Site increment over the upstream value is generally factors of two to three or less, making exact identification difficult.

As discussed in Section 4.2, there are sources of heavy metal releases to the Columbia River upstream of the Hanford Site. Thus, there are amounts of these metals, particularly chromium, copper, lead, mercury, and zinc, in sediment and water being transported through the Hanford Reach from operations, such as mining, upstream (Munn et al. 1995, Serdar 1993, Johnson et al. 1990). Recent events (Tri-City Herald 1997) have shown that upstream tributaries of the Columbia River may carry very high levels of metals, particularly during periods of high runoff. The concentrations are sufficient to be acutely toxic to wildlife. Contaminant metals tend to sorb to fine grained sediment, which deposit in slack water areas. Sizable quantities of sediment are deposited in the study area in the Hanford sloughs as well as behind both Priest

Rapids Dam upstream (a portion of Segment 1) and McNary Dam downstream (Segments 22-27). This sediment deposition with its relatively high concentrations of metals may help explain some of the results discussed below.

6.3.2 Uncertainty

Uncertainty is inherent in any risk assessment. The uncertainty within the ecological and human health assessments are discussed in Sections 4.2.10 and 5.2.3.3, respectively. Uncertainties include those associated with the exposure models, measured media data, representativeness of the data, use of surrogate and extrapolated data, exposure scenarios, accuracy of modeled processes, and toxicological and dose response references.

6.3.3 Potentially Hazardous Contaminants

The contaminants discussed in this section are those identified by the ecological and human health screening assessments to be potentially hazardous (see Figure 6.1 and Table 6.1). The intent of the following discussion of each potentially hazardous contaminant is to focus possible remedial decisions on those contaminants and media with the potential for the greatest risk reductions.

Benzene. Benzene is seen in low concentrations in seep water, frequently in conjunction with xylenes. It is a measurement surrogate for petroleum hydrocarbons. Some instances of petroleum contamination are known at the Hanford Site. The highest levels are seen at the 100-K and 100-F Areas. The primary exposure pathway is consumption of seep water.

Carbon-14. Carbon-14 is not detected in surface water. The Native American and Resident scenarios are uniformly controlled by ingestion of carbon-14 derived from seep water. Seep water was surrogated with groundwater in almost all segments along the Hanford Site. A single, particularly high value in the 100-K Area is evident in the deterministic data.

Cesium-137. Cesium-137 is a constituent of worldwide fallout and is present in soil and river sediment both upstream and downstream of the Hanford Site. Although in general the concentrations of cesium-137 in sediment are not greatly different from areas away from the Hanford Site, there is a greater variability in the measurements, indicating that a few localized zones of increased concentration exist. The primary risk is to biota that burrow into or live on the sediment. The primary pathway is external irradiation of these biota. For humans, the scenarios with high fish consumption show somewhat elevated risks from surface water, but this is largely driven by the surrogation process from a very few measured segments.

Chromium. This metal is identified as existing in elevated concentrations in several Hanford Reach river segments. For biota, the primary media of concern are sediment and pore water within the sediment (modeled using measurements of seep water or groundwater), and for humans the primary media are also sediment and the associated seeps. This indicates that the primary problem is groundwater contamination inland of the areas of the seeps, which is resulting in contamination of the sediment around the point where the groundwater issues into the river.

Cobalt-60. This radionuclide exists in both discrete particulate form and as generalized diffuse contamination. The particles have higher discrete activity and are somewhat easier to detect, but the more significant problem is with the diffuse sources. As with cesium-137, the primary ecological problem is direct external irradiation of biota that burrow into the sediment contaminated with diffuse cobalt-60 contamination.

Copper. In general, the risk to humans or biota from copper is similar above and below the Hanford Site. However, in absolute terms, this metal is one of highest risk to biota and humans. The modeling indicates that pore water (modeled using groundwater measurements) in the 100-K Area may be elevated, thus exposing biota. Copper is one of the metals that may also be enhanced from upstream sources.

Cyanide. The excess risk calculated for this chemical compound is associated with pore water (modeled using groundwater) for biota and with seep water (also modeled using groundwater) for humans.

Europium-152. Europium-152 is an activation product, similar in source to cobalt-60. Although discernible above background throughout the Hanford Reach in sediment, the risk to humans from europium-152 is primarily from ingestion of seep water in Segment 13.

Europium-154. Like europium-152, the activation product europium-154 is slightly elevated throughout the Hanford Reach. The primary exposures are via seep water, although the primary mechanism in Segments 17 and 18 is via surface water.

Iodine-129. Iodine-129 is detectable above background at very low levels in Hanford surface water, but the primary pathway of exposure is via drinking seep water. The only segment with concentrations measured sufficiently high to score over a risk of 10^{-6} is Segment 19.

Lead. The risk for lead to biota is dominated by concentrations in sediment and pore water, and the risk to humans is dominated by concentrations in sediment. Lead is one of the metals that may also be enhanced in sediment from upstream sources, but there are signs that lead may be somewhat enhanced in Hanford Site groundwater, particularly in the vicinity of the old Hanford townsite.

Mercury. The risk from mercury is primarily to biota from sediment. Mercury is one of the metals that may also be enhanced from upstream sources.

Neptunium-237. The only positive measurements for neptunium-237 occur in sediment in Segments 8 and 9, which in the modeling lead to small ingestion intakes. These are single point measurements and do not represent wide area contamination.

Nickel. The ecological modeling identifies nickel in sediment as a possible problem in the 300 Area only.

Nitrates. The risk to humans from nitrates is derived from the pathway of drinking seep water. Nitrates are known to be elevated in Hanford Site groundwater with samples in groundwater above the EPA drinking water standards in several of the reactor areas (see, for example, Dirkes and Hanf 1996).

Strontium-90. The primary risk to humans from strontium-90 comes from consuming foods grown in contaminated sediment. Risk from consumption of seep water comes in a close second. It is likely that the concentrations in the sediment are related to the seep water concentration at most of the locations that are coincident with reactor areas.

Sulfates. Sulfates are measured in surface water and seeps in numerous locations. The primary pathway is direct ingestion. The concentrations averaged in Segment 7 are slightly higher than elsewhere, but the risk from sulfates is generally low.

Technetium-99. Environmental concentrations of technetium-99 are not high, but the soil-to-plant uptake factor for technetium is very large. Vegetation has a strong propensity to concentrate technetium from soil. The key medium for technetium-99 is sediment. In the case of the ecological results, the risk is actually related to the chemical toxicity of technetium in plants. For the human health results, the risk is associated with consumption of food plants grown in the technetium-contaminated sediment in the riparian zone.

Tritium (Hydrogen-3). Tritium is widely distributed in Hanford Site groundwater. However, it has a low biological uptake and generally short retention time in plants and animals because it is associated with water. The primary route of exposure to humans is via consumption of seep water. The most extensive region where seep water contaminated with tritium enters the Columbia River is the vicinity of the old Hanford townsite.

Uranium-234/238. Although uranium is also ubiquitous in the environment, several areas have concentrations elevated above background levels. The media of interest include sediment and seep water near the 300 Area. A prominent pathway is the consumption of prey animals by animals farther up the food chain.

Zinc. The risk to biota is predominantly influenced by pore water and sediment. This metal provides the highest absolute contribution of risk to biota, but the median relative ratio to the upstream value is generally less than 1 for risk to humans. Zinc is one of the metals that may also be enhanced from upstream sources.

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Appendix I-A

Analytes Evaluated, Parameter Values, and Numerical Results

Appendix I-A

Analytes Evaluated, Parameter Values, and Numerical Results

The tables of data for this appendix are Microsoft Excel 5.0 files on diskette. Table A.1 (diskette file con-apa1.xls) provides a list of all radionuclides and chemicals for which monitoring has been reported in the reviewed literature of samples from the Columbia River and groundwater in the Hanford Site 100, 300, 1100 Areas, and other areas within 150 meters (500 feet) of the Columbia River. For those contaminants which had a detected level, the highest concentration reported is listed. A total of 568 analytes are listed. The 73 analytes for which detected levels were reported are listed in Table 2.1.

Table A.2 (diskette file con-apa2.xls) provides a list of all radionuclides and chemicals for which monitoring has been reported in the reviewed literature of samples from soil and sediment in the Hanford Site 100, 300, and 1100 Areas. For those contaminants which had a detected level, the highest concentration reported is listed. A total of 560 analytes are listed. The 86 analytes for which detected levels were reported are listed in Table 2.2.

The data depicted in Tables A.1 and A.2 are from a variety of documents containing different measurements. Whereas the measurements can at times appear contradictory, they reflect the data as they appear in the documents reviewed.

The equations detailed in Section 2.3 require parameters for each radionuclide and chemical evaluated. The parameters used to screen samples from the Columbia River and groundwater within 150 meters (500 feet) of the Columbia River are provided in Table A.3 (diskette file con-apa3.xls). The parameters used to screen samples of soil and sediment are provided in Table A.4 (diskette file con-apa4.xls). The parameters used to screen samples of groundwater farther than 150 meters (500) feet from the Columbia River are provided in Table A.5 (diskette file con-apa5.xls).

This appendix also provides the numerical results of applying the screening equations in Section 2.5 to the detected analytes described in Sections 2.3 and 2.8. Table A.3 (diskette file con-apa3.xls) presents the numerical results of screening samples from the Columbia River and groundwater within 150 meters (500 feet) of the Columbia River. Table A.4 (diskette file con-apa4.xls) presents the numerical results of screening soil and sediment samples. Table A.5 (diskette file con-apa5.xls) presents the numerical results of screening samples from groundwater farther than 150 meters (500 feet) from the Columbia River. Application of the equations and assumptions defined in Section 2.5 results in a series of complementary, but not necessarily intercomparable, screening values for each contaminant. The varying numbers of assumptions and associated varying degrees of conservatism require that each of the screenings be evaluated separately. The results of the combined screenings, however, then define the overall list of contaminants to be analyzed in the screening assessment.

The following abbreviations are used in the Microsoft Excel tables in this appendix. All units are as reported in the reviewed literature. The column headings, such as 100-KR-4, refer to sampling locations at operable units, described in Section 2.1.

aCi/L	=	attocuries per liter (one one-millionth of a pCi/L)
AWQC	=	ambient water quality criteria
Bkg	=	background denotes that the highest concentration found was at background level so eliminated from consideration
CAS#	=	Chemical Abstract Service number, a unique numerical identifier for chemicals
EPA-10	=	eliminated from the human risk assessment based on the guidance in EPA Region 10 Supplemental Risk Assessment Guidance for Superfund (EPA 1991).
GW	=	groundwater
HEIS	=	Hanford Environmental Information System database
Kd	=	sediment/water equilibrium partitioning coefficient
Koc	=	carbon matter partitioning coefficient
Kow	=	octanol/water partitioning coefficient
L/kg	=	liters per kilogram
LC ₅₀	=	lowest concentration reported to be lethal to 50% of the organisms 100 days after exposure (EPA 1985)
LD ₅₀	=	near limit of detection
µg/kg	=	micrograms per kilogram
µg/L	=	micrograms per liter
MeV	=	million electron volts
mg/kg	=	milligrams per kilogram
mg/L	=	milligrams per liter
ml/g	=	milliliters per gram
ND	=	not detected in sample; not all data compilers used this convention; some analytes show no entry where an ND is appropriate
pCi/g	=	picocuries per gram
pCi/kg	=	picocuries per kilogram
pCi/L	=	picocuries per liter
ppb	=	parts per billion
SD	=	sediment
SL	=	soil
Suspect	=	noted in the source database as being unreliable (see Section 3.4)
SW	=	surface water (Columbia River water)
SW-LD	=	reported sample in surface water very near the limit of detection and, therefore, unreliable
TLM	=	lowest concentration below which no effects on aquatic life are observed (EPA 1985)
w/Pu239	=	concentration included in the value reported for plutonium-239
w/U233	=	concentration included in the value reported for uranium-233
*	=	laboratory results marked as suspect data (see Section 2.4.5).

Appendix I-B

Media Files, Plots, and Final Data File

Appendix I-B

Media Files, Plots, and Final Data File

Media Files

The concentration input files resulting from the data selection process are called the media files. The media files were derived from the Microsoft Access database of raw files (see Appendix A in the final publication of Volume II of the draft data report). The media files are provided on diskette in this report as comma separated files that can be opened and read by Microsoft Excel 5.0

Each medium is provided in a separate file. The media are groundwater (GW), sediment (SD), seeps (SP), surface water (SW), and external radiation (ER). Each media file contains a record for each contaminant in each segment. The records are sorted by contaminant first, then segment. For each medium, a file is constructed that contains the following information:

Media Files

Media	Medium name
Segment_No	Segment number
Contaminant	Contaminant name
Units	Units of measurement
Max_Value	Maximum concentration
Max_Qualifier	Qualifier associated with the maximum concentration
Max_Conc_Flag	Concentration flag associated with the maximum concentration, used instead of the qualifier
Max_Samp_Num	Identifying number for the sample with the maximum concentration
Max_Samp_Date	Date of the sample with the maximum concentration
Max_Samp_Owner	Organization that has responsibility for the sample with the maximum concentration
Max_NScoord	North-south coordinate for the sample with the maximum concentration
Max_EWcoord	East-west coordinate for the sample with the maximum concentration
GM	Geometric mean
GSD	Geometric standard deviation
Nobs/Num_Obs	Number of records for that contaminant/medium combination
Nfit/Num_Obs_fit	Number of null or negative values that were estimated if the fitting process was used to calculate the geometric mean and geometric standard deviation (see "Compute Stochastic Parameters" in Section 3.4.3.2 for explanation of fitting process)
-999	Missing/not sampled
#####	Widen column so number can appear
GW	Groundwater

NA	Not available
ND	Not detected
NS	Not sampled
SD	Sediment
SP	Seeps
SW	Surface water
TLD	External radiation

If there were no data for a contaminant and segment combination, there is an "NA" in the media file for the pertinent record. This is the case for the maximum and its associated information and for the geometric mean and geometric standard deviation. If data are marked as undetected (qualifier of "u") in segments with no detected values for the particular contaminant in question, a geometric mean and geometric standard deviation were calculated on the detection limits reported (see Section 3.4.2), but the maximum value and its associated information are reported as not available (NA). The media file names are:

med-gw.csv	groundwater data	med-sw.csv	surfacewater data
med-sd.csv	sediment data	med-tld.csv	external radiation data
med-sp.csv	seep data		

Plots of the Maximum Values and Geometric Means

The plots in this appendix depict the maximum values and geometric means of the contaminants for which data, extrapolated data, or surrogate data are available. Extrapolation is the filling of data gaps using data from the same medium but from a different location. Surrogation is the filling of data gaps using data from the same location but from a different medium. The following rules were applied to fill some of the data gaps:

- ◆ Groundwater: No substitutions
- ◆ Sediment: No substitutions
- ◆ Seep Water: Use groundwater data as a surrogate where available
- ◆ Surface Water: If no measured data are available for Segment 1, extrapolate from Segment 2 if available. In Segments 2-27, extrapolate from the nearest upstream segment with measured data

Because Segment 1 is upstream of the operating areas, the values for Segment 1 indicate the background levels of the contaminants. The key to the plots is as follows:

- x Maximum concentration
- Point where the maximum concentration and geometric mean coincide
- Geometric mean
- Connecting line for maximum values
- ... Connecting line for geometric mean values

Final Data File

The file containing the selected data in the media files plus the substituted data is the "final data file." The final data file was the file used in the human health (along with the external radiation media file) and ecological screening risk assessments. Of the possible 3,024 data values, 1,153 have no data even after the substitution.

The final data file contains the original groundwater, seep, sediment, and surface water data. When no seep data were available, groundwater data were used as a surrogate. When no surface water data were available, values extrapolated for the same contaminant in the next upstream segment were used.

The final data file (fin-data.xls) is provided on diskette in this report as a comma separated file that can be opened and read by Microsoft Excel 5.0. The file contains the following information:

Segment	Segment number
Con_long_name	Contaminant name
gwmax (μCi/L or mg/L)	Maximum groundwater concentration
gwgm (log units)	Geometric mean of groundwater concentrations
gwgsd (log units)	Geometric standard deviation of groundwater concentrations
sdmax (μCi/kg or μmg/kg)	Maximum sediment concentration
sdgm (log units)	Geometric mean of sediment concentrations
sdgsd (log units)	Geometric standard deviation of groundwater concentrations
spmax (μCi/L or μg/L)	Maximum seep concentration
spgm (log units)	Geometric mean of seep concentrations
spgsd (log units)	Geometric standard deviation of seep concentrations
swmax (μCi/L or μmg/L)	Maximum surface water concentration
swgm (log units)	Geometric mean of surface water concentrations
swgsd (log units)	Geometric standard deviation of surface water concentrations
-9.99E+02	Missing/not sampled
#####	Widen column so number can appear

Ground Water - Ammonia

Ground Water - Benzene

Ground Water - Carbon-14

Ground Water - Cesium-137

Ground Water - Chromium

Ground Water - Cobalt-60

Ground Water - Copper

Ground Water - Cyanide

Ground Water - Europium-152

Sediment - Benzene

Sediment - Cesium-137

Sediment - Chromium

Sediment - Cobalt-60

Sediment - Copper

Sediment - Europium-152

Sediment - Europium-154

Sediment - Lead

Sediment - Mercury

Sediment - Neptunium-237

Sediment - Nickel

Sediment - Nitrate

Sediment - Strontium-90

Sediment - Technetium-99

Sediment - Uranium-234

Sediment - Uranium-238

Sediment - Xylenes (total)

Sediment - Zinc

Seep - Strontium-90

Seep - Sulfate

Seep - Technetium-99

Seep - Tritium

Seep - Uranium-234

Seep - Uranium-238

Seep - Zinc

Surface Water - Zinc

Surface Water - Uranium-238

Surface Water - Uranium-234

Appendix I-C

Species List and Scoring of Tier I Species

Appendix I-C

Species List and Scoring of Tier I Species

A master species list was assembled that included terrestrial and aquatic plant and animal species known to occur in riverine and riparian habitats of the Columbia River between the vicinity of Priest Rapids Dam and the Columbia River estuary. The master list was developed by selecting species from databases and records maintained by federal and state resource management agencies associated with the Columbia River and its environs.

Species distributions and habitat preferences were also obtained from these agencies. The majority of information was obtained from the U.S. Fish and Wildlife Service national wildlife refuges. Information on species distributions and habitat preferences was used to exclude species that primarily use upland areas. From the resulting master species list, 368 species were identified as those that occur within the study area. Table C.1 provides the master species list. The table is a Word Perfect 5.1 for DOS file on diskette and provides the following information:

- ◆ Class categories: algae, amphibians, aquatic invertebrates, birds, emergent vegetation, fish, macrophytes, mammals, reptiles, terrestrial invertebrates, and terrestrial vegetation
- ◆ Common name
- ◆ Scientific name
- ◆ General location to indicate whether the species occur within the study area (the riverine and riparian areas between the vicinity of Priest Rapids Dam and McNary Dam)
- ◆ Habitat for each species: aquatic, benthic, buildings, coastal shoreline, cobble-gravel substrate, disturbed areas, estuarine, gravel substrate, island, marsh, riparian, sand-cobble substrata, sand-rock substrate, semi-aquatic, semi-pelagic, shoreline, upland, wetland
- Specific location to indicate where data were available on the distribution of the species

Because of redundancy in exposure and the increased uncertainty in the risk assessments of the species for which data are lacking, the 368 study area species were reduced further in number. The Pacific Northwest National Laboratory formed a panel of regional biologists who developed a set of six criteria that were approved by the CRCIA Team for screening the study area species.

The six criteria developed by the panel were:

- ◆ Commercial or recreational importance
- ◆ Protection status under the Endangered Species Act or similar state legislation
- ◆ Critical component of either the riparian or aquatic ecosystem: key predator or prey
- ◆ High potential exposure to contaminants
- ◆ Availability of toxicological benchmarks for the species
- ◆ Representative of a foraging guild

Each species received a positive or negative response to each of the six criteria. Three or more positive responses were selected as an arbitrary cutoff, resulting in selection of 93 (roughly 25 percent) of the 368 study area species. These 93 species were submitted to the CRCIA Team for review and input. An additional 88 species (based on their cultural and ecological importance) were provided by the CRCIA Team to create a list of 181 Tier I species. Table C.2 provides the list of 181 Tier I species. The table is a Word Perfect 5.1 for DOS file on diskette and provides the following information:

- ◆ Identification of which species met which of the six criteria
- ◆ Criteria scores for each species
- ◆ Identification of which species were selected by the CRCIA Team for further evaluation

Of the 181 Tier I species, some were grouped based on similar life styles and trophic levels resulting in 121 species. The CRCIA Team added 5 species to the 121 for a total of 126 species. The 126 species were scored (using the conceptual exposure model described in Section 4.1.2.2.1) for their potential exposure to contaminated media. Scores were scaled to reflect the general magnitude of a species potential exposure to contaminants in each medium, the duration of exposure, and acute radiation sensitivity. These scores represent an index for screening the relative exposure of species within taxonomic groups. These scores do not represent real differences in exposure. Species were scored specifically on:

- ◆ Exposure to biotic and abiotic media - ingestion of prey with separate scores assigned for biomagnifying and non-biomagnifying contaminants with individual contaminants not identified as biomagnifying or non-biomagnifying but rather only grouped generically as such; ingestion of sediment/soil, pore water/groundwater, and surface water; dermal contact with sediment/soil, pore water/groundwater, and surface water; and inhalation of airborne contaminants. All media scores were scaled from 1 to 4 to ensure that all pathways/media were considered of equal importance in their contribution to an individual's overall exposure. In some pathway/media exposure scenarios scores were scaled from 0 to 4 (see Sections 4.1.2.2.3-4.1.2.2.6) because these scenarios included the possibility of no exposure. The use of the zero, however, did not change the sum of the species' scores or the ultimate rankings. Sections 4.1.2.2.2-4.1.2.2.8 describe the basis and provide examples of the score assignments.
- ◆ Exposure duration - residence time in the study area. Exposure duration scores were scaled from 1 to 4. Section 4.1.2.2.9 describes the basis and provides examples of the score assignments.

- ◆ Acute radiation sensitivity - estimate using only the LD₅₀ (dose that is lethal to 50 percent of test organisms) for radiation exposure (Whicker and Schultz 1982). Acute radiation sensitivity scores were also scaled from 1 to 4. Section 4.1.2.2.10 describes the basis and provides examples of the score assignments.

The scores and resulting ranks, which indicated the qualitative, relative exposure of species within taxonomic groups, are presented in Table C.3. The table is a Microsoft Excel 5.0 file on diskette. The scores and resulting ranks are described in detail in Section 4.1.2.2.11. A summary of that description is:

- row 1 = summation of rows 3, 5, 6, and 7
- row 2 = summation of rows 4, 5, 6, and 7
- row 8 = summation of rows 9, 10, and 11
- row 13 = summation of rows 1, 8, and 12
- row 14 = summation of rows 2, 8, and 12
- row 16 = multiplication of media weightings for in-river source areas from Table 4.14 with rows 3, 5, 6, 7, 9, 10, 11, and 12 followed by summation of these rows
- row 17 = multiplication of media weightings for in-river source areas from Table 4.14 with rows 4, 5, 6, 7, 9, 10, 11, and 12 followed by summation of these rows
- row 18 = rank based on score in row 16
- row 19 = rank based on score in row 17
- row 20 = multiplication of media weightings for outfall source areas from Table 4.14 with rows 3, 5, 6, 7, 9, 10, 11, and 12 followed by summation of these rows
- row 21 = multiplication of media weightings for outfall source areas from Table 4.14 with rows 4, 5, 6, 7, 9, 10, 11, and 12 followed by summation of these rows
- row 22 = rank based on score in row 20
- row 23 = rank based on score in row 21
- row 24 = average of rows 16 and 20
- row 25 = average of rows 17 and 21
- row 26 = rank based on score in row 24
- row 27 = rank based on score in row 25
- row 28 = maximum rank in rows 26 and 27
- row 34 = highest number in rows 24 and 25 divided by 15, then added to scores in rows 30 and 32
- row 35 = rank based on score in row 34

Appendix I-D

Ecological Risk

Appendix I-D

Ecological Risk

Whereas Section 4.2 presents the methodology and key results of the screening assessment of risk to the environment, this appendix provides the details of the input and output of the assessment.

Much of the information in this appendix is provided on diskette. Two of the files on diskette are very large. To make them available, they have been compressed with the commercial compression routine PKZIP (PKWARE 1992). "Exe" as the extension of the file name indicates those files that have been compressed and are capable of decompressing themselves. When these files are decompressed, they will automatically reestablish the computer code and necessary input files.

To decompress an "exe" file:

- ◆ Create a directory and copy the "exe" files into it from the diskette.
- ◆ To decompress the files:
 - In DOS, while in the directory you created, type the "exe" file name and hit enter.
 - In Microsoft Windows File Manager, double click on each "exe" file and it will decompress. To view the decompressed file names in File Manager, click on REFRESH under WINDOW.
 - In Microsoft Windows 95, click on START, then RUN, then BROWSE; indicate directory you have created; double click on each "exe" file to decompress it.
- ◆ To view the individual files, open the files in any text processing software or spreadsheet.

Information in this appendix is provided on the following:

- ◆ Measurement Endpoint Values Used in the Risk Assessment
- ◆ Exposure Model Description and Parameters
- ◆ Calibration Parameters for Copper and Zinc
- ◆ Environmental Hazard Quotients
- ◆ Risk Categories from Stochastic Modeling

Measurement Endpoint Values Used in the Risk Assessment

A Microsoft Excel file (meas-end.xls) on diskette lists the benchmark species and toxicological responses used in determining toxicological values for the species of interest. The file identifies the species, contaminants, LD₅₀ and LOEL values, surrogate species used if there was one, and the sources of information.

Exposure Model Description and Parameters

The following description represents a compilation of exposure formulas that were primarily derived from EPA's wildlife exposure factors handbook (EPA 1993). The parameters used in the formulas are in a Microsoft Excel file (paramtrs.xls) on diskette.

Air-Respiring or Transpiring Species

Plants

Rain Splash

$$C_{\text{par}} = EC_{\text{soil}} * K_{\text{ps1}} \text{ (Hope 1995)}$$

where

- C_{par} = Equilibrium concentration in above-ground plant parts from rain splash ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ wet)
- EC_{soil} = Concentration in surface soil (top ~1 cm) ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ dry)
- K_{ps1} = Plant-soil partition coefficient for rain splash on fresh-weight basis (kg soil / kg plant wet weight)

Calibration

- K_{ps1} = 0.0034, Coefficient of Variation = 1 (McKone 1993)
- EC_{soil} = Measured concentration from database or estimated from equilibrium with groundwater

Root Uptake to Above-Ground Plant Tissue. The equation below was modified from Hope (1995). One of the terms in parentheses would be used depending on whether the contaminant was organic (K_{ps2}) or inorganic [$B_v(1-f_w)$].

$$C_{\text{pau}} = EC_{\text{soil}} * [K_{\text{ps2}}, B_v(1-f_w)]$$

where

- C_{pau} = Equilibrium concentration in above-ground plant parts from root uptake ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ wet)
- K_{ps2} = Plant-soil partition coefficient for root-zone soil to above-ground plant parts for organic contaminants - fresh weight basis (kg soil / kg plant wet weight)
- B_v = Bioconcentration factor for vegetative plant parts for inorganic contaminants - dry weight basis (unitless)
- f_w = Weight fraction of plant tissue that is water (unitless)

Submodel. In the equation below the regression model was reported in McKone (1993). The coefficient of variation equals 4).

$$K_{\text{ps2}} = 7.7 * K_{\text{ow}}^{-0.58}$$

where

- K_{ow} = Octanol-water partition coefficient

Calibration

B_v = See paramtrs.xls file on diskette
 f_w from Spector (1956), Martin et al. (1951, p. 12) and EPA (1993, p. 4-14)
 K_{ow} from MEPAS chemical database (Streng and Peterson 1989)

Special Case for Tritium (Hydrogen-3). B_v in the model above incorporates field- or experiment-derived conversion of sediment-bound contaminants into a pore-water phase, which is the primary phase for uptake of metals (Kabata-Pendias and Pendias 1984). This conversion is problematic for tritium because tritium is carried entirely in the water phase ($K_d = 0$). Plants take up tritium from groundwater and porewater (for example, Rickard and Price 1989) at a concentration ratio of somewhat less than 1 (Driver 1994). Consequently, the present model was set up to utilize a $B_{porewater}$ value for tritium of 0.9, which was multiplied by the porewater (in other words, groundwater) concentration to obtain an equilibrium plant concentration.

Foliar Uptake from Soil by Vapor

$$C_{pav} = EC_{vap} * K_{pal} \text{ (Hope 1995)}$$

where

C_{pav} = Equilibrium concentration in above-ground plant parts from vapor uptake ($\mu\text{g/kg}$ or $\mu\text{Ci/kg wet}$)
 EC_{vap} = Concentration of gas-phase contaminant (μg or $\mu\text{Ci/m}^3$)
 K_{pal} = Plant-air partition coefficient for air to above-ground plant parts for organic contaminants ($\text{m}^3/\text{kg wet weight}$)

Submodel: K_{pal}

$$K_{pal} = (f_{pa} + (f_{pw} + f_{pl} * K_{ow}) \times (R \times T)/H) * (1/\rho_p)$$

(Reiderer 1990, coefficient of variation = 14, McKone 1993)

where

f_{pa} = Volume fraction of plant tissue in air (unitless)
 f_{pw} = Volume fraction of plant tissue that is water (unitless)
 f_{pl} = Volume fraction of plant tissue that is lipid (unitless)
 R = Universal gas constant ($\text{Pa}\cdot\text{m}^3/\text{mol}\cdot\text{K}$)
 T = Temperature (K)
 H = Contaminant-specific Henry's law constant ($\text{Pa}\cdot\text{m}^3/\text{mol}$)
 ρ_p = Plant tissue density (kg/m^3)

Submodel: EC_{vap}

$EC_{vap} = EC_{soil} * 1/\{(LS * V * Dh)/A\} * [(3.14 * \zeta * I)^{0.5}/(2 * D_{ei} * E * K_{as} * 10^{-3} \text{ kg/g})]\}$
 (EPA 1991)
 LS = Length of side of contaminated area (m)

- V = Wind speed in mixing zone (m/s)
 D_h = Diffusion height (m)
 A = Area of contamination (cm^2)
 ζ = Effective diffusion rate (cm^2/s)
 I = Exposure interval (s)
 D_{ei} = Effective diffusivity (cm^2/s)
 E = Soil porosity (unitless)
 K_{as} = Soil/air partition coefficient (g soil/ cm^3 air)

Submodel: ζ

$$\zeta = (D_{ei} * E) / (E + (\rho_s * (1-E) / K_{as}))$$

ρ_s = Soil density (g/cm^3)

Submodel: K_{as}

$$K_{as} = (H * 41) / (K_d * 1.0125 \text{E} 5 \text{ Pa/atm}) \text{ (EPA 1991)}$$

where

- 41 = Units conversion factor
 K_d = Soil-water partition coefficient (cm^3/g)

Submodel: K_d

$$K_d = 0.62 * K_{ow} * f_{oc} \text{ (regression model in Nicholls 1991)}$$

f_{oc} = Soil organic carbon content (unitless)

Submodel: D_{ei}

$$D_{ei} = D_i * E^{0.33} \text{ (EPA 1991)}$$

where

- D_i = Molecular diffusivity (cm^2/s)

Calibration

- f_{pa} = 0.5 (McKone 1993)
 f_{pw} = 0.4 (McKone 1993)
 f_{pl} = 0.01 (McKone 1993)
 R = 8.314
 T = 285 K default Hanford average (Stone et al. 1983)
 H = from MEPAS database (Streng and Peterson 1989)
 ρ_p = 1000 (McKone 1993)
 ρ_s = for sediment or 2.65 default (EPA 1991)
 E = 0.35 default

- ρ_a = 0.05
 f_{oc} = from segment or 0.01 default
 K_{ow} = from MEPAS database
 LS = 1000 m
 V = 2.68 m/s default Hanford average @ 2.1 meters (7 feet) (Stone et al. 1983)
 Dh = Average distance from ground to middle of foliage [fungi: 0.05 m, grasses/forbs: 0.1 m, trees: 5 m]
 A = 50 cm * LS * 100 cm/m
 D_i = Chemical-specific from MEPAS database
 I = $3.1536 * 10^7$ sec default (1 year)

Foliar Adsorption of Particulates from Soil

$$C_{pap} = EC_{par} * K_{pa2} \text{ (Hope 1995)}$$

where

- C_{pap} = Equilibrium concentration in above-ground plant parts from particulate adsorption ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ wet)
 EC_{par} = Air concentration of particulate-bound contaminant (μg or $\mu\text{Ci/m}^3$)
 K_{pa2} = Plant-air partition coefficient for air to above-ground plant parts for particulate-bound contaminants (m^3/kg wet weight)

Submodel: EC_{par}

$$EC_{p_air} = EC_{soil}/PEF \text{ (EPA 1991)}$$

where

- PEF = Particulate emission factor (m^3/kg)

Submodel: PEF

$$PEF = (LS * V * Dh * 3600 \text{ s/hr} / A / 10,000 \text{ cm}^2/\text{m}^2) * (1000 \text{ g/kg} (Rf * (1-G) * (U_m/U_t)^3 * F(x))) \text{ (EPA 1991)}$$

where

- Rf = Respirable fraction ($\text{g/m}^2\text{-hr}$)
 G = Fraction of vegetative cover (unitless)
 U_m = Mean annual wind speed (m/s)
 U_t = Erosion threshold wind speed at 10 m (m/s)
 $F(x)$ = Cowherd et al. (1985) function (unitless)

Submodel: U_t

$$U_t = \text{TFV} * \ln(10 \text{ m/SRH})/0.4 \text{ (Cowherd et al. 1985)}$$

where

TFV = Threshold friction velocity (m/s)

SRH = Surface roughness height (m)

Submodel: TFV

$$\text{TFV} = \text{NECF} * (64 + 0.0055 * \text{APSD} * 1000)/100 \text{ (regression model in Cowherd et al. 1985)}$$

where

NECF = Non-erodible elements correction factor (unitless)

APSD = Aggregate particle size distribution (mm)

Calibration

K_{pa2} = 3300 (coefficient of variation = 1.5, McKone 1993)

Rf = 0.036 (EPA 1991)

U_m = 3.44 m/s (Stone et al. 1983)

SRL = 0.018 m (grass - Jørgensen et al. 1991, p. 230)

NECF = 0

APSD = 0.04 mm (coarse silt size - Gee and Bauder 1986, p. 384)

G = 0.5

F(x) = 0.0497 (EPA 1991)

Total Plant Burden

$$\text{Internal burden: } C_{pai} = C_{pav} + C_{pau}$$

where

C_{pai} = Equilibrium tissue concentration of contaminants (μg or $\mu\text{Ci/kg}$ tissue)

(Note this derivation assumes that none of the adsorbed contaminant enters the plant.)

$$\text{Total burden (as eaten by herbivore): } C_{pat} = C_{par} + C_{pap} + C_{pai}$$

where

C_{pat} = Equilibrium concentration of contaminants in and on plant tissue (μg or $\mu\text{Ci/kg}$ tissue)

Terrestrial Animals

Dermal Contact - Sediment

$$C_{dersi} = D_{dersi} / K_{ei} \text{ (from Hope 1995)}$$

where

C_{dersi} = Equilibrium contaminant body burden in species i from dermal contact with soil ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ body weight)

D_{dersi} = Absorbed daily dose for species i from dermal contact with soil ($\mu\text{g/kg}$ or $\mu\text{Ci/kg/day}$)

K_{ei} = Contaminant-specific depuration rate for species i (1/day)

Submodel: D_{ders}

$$D_{ders} = [(SA_i * P_{csi} * S_{ai} * EC_{soil} * CF * \delta_i / W_i] * \theta_i * \iota_i \text{ (modified from EPA 1991)}$$

where

SA_i = Surface area of species i (cm^2)

P_{csi} = Fraction of surface area of species i in contact with soil per day (1/day)

S_{ai} = Skin adherence factor for species i (mg/cm^2)

CF = Conversion factor (10^{-6} kg/mg)

δ_i = Contaminant-specific dermal absorption factor for species i (unitless)

W_i = Body weight of species i (kg wet weight)

θ_i = Area use factor for species i (ratio of contaminant area to home range - unitless)

ι_i = Seasonality factor for species i (fraction of year spent at the contaminated site - unitless)

Submodel: SA_i

Birds: $SA_i = 10 * (W_i * 1000 \text{ g/kg})^{0.667}$ (EPA 1993)

Mammals: $SA_i = 12.3 * (W_i * 1000)^{0.65}$ (EPA 1993)

Woodhouse's toads: $SA_i = 0.953 * (W_i * 1000)^{0.725}$ (EPA 1993)

Lizards: $SA_i = 8.42 * (W_i * 1000)^{0.694}$ (EPA 1993 - salamander applied to lizards)

Western aquatic garter snake: $= 2 * \pi * 1 \text{ cm radius} (1 \text{ cm} + 106 \text{ cm length})$
(EPA 1993, Stebbins 1985)

Terrestrial arthropods: 0.0002 cm^2

Calibration

δ_i = See paramtrs.xls on diskette

K_{ei} = See paramtrs.xls on diskette

PCs = Mammal: 0.22 (Maughan 1993); other vertebrates: 0.25, arthropods: 1

W_i = for species using EPA (1993), Dunning (1993), Silva and Downing (1995), Nagy (1983)

S_a = 1.45 (EPA 1991)

θ_i = 1

ι_i = 1 for all species except common snipe (0.33), bufflehead (0.5), Forster's tern (0.5), cliff swallow (0.5), and bald eagle (0.5) (Ennor 1991)

Dermal Contact - Water

$$C_{derwi} = D_{derwi}/K_{ei} \text{ (Hope 1995)}$$

where

C_{derwi} = Equilibrium contaminant body burden for species i from dermal contact with water (μg or $\mu\text{Ci/kg}$ body weight)

D_{derwi} = Absorbed daily dose for species i from dermal contact with water ($(\mu\text{g}$ or $\mu\text{Ci/kg-day})$)

Submodel: D_{derw}

$$D_{derwi} = [(SA_i * P_{cwi} * ET_i * EC_{\text{surface}} * CF * K_{pi})/W_i] * \theta_i * \iota_i$$

(modified from EPA 1991 to include use and seasonality factors)

where

SA_i = Surface area of species i (cm^2)

P_{cwi} = Fraction of surface area of species i available for contact with water (unitless)

ET_{wi} = Average exposure time to water per day for species i (hr/day)

EC_{surface} = Concentration in surface water ($\mu\text{g/L}$ or $\mu\text{Ci/L}$)

CF = Volumetric conversion factor for water ($1 \text{ L}/1000 \text{ cm}^3$)

K_{pi} = Contaminant-specific dermal absorption factor for species i from water (cm/hr)

W_i = Body weight of species i (kg wet weight)

θ_i = Area use factor for species i (ratio of contaminant area to home range - unitless)

ι_i = Seasonality factor for species i (fraction of year spent at the contaminated site - unitless)

Calibration

K_{pi} = See paramtrs.xls file on diskette

ET and P_{cwi} (EPA 1993):

Species	ET_i	P_{cwi}
Woodhouse's toad	20	1
Western aquatic garter snake	12	1
Beaver, muskrat	20	1
Mule deer	1	0.8
Raccoon	2	0.1
Terrestrial arthropods, lizards, coyote, weasel, western harvest mouse, California quail, cliff swallow, northern harrier, American kestrel	0	0
Bald eagle	2	0.8
Forster's tern	8	0.5
Great blue heron	20	0.1
Other waterfowl	20	0.5

Total Dermal Dose. Equilibrium body burden from dermal exposure:

$$C_{\text{deri}} = C_{\text{dersi}} + C_{\text{derwi}}$$

where

C_{deri} = Total equilibrium body burden from dermal exposure for species i (μg or $\mu\text{Ci/kg}$ body weight)

Absorbed dose:

$$D_{\text{deri}} = D_{\text{dersi}} + D_{\text{derwi}}$$

where

D_{deri} = Total daily dermal absorbed dose for species i (μg or $\mu\text{Ci/kg}$ body weight/day)

Inhalation - Vapor

$$C_{\text{ivi}} = D_{\text{ivi}} * (\alpha_{\text{vapi}}/K_{\text{ei}}) \text{ (Hope 1995)}$$

where

C_{ivi} = Equilibrium contaminant body burden for species i from inhalation of vapor ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$)

D_{ivi} = Applied daily dose to species i from vapor inhalation ($\mu\text{g/kg}$ or $\mu\text{Ci/kg-day}$)

α_{vapi} = Inhalation absorption factor for species i (unitless)

Submodel: D_{ivi}

$$D_{\text{ivi}} = [(IR_i * EC_{\text{vap}})/W_i] * \theta_i * \iota_i \text{ (modified from Hope (1995) using EPA (1993) calculation for } EC_{\text{vap}} \text{ as above)}$$

where

IR_i = Resting inhalation rate of species i (m^3/day) and rest as above

Calibration

IR_i :

Species	Resting IR	Correction Factor for Field IR	IR_i
Mammals	$= 0.5458 * W_i^{0.80}$ (EPA 1993)	2 (EPA 1993)	$2 * 0.5458 * W_i^{0.80}$
Birds	$= 0.4089 * W_i^{0.77}$ (EPA 1993)	2 (EPA 1993)	$2 * 0.4089 * W_i^{0.77}$
Woodhouse's toad	see below	2 (EPA 1993)	$5.8 * 10^{-4}$
Lizards (<i>Uta</i>) and western aquatic garter snake	see below		$0.00045 * (W_i * 1000)^{0.8}$
Terrestrial arthropods	see below		$0.00045 * (W_i * 1000)^{0.8}$

Woodhouse's toads - EPA (1993) gives the resting metabolic rate of 74.8 g bullfrog adults at 5°C as 1-L O₂/kg/d. Because gas exchange through the skin accounts for 18 percent of the O₂ uptake (EPA 1993), the respired intake fraction necessary to support the referenced metabolic demand is 0.82-L O₂ respired/kg/d. The fraction of O₂ in dry atmosphere is 20.95 percent (Schmidt-Nielson 1975, p. 8), thus the volume of respired air required to support the referenced metabolic rate is 0.82-L O₂/0.2095-L O₂/L air, or 3.914-L air/kg toad/d. Finally, multiplication of this result by a correction factor (1 m³/1000 L) and the weight of the toads (0.0748 kg) gives the resting calibrated value of 2.9×10^{-4} m³/d per toad, which is multiplied by 2 to provide a field-corrected inhalation rate of 5.8×10^{-4} m³/d per toad.

Reptiles - EPA (1993) cites the formula for active field metabolic rate for adult lizards and snakes as:

$$MR (\text{ml O}_2/\text{hr}) = 0.013 * (W_i * 1000)^{0.80} * 10^{0.038 * ^\circ\text{C}} * 10^{0.14}$$

Assuming these reptiles are in equilibrium with the average annual Hanford temperature (12°C - Stone et al. 1983), using the atmospheric composition of O₂ as above, and converting hours to days and milliliters to m³ gives:

$$IR (\text{m}^3/\text{day}) = 10^{-6} \text{ m}^3/\text{ml} * 24 \text{ hr/day} * 1 \text{ ml air}/2095 \text{ ml O}_2 * 0.013 \text{ ml O}_2/\text{hr} * (W_i * 1000)^{0.80} * 10^{0.00456} * 10^{0.14}$$

or

$$IR_i (\text{m}^3/\text{day}) = 0.00045 * (W_i * 1000)^{0.80}$$

Terrestrial arthropods - inhalation treated as per reptiles.

α_{vapi} = See paramtrs.xls file on diskette

Inhalation - Particulates

$$C_{\text{ipi}} = D_{\text{ipi}} * (\alpha_{\text{pari}}/K_{\text{ei}}) \text{ (Hope 1995)}$$

where

C_{ipi} = Equilibrium contaminant body burden for species i from inhalation of particulates ($\mu\text{g}/\text{kg}$ or $\mu\text{Ci}/\text{kg}$)

D_{ipi} = Applied daily dose to species i from particulate inhalation ($\mu\text{g}/\text{kg}$ or $\mu\text{Ci}/\text{kg-day}$)

α_{pari} = Inhalation particulate absorption factor (unitless)

Submodel: D_{ipi}

D_{ipi} = $[(IR_i * EC_{\text{par}})/W_i] * \theta_i * v_i$ (modified from Hope (1995) using EPA (1993) calculation for EC_{vap} as above)

Calibration

α_{pari} = See paramtrs.xls file on diskette

Total Inhalation Dose. Absorbed dose:

$$C_{inhi} = C_{ivi} + C_{ipi}$$

where

 C_{inhi} = Total equilibrium burden from inhalation for species i (μg or μCi / kg body weight)

Applied dose:

$$D_{inhi} = D_{ivi} + D_{ipi}$$

where

 D_{inhi} = Total inhalation applied dose for species i (μg or μCi /kg body weight/day)
Ingestion - Water

$$C_{ingwi} = D_{ingwi} * (\alpha_{ingi}/K_{ei}) \text{ (after Hope 1995)}$$

where

 C_{ingwi} = Equilibrium contaminant body burden for species i from ingestion of water (μg /kg or μCi /kg)

 D_{ingwi} = Applied daily dose to species i from water ingestion (μg /kg or μCi /kg-day)

 α_{ingi} = Ingestion absorption factor for species i (unitless)
Submodel: D_{ingwi}

$$D_{ingwi} = [(WI_i * EC_{\text{surface or EC}_{\text{springs}}})/W_i] * \theta_i * v_i$$

(modified from EPA (1993) using site use fractions as above)

where

 WI_i = Water ingestion rate of species i (L/day)

 EC_{springs} = Concentration in spring/seep water, where present ($\mu\text{g}/\text{L}$ or $\mu\text{Ci}/\text{L}$), otherwise, EC_{surface} is used as the default

 EC_{surface} = Concentration in surface water
Calibration WI_i : (EPA 1993)

Species	WI_i
Mammals	$= 0.099 \times W_i^{0.90}$
Birds	$= 0.059 \times W_i^{0.67}$
Woodhouse's toad	0
Lizards (<i>Uta</i>) and western aquatic garter snake	0
Terr. arthropods	0

 α_{ing} = See paramtrs.xls file on diskette

Ingestion - Soil

$$C_{ingsi} = D_{ingsi} * (\alpha_{ingi}/K_{ei}) \text{ (after Hope 1995)}$$

where

- C_{ingsi} = Contaminant body burden to species i from ingestion of soil ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ body weight)
 D_{ingsi} = Applied daily dose to species i from soil ingestion ($\mu\text{g/kg}$ or $\mu\text{Ci/kg-day}$)
 α_{ingi} = Ingestion absorption factor for species i (unitless)

Submodel: D_{ingsi}

$$D_{ingsi} = [(SI_i * NIR_{totali} * EC_{surface} * F_{dwi})] * \theta_i * \iota_i$$

(modified from EPA (1993) using site use fractions as above)

where

- SI_i = Soil ingestion rate of species i (kg soil ingested/kg dry diet)
 NIR_{totali} = Total normalized ingestion rate for species i (kg prey wet weight/kg predator body weight/day)
 F_{dwi} = Conversion factor, dry diet to wet diet for species i (kg dry/kg wet)

Submodel: NIR_{totali}

$$NIR_{totali} = FMR_i / (\sum (P_{ij} * ME_j) * W_i)$$

(EPA 1993, equations 4-11 and 4-12)

where

- FMR_i = Free-living metabolic rate of predator (kcal/day)
 P_{ij} = Wet weight or volume fraction of i's diet consisting of prey j (unitless)
 ME_j = Metabolizable energy from prey j (kcal/kg prey wet wt)

Submodel: FMR_i

Birds: $FMR_i = 3.12 * (W_i * 1000 \text{ g/kg})^{0.605}$ (EPA 1993)
 Herbivorous mammals: $FMR_i = 1.419 * (W_i * 1000 \text{ g/kg})^{0.727}$ (EPA 1993)
 Non-herbivorous mammals: $FMR_i = 0.6167 * (W_i * 1000 \text{ g/kg})^{0.862}$ (EPA 1993)
 Rodents: $FMR_i = 2.514 * (W_i * 1000 \text{ g/kg})^{0.507}$ (EPA 1993)
 Reptiles: $FMR_i = 0.053 * (W_i * 1000 \text{ g/kg})^{0.799}$ (EPA 1993)
 Woodhouse's toads: $FMR_i = 0.000288 * (0.047 * (W_i * 10^6 \text{ mg/kg})^{1.06})^{0.878}$
 (derived from EPA 1993 using tadpole FMR)
 Terrestrial arthropods: as per reptiles

Submodel: ME_j

$$ME_j = (GE_j * AE_j) \text{ (EPA 1993)}$$

where

GE_j = Gross energy from prey j (kcal/kg wet weight)

AE_j = Assimilation efficiency of prey j (unitless)

Calibration

SI_i : (Beyer et al. 1994)

Species	SI_i
Mule deer	0.02
Raccoon, muskrat, beaver	0.09
Western harvest mouse	0.02
Coyote	0.09
Weasel	0.03
American coot, snipe	0.18
Mallard	0.033
Canada goose	0.08
Raptors and fish-eating birds	0.02 (average of fish-eating species)
California quail	0.09 (used value for wild turkey)
Cliff swallow	0.02 (lowest value of birds)
Woodhouse's toad	0.06 (see below)
Lizards (<i>Uta</i>), and western aquatic garter snake	0.054 (see below)
Terr. arthropods	0.054 (as per reptiles)

For Woodhouse's toad and reptiles, SI was estimated using the average of box (4.5%) and painted turtle (5.9%) estimates because of the lack of data for these groups (Beyer et al. 1994).

F_{dw} = $1 - \%H_2O = 0.17$ for all diets (average of fresh diets in EPA 1993, p. 4-14)

P_{ij} = Species-specific values from Terres (1980), Martin, et al. (1951), Zeiner et al. (1990), Svendsen (1982), Becker (1973), Dauble et al. (1980), Brandt et al. (1993), Hanson and Browning (1956), Fitzner and Rickard (1975), Fitzner and Schreckhise (1979), Ehrlich et al. (1988), Johnsgard (1990); see paramtrs.xls file on diskette

GE_j = Values for species groups from EPA (1993, p. 4-13-4-14). Assigned values are shown below.

AE_j = Values were assigned to prey based on major taxon using EPA (1993, p. 4-15). Data were averaged between avian and mammalian predators where both values were given. Assigned values are shown below.

Prey Group	Assigned GE _i	Assigned AE _i
Birds	1900	(0.78 + 0.84)/2 = 0.81
Mammals	1700	(0.78 + 0.84)/2 = 0.81
Reptiles	1400	0.81 (as per birds, mammals)
Amphibians	1200	0.81 (as per birds, mammals)
Fish	1200 (bony fish value)	(0.79 + 0.91)/2 = 0.85
Salmon adults	1600 (Halfon et al. 1996)	0.85
Salmon larvae	1400 (Halfon et al. 1996)	0.85
Rainbow trout adults	2100 (Halfon et al. 1996)	0.85
Rainbow trout larvae	1500 (Halfon et al. 1996)	0.85
Terrestrial insects	1600 (average of insects)	(0.72 + 0.87)/2 = 0.80
Crayfish	1100 (shrimp value)	0.77
Insect larvae	1200	0.77
Daphnia	740 (cladoceran value)	0.77
Hyaella	1100 (amphipod value)	0.77
Tadpoles	1200 (as per amphibians)	0.77
Molluscs	800 (bivalves sans shells)	0.77
Periphyton, phytoplankton	510	0.23
Macrophytes	520	0.23
Emergent vegetation (tule, Columbia yellowcress)	1600	0.39
Reed canarygrass, sedges, rushes	1300	0.47 (as per leaves and grasses)
Black cottonwood, mulberry	3200 (stems and twigs, 25% water)	0.34 (as per stems, twigs)
Fern, fungi	630 (as per dicot leaves)	0.73 (as per green forb)

Ingestion - Food

$$C_{ingfi} = D_{ingfi} * (\alpha_{ingi}/K_{ei}) \text{ (after Hope 1995)}$$

where

C_{ingfi} = Equilibrium body burden for species i from ingestion of food ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ body weight)

D_{ingfi} = Applied daily dose to species i from food ingestion ($\mu\text{g/kg}$ or $\mu\text{Ci/kg} \cdot \text{day}$)

Submodel: D_{ingfi}

$$D_{ingfi} = \sum (C_j * NIR_j) * \theta_i * \iota_i \text{ (modified from Hope (1995) using EPA (1993))}$$

where

C_j = Average contaminant concentration in jth food item ($\mu\text{g/kg}$ or $\mu\text{Ci/kg}$ wet weight)

NIR_j = Normalized ingestion rate of jth food type on a wet-weight basis ($\text{kg prey/kg body weight predator/day}$)

Submodel: NIR_j

$$NIR_j = P_{ij} \times NIR_{totali} \text{ (EPA 1993, equation 4-10)}$$

Calibration: C_j . Plant prey:

$$C_j = C_{pat}$$

Animal prey:

$$C_j = C_{ingf} + C_{ings} + C_{ingw} + C_{inh} + C_{der}$$

Total Ingestion Dose. Applied daily dose:

$$D_{ingi} = D_{ingfi} + D_{ingsi} + D_{ingwi}$$

where

$$D_{ingi} = \text{Applied daily dose for species } i \text{ from ingestion } (\mu\text{g/kg or } \mu\text{Ci/kg} \cdot \text{day})$$

Absorbed dose:

$$C_i = C_{ingfi} + C_{ingsi} + C_{ingwi} + C_{inhi} + C_{deri}$$

where

$$C_i = \text{Equilibrium body burden for species } i \text{ from ingestion } (\mu\text{g/kg or } \mu\text{Ci/kg body weight})$$

Water-Respiring or Transpiring Species

The basic models used in the screening assessment for estimating exposures of aquatic organisms to metal or organic contaminants in sediments, pore water, surface water, and the subsequent transfer through the food chain consist of mass-balance equilibrium models originally derived by R.V. Thomann and coworkers (Thomann 1989, Thomann et al. 1992, 1995). The basic equilibrium models presented in these papers were further modified by the authors to provide a system of equations generally applicable when only sediment data are available. The essential assumption used in that modification is that the aquatic system is not depurating contaminants, such that the three abiotic compartments (sediment, pore water, and surface water) are in static equilibrium (Thomann et al. 1992). This assumption may only be valid for large lacustrine systems. Clearly, it is invalid for the Columbia River. However, the basic models may be utilized directly with only minor modification to address the Columbia River system.

Derivation of Dose

The basic equation for contaminant mass balance in an organism i feeding on prey j (including sediment) is given by:

$$dV_i/dt = k_{ui}(b_{pore} * EC_{pore} + b_{surface} * EC_{surface}) + \sum (P_{ij} * \alpha_{ij} * I_{ij} * V_j) - (K_i + G_i)V_i$$

(after Thomann et al. 1992, 1995)

where

- V_i = Body burden in predator species i (metals: μg or $\mu\text{Ci/kg}$ dry weight - Thomann et al. 1995; organics: μg or $\mu\text{Ci/g}$ lipid - Thomann et al. 1992)
 V_j = Body burden in prey species j (metals: μg or $\mu\text{Ci/kg}$ dry weight - Thomann et al. 1995; organics: μg or $\mu\text{Ci/g}$ lipid - Thomann et al. 1992) or in sediment (metals: μg or $\mu\text{Ci/kg}$ dry sediment - Thomann et al. 1995; organics: μg or $\mu\text{Ci/g}$ organic carbon - Thomann et al. 1992)
 k_{ui} = Contaminant uptake from dissolved sources for species i (metals: $\text{L/g dry weight / day}$ - Thomann et al. 1995; organics: L / g lipid / day - Thomann et al. 1992)
 b_{pore} = Relative exposure to pore water (unitless)
 b_{surface} = Relative exposure to surface water ($b_{\text{surface}} = 1 - b_{\text{pore}}$) (unitless)
 EC_{pore} = Contaminant concentration in pore water ($\mu\text{g/L}$ or $\mu\text{Ci/L}$)
 EC_{surface} = Contaminant concentration in surface water ($\mu\text{g/L}$ or $\mu\text{Ci/L}$)
 P_{ij} = Preference for consumption of food item j, including sediment as a separate prey item (unitless)
 α_{ij} = Chemical assimilation efficiency for contaminant consumed along with prey j (g contaminant assimilated/g contaminant ingested)
 I_{ij} = Feeding rate of species i on prey item j (organic model: g prey lipid/g predator lipid/day, metal model: g prey dry weight/g predator dry weight/day) or on sediment (organic model: g organic carbon ingested/g predator lipid/day, metal model: g sediment dry weight/g predator dry weight/day)
 K_i = Loss rate of contaminant for species i, including depuration and metabolism (1/day)
 G_i = Growth rate of species i (1/day)

At steady state, $dV_i/dt = 0$, and the above equation reduces to:

$$V_i = [k_{ui} (b_{\text{pore}} * EC_{\text{pore}} + b_{\text{surface}} * EC_{\text{surface}}) + \sum (P_{ij} * \alpha_{ij} * I_{ij} * V_j)] / (K_i + G_i)$$

This form is utilized directly by Thomann et al. (1992) for analyzing body burdens of organic contaminants in aquatic species. To analyze body burdens of metals in aquatic species, Thomann et al. (1995) condense this analysis further, utilizing the fact that $k_{ui} / (K_i + G_i) = BCF_i$, which is the contaminant-specific bioconcentration factor reflecting uptake directly from the surrounding aqueous medium. This gives the following equation:

$$V_i = BCF * (b_{\text{pore}} * EC_{\text{pore}} + b_{\text{surface}} * EC_{\text{surface}}) + \sum (P_{ij} * \alpha_{ij} * I_{ij} * V_j) / (K_i + G_i)$$

As given, the two equations return body burden estimates in units that differ between metals and organics. Further, the units are not comparable to those used in the in-air species exposure model (see previous section). Instead, the V_i must be converted to $\mu\text{g/kg}$ wet weight (or pCi/kg wet weight for radionuclide contaminants). To accomplish that conversion, the following are applied:

$$\begin{aligned} \text{Metals: } C_i &= V_i / \text{awd}_i \\ \text{Organics: } C_i &= V_i * 1000 \text{ g/kg} * f_{Li} \end{aligned}$$

where

awd_i = Wet-to-dry weight ratio for species i (g wet/g dry)

f_{Li} = Fraction lipid in species i (g lipid/g wet)

and C_i is as per in-air species given earlier.

It is these C_i 's that are used as input into the in-air model as body burdens of aquatic prey for in-air species such as coyote and bufflehead.

Submodel: K_{ei} for Organic Contaminants

$$K_i = (k_{ui}/K_{ow}/1000 \text{ g/L}) + K_{mi} \text{ (Thomann 1989)}$$

where

K_{mi} = Chemical loss rate in species i due to metabolism and fecal loss (1/day)

Submodel: G_i

$$G_i = \delta * w_i^{-\beta} \text{ (Thomann et al. 1992)}$$

where

δ and β are regression parameters

Submodel: I_{ij}

For Intake of Organic Contaminants from Prey. For biotic prey:

$$I_{ij} = ((G_i + \rho_i)/a_i) * (awd_j/awd_i) * (f_{Lj}/f_{Li}) * (f_{oci} f_{ocj}) \text{ (Thomann et al. 1992)}$$

where

ρ_i = Oxygen respiration rate for species i (g O_2 /g lipid/day)

a_i = Organic carbon assimilation rate for species i (g organic carbon assimilated/g organic carbon ingested)

f_{oci} = Fraction organic carbon in species i (g organic carbon/g dry weight)

For Intake of Metals/Radionuclides from Prey. The above equation return values with units of g prey lipid/g predator lipid/day. The equivalent units for the metal uptake model of Thomann et al. (1995) are g prey dry weight/g predator dry weight/day. For the purposes of evaluating metal and radionuclide uptake in aquatic systems, the following conversion was applied to produce consumption rates in the correct units:

$$\text{prey: } I_{\text{metal}} = I_{\text{organic}} * awd_j * f_{Lj}/awd_j/f_{Lj} = ((G_i + \rho_i)/a_i) * (f_{oci}/f_{ocj})$$

For Intake of Contaminants from Sediment Ingestion

Thomann et al. (1992, 1995) estimate sediment ingestion as a purposeful portion of the organism's diet, meaning the organism searches for and consumes the sediment as a carbon source for food. This is a

valid assumption for species that consume sediment as the primary portion of their diet. None of the species identified for the screening assessment include sediment feeders. Instead, sediment intake can be more reasonably viewed as an incidental result of feeding on benthic organisms.

Using this assumption, sediment intake can be expressed as

$$\text{BAF}_{\text{ised}} = [\text{P}_{\text{ised}} * \alpha_{\text{ised}} * \Sigma (\text{P}_{\text{ij}} * \alpha_{\text{ij}} * \text{I}_{\text{ij}})] / (\text{K}_i + \text{G}_i)$$

where the subscript “ised” refers to organism i feeding on sediment, BAF_{ised} refers to the sediment-to-predator bioaccumulation factor (Thomann et al. 1992), and the remainder of the variables are as previously defined.

Submodel: k_{ui} for Organic Contaminants

$$k_{\text{ui}} = (2.67 \text{ g O}_2/\text{g C} * f_{\text{oci}} * \rho_i * E_c) / (\text{awd}_i * C_0 * f_{\text{Li}}) \text{ (Thomann 1989)}$$

where

- w_i = Wet body mass for species i (g)
- E_c = Chemical transfer efficiency (unitless)
- C_0 = Oxygen concentration in the river (mg/L)

This parameter is not used in the model for metal uptake. Instead, the BCF relationship is used and BCF's are obtained from the literature, as described below.

Submodel: BCF_i for Organic Contaminants

$$\text{BCF}_i = k_{\text{ui}} / (\text{K}_i + \text{G}_i) \text{ (by definition)}$$

Submodel: ρ_i

$$\rho_i = \phi * w_i^{-\gamma} \text{ (Thomann 1989)}$$

where

ϕ and γ are regression parameters.

Calibration

- BCF_i = For organic contaminants, the submodels for k_{ui} and BCF_i were used; otherwise, BCF values were obtained from the literature using a L/kg dry weight basis (see paramtrs.xls file on diskette)
- E_0 = 0.8 (Thomann et al. 1992)
- E_c = Function of K_{ow} (see below - Thomann et al. 1992)

Log K_{ow}	E_c
2	0.02511886
2.5	0.04466836
3	0.07943282
3.5	0.14125375
4	0.25118864
4.5	0.8
5	0.8
5.5	0.8
6	0.8
6.5	0.8
7	0.6
7.5	0.4
8	0.2
8.5	0.05
9	0.01

- K_m = 0 (assumes no loss due to metabolism of contaminants)
 α_{ij} = See paramtrs.xls file on diskette
 K_i = See paramtrs.xls file on diskette for values for inorganics
 C_0 = 0.011 @ 10°C (equilibrium solubility value)
 δ = 0.002 @ 10°C (Thomann 1989)
 β = -0.25 (range -0.2 - -0.3) (Thomann 1989)
 ϕ = 0.032 (range 0.014 - 0.05) (Thomann 1989)
 γ = -0.2 (range -0.2 - -0.3) (Thomann 1989)

Predation fractions for aquatic organisms were determined using studies in the Hanford Reach and the general literature. Bivalve, snail, aquatic insect, toad larvae, and juvenile lamprey diets were estimated based on their feeding behavior (in other words, grazers, filter feeders; C.E. Cushing, Pacific Northwest National Laboratory, personal communication August 12, 1996) and the known ratios of periphyton, phytoplankton, particulate matter, and periphyton in the water column. Crayfish diet composition was taken from Pennak (1989). Feeding habits of resident and anadromous fish have been described in both reports and the open literature, including largescale sucker (Dauble 1986), smallmouth bass (Battelle 1977a, 1977b, 1978, 1979a, 1979b), carp (Battelle 1977b), Pacific lamprey (Scott and Crossman 1973), mountain whitefish (Battelle 1977a, 1977b, 1978, 1979a, 1979b), white sturgeon (Battelle 1977a, 1977b, 1978, 1979a, 1979b), channel catfish (Battelle 1977a, 1977b, 1978, 1979a, 1979b), Battelle 1977a, 1977b, 1978, 1979a, 1979b), rainbow trout (Battelle 1977a, 1977b, 1978, 1979a, 1979b), and juvenile chinook salmon (Becker 1973, Dauble et al 1980). Relative proportions of food items were based on volume (Windell 1970) and items were grouped by taxa to provide consistency with uptake parameters selected for the ingestion model. Predation fractions used in this model are shown in the paramtrs.xls file on diskette.

Radiological Dose Estimation

The above exposure analyses return estimates of ingestion exposure to radiological contaminants in units of picocuries/kilogram body mass/day (units of radioactive decay rate density). However, radiological effects result from radioactive energy density absorbed by a body in a unit of time, which is usually expressed in units of rads/day. Consequently, decay rates had to be converted to energy equivalents. Similarly, an organism can receive external energy from radioactive decay occurring in the abiotic media (air, water, or soil). The primary media of concern to the ecological risk analysis are soil (in other words, sediment) and water.

The methodology that was used to estimate radiological doses in the ecological screening assessment followed that used in PNNL's CRITTER2 code (Baker and Soldat 1992). CRITTER2 has two model components: one component estimates body burden from ingestion by means of transfer factors. The second component converts body burden to radiological dose and estimates external dose from radioactive decay in sediment and water. It is this second component of CRITTER2 that was used in the CRCIA model.

Dose Equations

Internal total-body dose rate to an organism is the sum of the individual dose rates from each radionuclide in the body:

$$R_{i,int} = \sum C_{i,c} * E_{i,c}$$

where

- $R_{i,int}$ = Radiological dose to organism i from internal radioactive decay (rad/day)
 - $C_{i,c}$ = Specific body burden of nuclide c in organism i (pCi/kg)
 - $E_{i,c}$ = Effective absorbed energy rate for nuclide c per unit activity in organism i (kg rad/pCi/day)
- and doses are summed across all radionuclides.

As shown in Baker and Soldat (1992), $E_{i,c}$ is a function of the effective absorbed energy in MeV/disintegration ($\epsilon_{i,c}$), viz.

$$E_{i,c} = 1 \text{ Ci}/10^{12} \text{ pCi} * \epsilon_{i,c} \text{ MeV/disintegration} * 3.7 \times 10^{10} \text{ disintegrations/sec/Ci} \\ * 86,400 \text{ sec/day} * 1.602 \times 10^{-11} \text{ kg rad/MeV}$$

or

$$E_{i,c} = 5.12 \times 10^{-8} * \epsilon_{i,c}$$

External dose rates from water exposures are a similar sum of exposures from all radionuclide sources:

$$R_{i,imm} = \sum (b_{pore} * EC_{pore,c} + b_{surface} * EC_{surface,c}) * DF_{imm,c} * F_{water,i} * CF_{water}$$

where

- $R_{i,imm}$ = External radiological dose to organism i from exposure to radioactive decay in water (rad/day)
 $DF_{imm,c}$ = Water immersion dose factor for nuclide c (mrad m³/μCi/year)
 $F_{water,i}$ = Fractional exposure of organism i to the water (unitless)
 CF_{water} = 3.65E-8 (conversion factor: μCi rad year/pCi/mrad/day)
 and other variables are as defined previously.

Finally, external dose received from contact with sediments is calculated as:

$$R_{i, sed} = \sum EC_{sed,c} * DF_{sed,c} * F_{sed,i} * CF_{sed}$$

where

- $R_{i, sed}$ = External radiological dose to organism i from exposure to radioactive decay in sediment (rad/day)
 $DF_{sed,c}$ = Sediment dose factor for nuclide c (mrad m²/μCi/year)
 $F_{sed,i}$ = Fractional exposure of organism i to the sediment (unitless)
 CF_{sed} = 5.4795E-5 (conversion factor: μCi rad year kg/pCi/m²/mrad/day) and other variables are as defined previously.

Finally, total radiological dose is obtained by summing the above quantities:

$$R_{i, total} = \sum (R_{i, imm} + R_{i, sed} + R_{i, int})$$

Calibration

The environmental and body burden inputs to the above equations utilize field-derived media concentrations as described in Section 4.0 and body-burden estimates obtained from the air- and water-respiring species exposure equations described earlier. Dose factors and the effective absorbed energy in MeV/disintegration were obtained from Baker and Soldat (1992). Dose factors are a function of the radionuclide. Effective absorbed energies are a function of both the radionuclide and the radius of the organism being evaluated. Equivalent radii for each species were obtained by assuming organisms represent a sphere of unit density and calculating radii from average body weight data, which were presented earlier.

Calibration Parameters for Copper and Zinc

The exposure model was calibrated to produce approximate average tissue concentrations for copper and zinc within Segment 1. The calibration procedure focused on selecting ranges for bioconcentration factors, ingestion assimilation fractions, and depuration rates from within the published ranges for these parameters that would produce estimates between one-half and five times the average tissue concentrations for species obtained from uncontaminated areas.

The calibration parameters used are in a Microsoft Excel file (par-calb.xls) on diskette. The file shows the chemical assimilation efficiency and, for both copper and zinc, the bioconcentration factors and total loss rates.

Environmental Hazard Quotients

EHQs (the ratio of estimated exposure dose or concentration to LOEL endpoint values) were computed using the deterministic method for river segments and contaminants for each Tier II species. The EHQs that were 1 or greater identified segments, contaminants, and species that were evaluated further in the stochastic modeling.

The EHQs computed are in a compressed file (ehq-det.exe) on diskette. The compressed file will automatically decompress when opened (see instructions at the beginning of this appendix). In the file, the EHQ is given for each species by contaminant and location.

Risk Categories from Stochastic Modeling

Species-contaminant-river segment combinations were classified into four groups based on results of the stochastic simulations: nominal, low, medium, and high potential risk. The categories were based on the proportion of the simulation results that exceeded LC_{50}/LD_{50} or LOEL endpoints. Results of these simulations are presented in a compressed file (risk-cat.exe) on diskette. The compressed file will automatically decompress when opened (see instructions at the beginning of this appendix). In the file are tables and graphs that show for both aquatic and terrestrial species the resulting LC_{50}/LD_{50} or LOEL values.

Appendix I-E

Human Health Risk

Appendix I-E

Human Health Risk

Whereas Section 5.2 presents the methodology and key results of the screening assessment of risk to human health, this appendix provides the details of the input and output of the assessment.

Much of the information in this appendix is provided on diskette. Several of the files on diskette are very large. To make them available, they have been compressed with the commercial compression routine PKZIP (PKWARE 1992). "Exe" as the extension of the file name indicates those files that have been compressed and are capable of decompressing themselves. When these files are decompressed, they will automatically reestablish the computer code and necessary input files. The files provided, if all decompressed, will require a total of over 140 megabytes of hard disk storage. The reader is cautioned to have ample disk storage available.

To decompress an "exe" file:

- ◆ Create a directory on your hard drive and copy the "exe" files into it from the diskette.
- ◆ To decompress the files:
 - In DOS, while in the directory you created, type the "exe" file name and hit enter.
 - In Microsoft Windows File Manager, double click on each "exe" file and it will decompress. To view the decompressed file names in File Manager, click on REFRESH under WINDOW.
 - In Microsoft Windows 95, click on START, then RUN, then BROWSE; indicate directory you have created; double click on each "exe" file to decompress it.
- ◆ To view the individual files, open the files in any text processing software or spreadsheet.

Computer Code and Parameters of Calculations

A computer code, HUMAN, implemented the equations of Section 5.2.1. The HUMAN code was developed under quality assurance controls. Documentation of the code requirements, development specifications, development testing, and user's manual are available in project records. A compressed copy of the HUMAN code in compiled FORTRAN is included on diskette with this report. The compression routine PKZIP2 (PKWare 1992) was used to make self-extracting files. Upon execution, these compressed files uncompress into the full suite of original ASCII or FORTRAN files.

The HUMAN code used as input the media files described in Section 3.0. Compressed copies of the deterministic media files are included on the diskette as well. These files are directly related to the media files described in Section 3.0 and Appendix I-B. The files were converted to a format readable by the HUMAN code. In addition, all of the deterministic and stochastic input files for the scenarios are provided in compressed form. Note that the stochastic media files are too large to put on diskette even when compressed. They may be obtained upon request.

The contents of the diskette are:

<u>Filename:</u>	<u>File description</u>
humancod.exe	Compressed, self-extracting, executable HUMAN code
hh_dt_ex.exe	Compressed, self-extracting, deterministic, external measurements media file used by HUMAN
hh_dt_ss.exe	Compressed, self-extracting, deterministic, environmental media concentrations file used by HUMAN
det_key.exe	Eleven compressed, self-extracting, scenario input files for the HUMAN code for the deterministic calculations
sto_key.exe	Eleven compressed, self-extracting, scenario input files for the HUMAN code for the stochastic calculations

Results of the Calculations

All numerical results of the calculations described in Section 5.2 are provided in this appendix and included on a diskette provided with the report.

Human health risk estimated for each scenario at each location is shown in Figures E.1-E.9. For each scenario, there are three graphics: one depicting the estimate of risk from carcinogenic chemicals, one depicting the hazard index estimated from toxic chemicals, and one depicting the estimate of risk from radionuclides.

Figures E.1-E.9 follow the format described in Section 5.2 for Figures 5.5-5.6. As with the figures in Section 5.2, the absolute values of the risk estimates may be quite high. As described in Section 5.2, the absolute magnitude of the estimated risk is merely indicative of potential areas of concern because the estimates are based on conservative assumptions and do not apply to any real human populations at this time. However, the actual results are provided for those readers wishing to understand the nature of the screening level calculations performed for this assessment. The results of the screening assessment of human risk will be used to support cleanup decisions and to focus a subsequent and more comprehensive risk assessment.

The numerical results of the calculations are provided to the reader on diskette. The diskette contains all of the output from the input files described in the previous section. The calculations run were both deterministic (single valued input and output) and stochastic (parameters varied over their expected ranges).

Figure E.1. Human Health Risk Estimate for the Industrial Worker Scenario

Figure E.2. Human Health Risk Estimate for the Fish Hatchery Worker Scenario

Figure E.3. Human Health Risk Estimate for the Avid Recreational Visitor Scenario

Figure E.4. Human Health Risk Estimate for the Casual Recreational Visitor Scenario

Figure E.5. Human Health Risk Estimate for the Native American Upland Hunter Scenario

Figure E.6. Human Health Risk Estimate for the Native American River Focused Hunter and Fisher Scenario

Figure E.7. Human Health Risk Estimate for the Native American Gatherer of Plant Materials Scenario

Figure E.8. Human Health Risk Estimate for the Resident Scenario

Figure E.9. Human Health Risk Estimate for the Agricultural Resident Scenario

Both sets of results are provided. The results of the deterministic calculations are provided in the self-extracting, compressed file "determ.exe." Additional details for each of these cases are provided in the self-extracting, compressed file, "det_dtl.exe." The results of the stochastic calculations are provided in self-extracting, compressed file, "stochast.exe." Additional details for each of these cases are provided in the self-extracting, compressed file, "stoc_dtl.exe." The values found in these various files were used to make the summary spreadsheet, "results.xls."

The contents of the diskette are:

<u>Filename:</u>	<u>File description</u>
determ.exe	Compressed, self-extracting file containing all of the calculational results of the HUMAN code runs for the deterministic simulations
det_dtl.exe	Compressed, self-extracting file containing secondary output from the deterministic runs, providing additional detail on the pathways and sources of exposure for each location and for each contaminant
stochast.exe	Compressed, self-extracting file containing all of the calculational results of the HUMAN code runs for the stochastic simulations
stoc_dtl.exe	Compressed, self-extracting file containing secondary output from the stochastic runs, providing additional detail on the pathways and sources of exposure for each location and for each contaminant
results.xls	Microsoft Excel 5.0 file of the numerical results as well as the graphical displays of those results (Figures E.1-E.9) by scenario

Computer Code for the Statistical Analysis of Downstream/Upstream Comparisons and the Results

As described in Section 5.2, the human risk results at Hanford-influenced locations were compared with those estimated for an upstream and, therefore, presumably minimally contaminated location (Segment 1). Graphical summaries of the results of the statistical evaluation are provided in Section 5.2.4 (Figures 5.36 and 5.37) for the Ranger and Native American Subsistence Resident scenarios, respectively. Summaries for the other scenarios (Figures E.10-E.18) are provided here.

Because the distributions hold more information than can be easily used, means of comparing the entire upstream and downstream distributions were developed. These techniques were based on detailed statistical approaches called the Mann-Whitney U Test and the Kruskal-Wallis One-Way Anova Test (Gibbons 1971).

A computer code to implement the Kruskal-Wallis and Mann-Whitney statistical tests (RISKS) was prepared. The RISKS code was developed under quality assurance controls. Documentation of the code

	Background										Based on stochastic output of Industrial Worker Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Hom	Area		Bluffs	Area	Slough		Slough	Town.	Syr.		Area	Area	Richlan	Riv.	Riv.	Carc.	Walla R	Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cu/Cat																											
Cu/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
Bu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
Tc-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.10. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Industrial Worker Scenario

Background											Based on stochastic output of Fish Hatchery Worker Scenario																
Above background, insignificantly											Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index											The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Analyte	Priest Rapids	B/C Area		KB/KW Area	K- Trench	N Area		D Area	Horn	Area		White Bluffs	F Area	F Slough		Hanf. Slough	Hanf. Town.	Supp. Sys.		300 Area	1100 Area	Richlan	Yakima Riv.	Snake Riv.	Boise Carc.	Walla Walla R.	McNary Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
Bu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
To-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.11. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Fish Hatchery Worker Scenario

	Background										Based on stochastic output of Avid Recreational Visitor Scenario																
	Above background, Insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Analyte	Priest Rapids	B/C Area		KE/KW Area	K- Trench	N Area		D Area	H Horn			White Bluffs	F Area	F Slough		Hanf. Slough	Hanf. Town.	Supp. Sys.		300 Area	1100 Area		Yakima Richlan	Snake Riv.	Boise Riv.	Walla Case	McNary Walla R. Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cr/Cat																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
Bu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
Te-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.12. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Avid Recreational Visitor Scenario

	Background										Based on stochastic output of Casual Recreational Visitor Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Priest	B/C		KB/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Horn	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richlan	Riv.	Riv.	Caso.	Walla R.	Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
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Kerosene																											
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Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
Te-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.13. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Casual Recreational Visitor Scenario

	Background										Based on stochastic output of Native American Upland Hunter Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Analyte	Priest	B/C		KE/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
	Rapids	Area		Area	Trench	Area		Area	Horn	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richlan	Riv.	Riv.	Casc.	Walla R.	Res.
Ammonia																											
Benzene																											
C-14																											
Ca-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
Bu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
Tc-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.14. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Native American Upland Hunter Scenario

	Background										Based on stochastic output of Native American Hunter/Fisher Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Analyte	Priest	B/C		KB/KW	K-	N		D	Hom	H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Ammonia	Rapids	Area		Area	Trench	Area		Area	Hom	Area		Bluff	Area	Slough		Slough	Town.	Sys.		Area	Area	Richlan	Riv.	Riv.	Casc.	Walla R	Res.
Benzene																											
C-14																											
Cs-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
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Kerosene																											
Lead																											
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Nitrate																											
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Phosphate																											
Sr-90																											
Sulfate																											
Tc-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.15. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Native American Hunter/Fisher Scenario

	Background										Based on stochastic output of Native American Gatherer Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard Index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard Index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Analyte	Priest Rapids	B/C Area		KB/KW Area	K- Trench	N Area		D Area	Horn	H Area		White Bluffs	F Area	F Slough		Hanf. Slough	Hanf. Town.	Supp. Sys.		300 Area	1100 Area		Yakima Richlan Riv.	Snake Riv.	Boise Casco	Walla Walla R.	McNary Res.
Ammonia																											
Benzene																											
C-14																											
Cr-137																											
Cr/Cr																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
Bu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
To-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.16. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Native American Gatherer Scenario

	Background										Based on stochastic output of Resident Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Priest	B/C		KB/KW	K-	N		D		H		White	F	F		Hanf.	Hanf.	Supp.		300	1100		Yakima	Snake	Boise	Walla	McNary
Analyte	Rapids	Area		Area	Trench	Area		Area	Horn	Area		Bluffs	Area	Slough		Slough	Town.	Sys.		Area	Area	Richland	Riv.	Riv.	Caso.	Walla R.	Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Eu-152																											
Eu-154																											
I-129																											
Kerosene																											
Lead																											
Mercury																											
Np-237																											
Nickel																											
Nitrate																											
Nitrite																											
Phosphate																											
Sr-90																											
Sulfate																											
Tc-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.17. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Resident Scenario

	Background										Based on stochastic output of Agricultural Resident Scenario																
	Above background, insignificantly										Results identified using "RISKS" program, implementing Kruskal-Wallis Test (2-sided) and Mann-Whitney U Test (1-sided) (Gibbons 1971)																
	Above threshold of 1E-6 for lifetime risk or 0.01 for hazard index										The statistical tests use a tail probability of 5%, yielding a 1-in-20 chance of false positives																
	Above threshold of 1E-4 for lifetime risk or 1.0 for hazard index																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Analyte	Priest Rapids	B/C Area	KB/KW Area	K- Trench	N Area			D Area	H Horn			White Bluffs	F Area	F Slough		Hanf. Slough	Hanf. Town.	Supp. Sys.		300 Area	1100 Area		Yakima Richland	Snake Riv.	Boise Riv.	Walla Casco	McNary Walla R. Res.
Ammonia																											
Benzene																											
C-14																											
Cs-137																											
Cr/Car																											
Cr/Tox																											
Co-60																											
Copper																											
Cyanide																											
Diesel																											
Bu-152																											
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Kerosene																											
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Phosphate																											
Sr-90																											
Sulfate																											
To-99																											
Tritium																											
U-234																											
U-238																											
Xylene																											
Zinc																											

Figure E.18. Statistical Evaluation of the Differences Between a Segment Not Affected by Hanford Site Operations and Downstream Segments Affected by Hanford Site Operations for the Agricultural Resident Scenario

requirements, development specifications, development testing, and user's manual are available in the project records. An executable copy of the RISKS code is available on diskette with this report.

The RISKS code used as input the output of the HUMAN code described earlier in this appendix. However, these files are so large as to make their distribution impossible. They may be reproduced using the HUMAN code and the input files provided. The input files used to make the calculations reported in Section 5.2 are provided on diskette. A summary of the results of the downstream/upstream comparisons is provided in the Microsoft Excel file (updown.xls).

The contents of the diskette are:

<u>Filename:</u>	<u>File description</u>
riskcode.exe	Compressed, self-extracting, executable RISKS code
riskkey.exe	Eleven compressed, self-extracting, input files used to control the RISKS code for each scenario
riskrpt.exe	Eleven compressed, self-extracting, output files containing the results of the downstream/upstream comparison calculations
updown.xls	EXCEL 5.0 file of the numerical results of the RISKS calculations as well as the graphical displays of those results (Figures 5.5-5.32) for each contaminant for the Ranger and Native American Subsistence Resident scenarios

Scenario Additivity

The scenarios presented in Section 5.1 and evaluated in Section 5.2 do not address all possible activities that could occur at Hanford. The scenarios were selected to provide a broad range of information, not to specify actual risk to real individuals. Generally speaking, the several residential scenarios should cover most foreseeable exposures. However, for those interested in compound lifestyles, such as might occur with a resident of the downstream City of Richland who is also an avid recreational visitor, a simplistic approximation is provided to allow additional evaluations.

The process of creating a compound scenario involves selecting the base scenario (that which forms the basic lifestyle of the individual) and adding to it a fraction or multiple of the additional scenario. The river segments applicable for each scenario need also to be defined.

For example, consider the hypothetical case of the risk from radionuclides to a near-river resident of the City of Richland (Resident Scenario, Segment 21) who occasionally visits the Wahluke Slope Wildlife Refuge Area (Segment 13) for recreational purposes. The median estimate for the lifetime risk from radionuclides to the Richland resident can be found in the radionuclides portion of Figure E.8 to be about 4.4×10^{-4} . The median lifetime risk to a casual visitor to the Wahluke Slope recreation area in the vicinity of F-Reactor (Segment 13) is found in the radionuclides portion of Figure E.4 to be about 1×10^{-5} . The joint risk is the sum of these two values, about 4.5×10^{-4} . The additional activities that the individual enjoys on the Hanford Site add about 2 percent to her/his lifetime risk. The simple addition works because

the time spent on site is so small in the Casual Recreational Visitor Scenario that adjustments to the residential portion of the scenario are not significant.

For a more complex example, consider the hypothetical case of the heavy metal risk (as measured using the hazard index) to a traditional Native American subsistence resident who might permanently live north of the 300 Area (Segment 19) but regularly fishes near the influx of the Yakima River at Columbia Point (Segment 22). In this case, the underlying assumption of the Native American Subsistence Resident Scenario is 365 days/year at Segment 19, and 150 days/year at Segment 22. These fractions need to be adjusted to make a reasonable total number of days per year. If we assume that the individual fishes 75 days/year, then the total risk from the Native American Subsistence Resident Scenario can be reduced by a factor of $(365-75)/365$, and the total risk from the Native American Hunter/Fisher Scenario can be reduced by a factor of $(150-75)/150$. The hazard index in Segment 19, assuming full-time occupancy, for the Native American Subsistence Resident Scenario is found in the toxic chemical portion of Figure 5.6 to be about 4.3. The hazard index in Segment 22 for 100 percent of the Hunter/Fisher scenario is found in the toxic chemical portion of Figure E.6 to be about 2.7. Thus, the overall hazard index for this combined lifestyle would be

$$(365-75)/365 * 4.3 + (150-75)/150 * 2.7 = 4.77$$

There is very little overall change in the average hazard index for the subsistence resident achieved by combining these two activities in this way. The net increase results because, while ingestion of foods from Segment 19 is assumed to be reduced, they are increased by foods caught by the individual fishing at Segment 22. Note, too, that the bulk of the overall hazard index results from Segments 19 and 22 are caused by the intake of copper and lead, which are not significantly above background. This level of detail can be found by decompressing the file, `nasubs_d.dtl`, from the diskette of results (compressed in the `det_dtl.exe` file) and viewing it with a text editor.

Other combinations of scenarios can be evaluated in a similar fashion. Those wishing more detail are advised to adapt one of the input files provided and run the HUMAN code.

Appendix I-F

Comments and Responses on the Contaminants, Data, Species, and Scenarios Draft Reports

Appendix I-F

Comments and Responses on the Contaminants, Data, Species, and Scenarios Draft Reports

A series of reports on the selection of contaminants, data, species, and scenarios for use in the screening assessment were published as draft reports. The comments received on those draft reports were taken into consideration in the final selection of contaminants, data, species, and scenarios to be used in the screening assessment. The sections on contaminants, data, species, and scenarios in this report now reflect the changes that resulted from the comments.

For each draft report, there are two tables. Because of the need to respond to each comment and because numerous comments were the same, the responses are on a separate table from the comments. The comments table is a compilation of the comments with a notation to indicate the applicable response. The response table provides the responses with notations as to which comments are being addressed.

The comments and response tables are on a diskette (Word Perfect 5.1 for DOS) included in this report. The file names are:

con-com.wp5	=	comments on the draft contaminants report
con-resp.wp5	=	responses to the comments on the draft contaminants report
sce-com.wp5	=	comments on the draft scenarios report
sce-resp.wp5	=	responses to the comments on the draft scenarios report
spe-com.wp5	=	comments on the draft species report
spe-resp.wp5	=	responses to the comments on the draft species report
dat-com.wp5	=	comments on the draft data report
dat-resp.wp5	=	responses to the comments on the draft data report.

Part II

Requirements for the Columbia River Comprehensive Impact Assessment

Disclaimer

Publication of Part II of this document is being performed as a public service by the U. S. Department of Energy and in conformance with Milestone M-15-80 of the Hanford Federal Facility Agreement and Consent Order, referred to as the Tri-Party Agreement. Its publication does not constitute endorsement of the opinions, conclusions, or recommendations contained therein by the U. S. Department of Energy. The U. S. Department of Energy is required by Tri-Party Agreement Milestones M-15-80A, M-15-80B, and M-15-80-T01 to respond to and develop recommendations concerning Part II. More information regarding Tri-Party Agreement requirements and U. S. Department of Energy required responses can be found in the text.

Summary

As the screening assessment documented in Part I was being conducted, the assessment specified in Part II was developed by the Columbia River Comprehensive Impact Assessment Team (CRCIA Team). Active participants on the CRCIA Team have been representatives from the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, Yakama Indian Nation, Hanford Advisory Board, Oregon State Department of Energy, Tri-Party agencies, and Hanford contractors. The CRCIA Team developed Part II to explicitly require any future assessment of Hanford impact on the Columbia River to embody, at a minimum, the methods, characteristics, and controls described in Part II. Those analyses involving the Columbia River which adhere to the spirit and substance of these requirements are far more likely to be acceptable to the governments and institutions which authored this section and far more meaningful in guiding cleanup decisions.

This is the only composite assessment of how effective the cleanup of the Hanford Site will be as expressed in terms of impact to the Columbia River. Other analyses address only some of the elements of the needed assessment. This is a composite assessment because, in part, all potentially harmful radioactive and chemical materials within the Hanford Site boundary (those planned by the U.S. Department of Energy, DOE, to exist at the completion of cleanup) are included in a single evaluation of impact resulting from potential exposure. The purpose of the Columbia River Comprehensive Impact Assessment (CRCIA) is to assess the effects of Hanford-derived materials and contaminants on the Columbia River environment, river dependent life, and users of river resources for as long as these contaminants remain intrinsically hazardous. This purpose is envisioned to be carried out by developing a suite of integrated analysis tools, which would be used for each revision of DOE's intended waste disposal plans defining the Hanford Site's final end state. As such, CRCIA becomes a major, critical part of the Hanford Site's final baseline risk assessment. CRCIA is also seen as a tool with which effectiveness can be estimated for each of the alternatives considered in strategic planning exercises, environmental impact statements, and the various projects' studies. This assessment was defined and this part of the document was prepared by the CRCIA Team (not DOE or its contractors) under a new public involvement paradigm described later in this summary, in Section 4.0 below, and in Appendix II-D.

In facing the question of what constitutes a comprehensive assessment, a serious problem soon became apparent: How can the assessment include all of the factors significant to potential river impact while keeping the effort to a manageable size which can be funded? Using expert judgment to "assume the assessment down-to-size" was rejected as an acceptable solution to this problem. Instead, a principle (specified as a

HOW TO USE THIS DOCUMENT

Part II of this document consists of this narrative section and specification sections, Appendixes II-A, II-B, II-C, and II-D. The specification sections enumerate the technical and management requirements for conducting the assessment. The appendixes are for the analysts who will perform the technical work. This narrative section supplements the specification sections with general guidance and non-technical explanations of the requirements. As may be seen in this section's table of contents, organization of the narrative and the appendixes are parallel aside from the introductory topics in the narrative section. While each section is complete in its own right, the reader may find it useful to study the narrative and appendixes in parallel, turning from one to the other as interest dictates.

requirement in Part II) was borrowed from other industries which routinely deal with large, complex problems yet have only limited resources. This principle requires the study's planning process be based upon sensitivity analyses and parametric analyses which sort the dominating factors from the smaller contributors to impact. Consequently, for any given level of resources allocated to this assessment, the biggest contributors to potential river impact will always be addressed. The challenge for analyst and manager alike is not to arbitrarily discard parts of the assessment to cut it down to size but rather to ensure that no factor is left out which would dominate the study results. Care has been taken in developing Part II to be fiscally responsible in defining the requirements for the technical work that must be conducted regardless of speculations on probable funding availability or limits presumed to exist in analytical methods, data collection techniques, or related technologies. Every effort has been made to ensure that the assessment will always focus on major contributors in such a way as to avoid obfuscation by the enormous number of smaller considerations.

Since the screening assessment in Part I of this document was scoped to be a less-than-comprehensive, limited-resource effort focused on identifying the most significant existing effects on the Columbia River, the comprehensive assessment in Part II subsumes the screening assessment in identifying both existing and future effects from the composite of all Hanford activities. In spite of the care in developing this document, it is recognized that it can and should be improved upon, especially in view of inevitable changes in waste disposal plans and experience gained in conducting this and similar assessments. It is intended that this be a living document with changes controlled by the authoring institutions.

Part II defines a new paradigm for predecisional participation by those affected by Hanford cleanup decisions. The CRCIA Team developed the requirements in Part II as well as the approach and structure for conducting and managing future assessment work. Appendix II-D describes this new paradigm and the associated management requirements. It is recognized that some time may be needed to make the adaptations in existing Hanford practices this new paradigm calls for. An implementation period is anticipated during which special attention will be given to working within existing policies and procedures while adaptations are being made.

Following the Introduction and the discussion of Principles and General Requirements, Part II is divided into four key sections: *WHAT* is to be analyzed, *HOW WELL* must the results represent actual and future impact to the Columbia River, technically *HOW* is the assessment to be performed, and what is the *MANAGEMENT* structure for the analysis work. Explanations and descriptions of these four areas are found below. Lists of the technical requirements parallel this structure in Appendixes II-A, II-B, II-C, and II-D. The parallel sections/appendixes are:

- ◆ Section 1.0/Appendix II-A, What the Assessment Must Include. These sections specify *WHAT* factors must be included in assessing river impact. They include the extent of Hanford Site activities and materials to be addressed, transport mechanisms and travel times, and contaminant introduction into the river. The requirements also address the distribution of the contaminants within the Columbia River as well as identification of habitat or other water uptake locations. The requirements specify potential species, ecosystems, human populations, and cultures that could be affected by

Hanford-derived contaminants in the Columbia River. This section also includes probable scenarios for the time frame of interest in which substantive change occurs to the river or ecosystem and cultural dependency on the river.

- ◆ Section 2.0/Appendix II-B, How Good the Impact Assessment Results Must Be. Requirements in these sections prescribe how complete the assessment results must be and *HOW GOOD* the analysis must be to produce the needed results.
- ◆ Section 3.0/Appendix II-C, Analytical Approach and Methods. Given the factors specified in the first two sections (1.0 and 2.0), these sections stipulate *HOW* the technical analyses are to be planned to ensure no dominant contributor is overlooked. Analytical methods, modeling requirements, data quality, uncertainty, and verification requirements are among the specifications included. While these requirements avoid specifying what tasks must be done or in what sequence work is to be performed, it is clear that this section must heavily influence how the assessment work is to be defined and the preparatory work which must precede the start of the analysis.
- ◆ Section 4.0/Appendix II-D, Conducting and Managing the Assessment. *MANAGEMENT* requirements are addressed in these sections to include methods to determine funding prioritization, sequence of technical work, the roles of peer reviewers, integration with Hanford Site strategic planning and other analyses, and support of environmental impact statement preparations. These sections also address the continuing involvement and authority of affected people and groups.

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Introduction

The Columbia River system is the center of the regional ecosystem and has supported indigenous cultures for over 10,000 years. The river is a dynamic, living entity consisting of many linked aquatic and terrestrial habitats with many overlapping spatial and temporal scales. The part of the Columbia River which flows through the Hanford Site is known as the Hanford Reach and constitutes the last free flowing, non-tidal segment of river in the United States. The Hanford Reach section of the Columbia River, and a small distance downstream, has been designated by the Washington State Department of Ecology (Ecology) as a Class A (excellent) surface water body. This designation requires all industrial surface water uses to be compatible with other uses, including drinking water, wildlife, and recreation.

The Hanford Reach is also known for its exceptionally high biodiversity of plants and animals. It features several habitats which are rare or are in decline along the Columbia River. These features include riparian habitats, White Bluffs, upland shrub-steppe communities, and wetlands. After flowing nearly 80 kilometers (50 miles) through the Hanford Site, the Columbia River continues for another 500 kilometers (300 miles) past Washington and Oregon communities to the Pacific coast, flowing through Oregon's most heavily populated urban area and important agricultural, commercial, and recreational areas. Nearly one million Oregonians, somewhat fewer Washingtonians and several Native American tribes live directly downriver from the Hanford Site. They rely on the Columbia River for commerce, fisheries, irrigation, recreation, and transportation.

Authority

The authority underpinning these requirements for a comprehensive assessment of Hanford impact on the Columbia River is DOE's need for acceptance of cleanup decisions and this assessment's results by the affected people. DOE is providing only publications services for Part II of this document. It is not issued as an expression of DOE's endorsement. Like DOE, the other Tri-Party agencies, Ecology and the U.S. Environmental Protection Agency (EPA), are members of the CRCIA Team which originated these requirements. However, these requirements have been promulgated by the CRCIA Team, not by the Tri-Party agencies, even though preparation of these requirements is the subject of Tri-Party Agreement (TPA) commitments (milestone M-15-80).

Background

The CRCIA Team first met in August 1995 for the purpose of forming with DOE a steering force to define the requirements for a fully comprehensive assessment of the Hanford Site's effect on river-dependent life. Additionally, the CRCIA Team has acted as an advisory body for the screening assessment, which the Tri-Party agencies initiated in 1993 as the original comprehensive assessment of river impact. This effort was recognized in the TPA in January 1994 by including milestones for the comprehensive assessment, now the screening assessment. Dates for these milestones have since been modified, in part because the scope and priorities of CRCIA have been controversial with respect to what constitutes a comprehensive assessment. This contention has essentially disappeared, primarily because of the

effectiveness of the CRCIA Team as a new predecisional paradigm in allowing the guidance of the screening assessment to rest in the hands of technical representatives of key socio-economic groups affected by Hanford's cleanup decisions. Development of these requirements has been the key condition in settling the controversy over comprehensiveness.

Those represented by the CRCIA Team are the Confederated Tribes of the Umatilla Reservation, Nez Perce Tribe, Yakama Indian Nation, Hanford Advisory Board, Oregon Department of Energy, DOE and their Hanford contractors, Ecology, and EPA.

How These Requirements Were Developed

Working to define a common ground on which the Tri-Party agencies and all participants could comfortably stand, the CRCIA Team developed the requirements through weekly facilitated workshops. Most participants had suggestions, criticisms, issues and concerns about previous, similar analyses. These were elicited from the participants in a systematic structure which, with some reorganization, became the framework for Part II of this document. The CRCIA Team had neither the expertise to design an analysis of this significance nor was it appropriate to preempt the performing contractor from designing the most effective approach. Therefore, the participants' issues and concerns were translated into the requirements to be met in designing and performing the analysis. DOE opted only for the role of a participant in these

workshops rather than to develop the document directly or through their contractors. The CRCIA Team provided its own facilitator and clerical support from among its members. DOE provided publication services. Thus, CRCIA Team defined requirements are provided in this document. These requirements are not a DOE negotiated position, even though DOE and their contractors were active contributors to the effort. The CRCIA Team strove for completeness. Judgments on relative importance of the issues and requirements were not allowed pending formal work to define which considerations dominate the assessment and which contribute little.

WHAT IS DOE'S COMMITMENT TO CRCIA AND THESE REQUIREMENTS?

DOE is pursuing follow-on work based on the "Requirements for a Comprehensive Assessment." As part of completing TPA Milestones M-15-80A, M-15-80B, and M-15-80B-T01, DOE is working with the CRCIA Team to identify specific work tasks which 1) are necessary for a comprehensive assessment, 2) are prioritized and address the most dominant risk factors first, and 3) can be performed within budget guidelines dictated. Agreed to tasks will be included in the multi-year work plan packages for FY 1998 and beyond.

Problem Statement

The previous assessments of Hanford impact on the Columbia River were performed to provide information for specific projects and were not comprehensive. Here is a partial list of examples of why previous assessments were not comprehensive:

- ◆ Previous assessments have not addressed the Hanford Site in its post-cleanup end state as a single, composite source of potential contamination. This is partly because the source term data used was drawn from lists of known inventories of materials and wastes in their existing states. The planned end states of the wastes has not been reflected in the data used.
- ◆ A composite source term has not been used which combines the effects of all chemical and nuclear materials and wastes within the geographical boundaries of the Hanford Site.
- ◆ Predictive cumulative effects of Hanford's multiple contaminant sources have not been addressed.
- ◆ The time frame considered for potential effects to occur has been inconsistent with (1) the point at which planned waste containment devices can be expected to be breached allowing contaminant migration to the Columbia River and (2) the period during which potential contaminants remain intrinsically dangerous.
- ◆ River-borne contaminant impact on human health has not considered the full suite of potential health effects or all human exposure scenarios. For example, previous assessments have only considered incremental cancer risk and hazard quotients.
- ◆ The cultural impact on potentially affected people has not been evaluated.
- ◆ Ecological effects have not been adequately considered.
- ◆ Existing environmental regulations are, as the only guidance, inadequate because they are generally not site specific and because they do not adequately consider protection of the affected peoples. Only a site-specific assessment of risk can meet these needs.

If the assessment prescribed in Part II is performed so as to eliminate prior inadequacies, it should satisfy the need for a final Hanford Site risk assessment in so far as potential impact to the Columbia River is concerned.

Purpose of the Assessment

The purpose of CRCIA is to assess the effects of Hanford-derived materials and contaminants on the Columbia River environment, river-dependent life, and users of river resources.

For CRCIA to be comprehensive, representatives of the major community groups (CRCIA Team members who are other than the Tri-Party agencies) on the CRCIA Team have agreed that the following objectives must be achieved if the results and conclusions are to be acceptable by all concerned:

- ◆ Estimate, with useful certainty, river-related human health and ecological risks for the time period that the Hanford materials and contaminants remain intrinsically hazardous

- Evaluate the sustainability of the river ecosystem, the interrelated cultural quality-of-life, and the viability of socio-economic entities for the time period that Hanford materials and contaminants remain intrinsically hazardous
- ◆ Provide results that are useful for decision making on Hanford waste management, environmental restoration, and remediation

Relationship to the Screening Assessment

The requirements specified in Part II strive to be comprehensive for any assessment of Hanford impact on the Columbia River. Since the screening assessment in Part I was conceived and evolved from a Tri-Party Agreement commitment to determine only the current state of the Columbia River as a basis for decisions on interim remedial actions, the screening assessment must be regarded as only an initial subset of any comprehensive assessment. The screening assessment was conducted simultaneously with the development of these requirements. While every effort was made to revise the screening assessment as individual requirements stabilized in the comprehensive definition, time and funding constraints made it impractical to achieve complete accord. To the extent that the screening assessment meets the comprehensive requirements, its data and results will be used to avoid unnecessary duplication of effort.

Uses and Users

WHAT IS A REQUIREMENT?

Use of the term "requirement" as used throughout Part II of this document is meant as a minimal constraint on the choices to be made in defining, planning, and conducting this assessment.

The requirements herein are prescribed in the following three forms:

1. Guiding principles and general requirements common to all aspects of the assessment. These requirements are found primarily in the narrative section.
2. Conceptual descriptions of requirements with actual or hypothetical examples. These statements are typically found as a statement of purpose at the beginning of each requirements section in the appendixes. Explanations are usually included in the narrative section as well. It is intended that the analysts add specific instances as applications become apparent in the course of the assessment. Direction may be included for the analysts to identify the remaining instances of these requirements.
3. Explicitly stated requirements make up the preponderance of the appendixes.

When conducted in accordance with the requirements in Part II, the results from a comprehensive assessment of the Columbia River will provide a sound basis for essentially two types of decision-making. The first is the group of decisions which, taken together, define how well the Hanford Site is cleaned up and how permanent the selected containment methods are expected to be. To provide a reliable basis for this class of decisions, the requirements must realistically specify how to calculate the effects on the species of interest. In turn, scenarios must be applicable for both individuals and socio-economic groups postulated to be affected. The users of the assessment results in this decision-making group include DOE, Ecology, EPA, other technical, management, and public groups directly involved in the Hanford cleanup and disposal decision-making process.

The second group of decisions includes those made in response to Hanford conditions by the

people and groups affected by the cleanup decisions. The assessment results are intended to objectively reflect the effect of Hanford's potential contamination assuming the approved cleanup and waste containment plan is accurately defined, effectively implemented, kept current with technical and funding decisions, and CRCIA is updated as cleanup decisions change. This group of users is extensive. It includes the communities and individuals who depend on the Columbia River for drinking water, agriculture and irrigation, sustenance/sport/commercial fishing, transportation or its support activities such as dredging, hydroelectric power generation, and recreation.

The CRCIA Board, as defined in Appendix II-D, must seek advice and recommendations from these groups in planning and directing the assessment. Periodic reports of findings will be made available to these groups. Special attention will be given to the timing of cleanup and disposal decisions making results available which are relevant to those decisions.

Avoiding Duplication of Other Work

Some elements of the assessment prescribed may have been performed, or are being performed, in other studies. Such efforts will be sought out and used in lieu of redoing the work if the studies were performed in an acceptable manner as defined in Part II. The CRCIA Team became aware of some efforts underway at the time of this writing which appear to be similar to CRCIA. Upon inquiry, however, each effort was found to be fundamentally lacking in one or more facets, much as discussed in the Problem Statement section above. Efforts will be undertaken with those performing those studies to try to find an accommodation of CRCIA needs. Several smaller studies involving the Columbia River also are underway or planned which are of more limited scope and focus on a specific problem. They are, by design, less than comprehensive. To the degree that these and similar limited scope studies in the future meet CRCIA requirements, their findings and conclusions can be used in CRCIA assessments.

CRCIA efforts also will be integrated with other Hanford Site activities. Examples of special interest are strategic planning documents and products such as environmental impact statements and budget planning documents. CRCIA is a tool with which effectiveness can be estimated for each alternative considered in strategic planning exercises and project studies.

About the Appendixes

The requirements in the appendixes were developed from the issues and concerns held by the constituencies of the CRCIA Team members. As such, the appendixes are not complete from the standpoint of comprising the total guidance needed for the assessment. The CRCIA Team members are generally conversant with technical work but had little or no direct experience in designing an analytical effort like CRCIA. It is, therefore, left to the analysts to not only design and conduct the assessment to meet the requirements in Part II but to also grasp the spirit and intent of each subject area and flesh out the requirements as needed to be consistent with the CRCIA Team's intent as well as adhering to good technical practice.

Four appendixes have been structured to organize these issues and concerns into technical and management requirements. Generally, a hierarchical pattern has been followed in which the requirements at any given level comprise a subset of a higher level parent requirement for that subject area. Figure 1 provides an example of this hierarchical organization. The reader will notice many of the requirement statements to be conceptual in nature while others are quite explicit. Some of these conceptually described requirements do not yet have lower level requirements and, therefore, may appear to contradict the hierarchical pattern. Nevertheless, the intent should be sufficiently clear to support the analysts' implementation. Questions may always be referred to the CRCIA Board for clarification.

This initial publication of Part II purposely truncates most of the lower level requirements because of insufficient time to develop an orderly presentation reasonably free of error and redundancy. Therefore, the reader may not find many instances of the complete requirements hierarchy depicted in Figure 1. However the temporarily missing requirements should be available by this draft's publication date for those who would like to request a copy.

Figure 1. Typical Requirements Hierarchy

Principles and General Requirements

Several requirements recurred in so many of the sections that it became obvious they constituted overarching considerations. These have been consolidated into Principles and General Requirements.

Principles

- ◆ **Dominance.** This is the principle that in virtually all things a relatively small number of factors dominates the outcome. It is of the utmost importance that this assessment not leave out any factors which dominate the results. Yet the magnitude of work and cost of the analysis must be responsibly managed. Sensitivity analyses, parametric analyses, and related methods will be used to identify and rank order the factors which dominate the outcome of this assessment. These factors may be physical attributes of the Hanford Site or waste disposal, or they may be technical characteristics and challenges within the study itself. Assumptions framed through expert judgment (in lieu of repeatable analyses) will not be used to identify dominant factors or discard smaller contributors. The resulting understanding of relative importance will be used to focus technical emphasis, management oversight, and assessment planning, as well as Hanford Site budget estimates and funding allocation for the CRCIA. This principle and its implementation while managing uncertainty is discussed more fully in Appendix II-C, Analytical Approach and Methods
- ◆ **Uncertainty.** The relative uncertainty inherent in assessment results will be quantified and used in the technical definition of the assessment as well as in the study's management and allocation of resources. The level of uncertainty which can be tolerated in using the study results as a basis for cleanup decisions will be a guiding requirement. Uncertainty will be uniformly managed across the various study tasks. Methods such as "Value of Information" (from decision theory) will be used to determine the usefulness of spending more effort to reduce uncertainty. It also will be recognized that uncertainty and the dominance principle are coupled. This is more fully addressed in Appendix II-C.

Care must be taken by the analysts not to dismiss an effect which may be important from a cultural perspective simply because popular analytical approaches may discard such effects.
- ◆ **Fidelity of Assessment Results.** In the same sense that a high-fidelity sound system faithfully reproduces the original musical performance with clarity and discernible differences among instruments, this assessment must be capable of detecting an impact and resultant effect which is or will be significant to the people affected by the cleanup and waste disposal decisions made at Hanford (see Figure 2). In this context, fidelity in this assessment includes the concepts of accuracy, resolution of information in both time and location, and statistical significance. Perhaps the primary consideration is that assessment results have enough fidelity to distinguish among cleanup and disposal alternatives in the Hanford Site decision-making process. Care must be taken by the analysts not to dismiss an effect which may be important from a cultural perspective simply because popular analytical approaches may discard such effects. This principle imposes a difficult challenge on those who do the technical design of the

ORIGINAL MUSICAL PERFORMANCE	ACTUAL HANFORD CONDITIONS
DIGITAL RECORDING PLAYBACK	CRCIA ANALYSIS
HIGH FIDELITY SOUND REPRODUCTION	HIGHLY REPRESENTATIVE RESULTS

Figure 2. Fidelity

assessment. An appreciation of cultural and socio-economic values of the river-dependent people is requisite to an acceptable assessment.

- ◆ **Preeminent Principles.** Of all the requirements and guidance imposed by Part II of this document, by far the most important are dominance, uncertainty, and fidelity. Each is highly dependent upon the other two. Together they outweigh all other considerations by a wide margin in technically designing the assessment, in making budget decisions, and in making day-to-day technical and management choices.
- ◆ **Use of Expert Judgment.** Experienced, knowledgeable analysts are expected to exercise their skills and judgment with the highest professionalism in planning and conducting this assessment. Substituting expert judgment for analytical quantification should, however, be avoided unless there is convincing rationale to the contrary. Clearly, time, available resources and significance of the matter at hand must guide the analysts. The bases in making such choices are credibility and replication. Pivotal matters in the assessment must be able to be replicated by qualified professionals outside of the Hanford community. The assessment cannot be placed in a position of disrepute because results cannot be verified.
- ◆ **Development and Use of Assumptions.** Adherence to the requirements in Part II should eliminate the need to make arbitrary assumptions to conduct the assessment. If, however, it becomes apparent that assumptions are needed, CRCIA Board approval must be sought before implementation of the candidate assumptions. Those with merit will likely result in a revision to Part II of this document. The analyst must document all assumptions.
- ◆ **Integration of Tasks Within the Assessment.** As the assessment is subdivided into work tasks, care will be exercised to ensure consistency and compatibility in the application of requirements, use of data, seamlessness of modeling, management of uncertainty, and related factors bearing on overall assessment quality.
- ◆ **Integration With Other Site Efforts.** Two primary areas require continuous management integration aside from the assessment tasks. First, the assessment must remain integrated with cleanup and waste disposal decisions including related environmental impact statements, records of decision, conceptual

design contract awards, planning bases for budget submittals, strategic planning, and Hanford Site project requirements documents. Second, integration must be achieved and maintained with other related analytical efforts, especially other studies involving the Columbia River. Any analyses involving the river or river corridor are expected to comply with the applicable portion of the requirements of Part II. Information from other studies may be used in this assessment only if those studies meet the requirements in Part II.

- ◆ **Use of Other Study Results.** While assessment efforts should not duplicate work appropriately done elsewhere, data which do not meet the requirements in Part II are not acceptable without convincing justification. This assessment will, however, use the Hanford Site disposition baseline for definition of disposal methods and, if available, estimates of containment performance. Composite source term information compiled elsewhere may be used if it meets CRCIA requirements.
- ◆ **Research and Development of Analysis Methods.** Several of the important objectives of this assessment lie beyond conventional analytical practices. Projecting mutagenic and cultural effects are examples. Modification of existing methods and development of new techniques will be needed. Design and planning of the assessment must include preliminary research and development (R&D) tasks to assure that proper analytical tools and technical information will be available as needed.
- ◆ **CRCIA Phased Approach.** While the CRCIA Team strove to capture the requirements for this assessment independent of any given definition or sequence of work tasks, a phased pattern seems to emerge. What may be thought of as the core set of calculations (such as contaminant inventory compilation, modeling, and exposure calculation) is described in Section 1.0. The elements of this core process received a high percentage of the CRCIA Team's attention. The screening assessment (Part I) represents the first phase of work in performing CRCIA and used some elements of this core process in assessing the current state of the Columbia River.

The next phase of work will center on designing and planning (including budget estimates and schedules) the work necessary to respond to the comprehensive requirements in Part II. This planning phase also may include some of the preparatory tasks requisite to the core process. Following the planning phase, the remaining preliminary tasks and analytical tools preparation will likely require a level of effort large enough to become recognized as the next phase of the assessment.

The first effort to produce useable assessment results constitutes the first phase following completion of the preparatory tasks. It will be complete when the core process has produced impact assessment results for each of the prescribed scenarios based upon the aggregate set of Hanford waste closure end states. Figure 4 graphically depicts this phase. The figure also shows each subsequent phase as being initiated by a planned or actual change in the Hanford post-cleanup end state. Performance of these iterative phases will be aligned with the timetable for key cleanup decisions, annual updates of strategic planning products, Hanford Site budget submittals, and 5-10 year plan revisions.

General Requirements

- ◆ **Columbia River Area to be Assessed.** The geographic section of the Columbia River to be assessed begins at the Priest Rapids Dam and proceeds downstream to the river's mouth at Astoria, Oregon. It includes the riparian zone on either side of the Columbia River and irrigation water drawn from the river. It also includes the aquatic and terrestrial life which depends on the river for biological, social, or economic reasons. It is stressed that the water ingested from the Hanford Reach area includes undiluted, or only somewhat diluted, groundwater found in seeps and springs in the riparian zone as well as groundwater upwellings in the river bottom where aquatic life habitat is found.
- ◆ **Time Period of Potential Impact.** The time period for which the impact to and through the Columbia River is to be assessed begins with the federal government's acquisition of Hanford lands in 1943. It continues through the period during which the radioactive and chemical materials remain intrinsically harmful, including radioactive decay daughter products and chemical reaction products. The current regulatory horizon (about 30-50 years) is inconsistent with the long term hazard from Hanford Site wastes and materials. The assessment must be guided by the materials' period of intrinsic hazard rather than the regulatory period.

It is beyond the scope of CRCIA to make estimates of past injury or damages. Nevertheless, to the extent that past Hanford events have resulted in present day cumulative effects or conditions which bear on future river related impact, these past events must be understood and taken into account in this assessment.

- ◆ **Radioactive and Chemical Materials.** Calculations involving radioactive and hazardous materials data will include radioactive decay daughter products and chemical compounds/properties estimated to occur with time and after reaction with other chemicals, soils, and river chemistry.
- ◆ **Impact Comparison Baseline.** "Impact" as used throughout this assessment is to mean and will be compared with conditions existing prior to the federal government's construction of the Hanford Site complex. Generally, this pre-Hanford state will be equated with today's conditions upstream from Hanford to the Priest Rapids Dam. However, it is recognized that some elements of this ecosystem baseline must refer to conditions above the dam in order to capture meaningful information.
- ◆ **CRCIA Standards.** Contaminant concentrations and doses prescribed in regulations can be used in the assessment for general information and guidance. However, caution must be exercised because few, if any, current regulations were written with the spectrum of effects in mind that are of interest in this assessment such as mutagenic effects, teratogenic effects, and cultural effects. Elevated levels of contaminants will not be ignored because they lie below regulatory levels or because of the absence of accepted research linking such contaminant levels to adverse effects. The assessment analysts must develop criteria for elevated levels which should be of concern based on considerations such as naturally occurring background levels of the contaminants, the presence of multiple contaminants and multiple exposure pathways, general environmental cleanup experience, the body of regulatory experience, and historical environmental events such as Chernobyl. Other considerations include health physics accepted practice, international standards such as those of the International Commission on Radiological

Protection, cause and effect correlations from the medical community, and new developments in ecology, toxicology, and risk assessment. In addition to the need for criteria for elevated contaminant levels, criteria also must be developed for the aggregate tolerable contaminant load in groundwater and total plume size, both based on the presence of multiple contaminants.

- ◆ **Required Results.** A primary result of the assessment is the actual or projected dose level from Hanford derived contaminants for each receptor and each dominant contaminant as it varies with time throughout the time period of interest. Receptor resultant impact will also be determined. These determinations must be made for individual dominant contaminants as well as multiple contaminants which, when assessed in combinations occurring at the same time, result in elevated toxicity levels above CRCIA standards criteria (see Standards, above). Analysts might expect to find suspiciously high levels of some contaminants for which biological effects are not well established. Any such findings must be retained and reported. From the concerns expressed by CRCIA Team members, some potential effects have been defined (see Appendix II-A, Section 9.0) which must be evaluated to determine the potential for their existence and their severity.
- ◆ **Assessment Control.** The aggregate of the requirements in Part II of this document makes indispensable a relentless, intense attention to control of the conduct of the assessment. Sensibly applying, and maintaining, the delicate balance among the principles of dominance, management of uncertainty, and fidelity require thoughtful conceptualization and planning of the assessment as well as continual reassessment and rebalancing of the on-going effort. The burden of this effort rests primarily on the performing contractor, particularly the assessment project manager. As described in Appendix II-D, final decision authority rests with the CRCIA Board, which will remain actively involved in managing the assessment. However, the DOE project manager, designated in Appendix II-D by the Board as the CRCIA Executive Administrator, shares the responsibility of ensuring the assessment meets the letter and intent of these requirements.
- ◆ **Assessment Frequency.** The description of recurring CRCIA assessments for each successive revision of DOE's planned site end state is found in Section 1.0 and is illustrated in Figure 4. Additional iterations of the assessment will be needed, however, in response to such developments as results from atmospheric studies which suggest new environmental scenarios, significant changes in data from Hanford studies, new information which causes changes in CRCIA models and related tools, and advances in ecology and toxicology.
- ◆ **Required Continuation of Columbia River Monitoring.** Much of the basis for detecting trends in river changes, so important to realistic assessment results, comes from monitoring current groundwater and river conditions. It is essential that the monitoring program be continued and periodically refocused to the findings and needs of this assessment.

1.0 What the Assessment Must Include

This section discusses what must be considered and included in the assessment. The next section, 2.0, prescribes assessment fidelity, describing the care and depth with which each factor must be treated to achieve the needed thoroughness in assessment results. Both sections are subdivided according to the framework of assessment tasks or modules shown in Figure 3.

Figure 3. Analysis Modules Comprising the Assessment with Icons as Guides to Related Discussions

The following discussion of these modules, as well as the specific requirements in Appendices II-A, II-B, II-C, and II-D, is based on the conduct of the assessment in accordance with the concept shown in Figure 4. Any given execution of the assessment process addresses each of the modules shown in Figure 3, maintaining their respective dependencies on one another for valid information. A successive execution of this assessment process is required for each of the socio-economic and climate change scenarios in described Subsection 1.1.0 below (also see Appendix II-A, Section 10.0) beginning with the scenario describing today's conditions. It is stressed that the frame of reference is the Hanford Site set of permanent disposal methods planned and approved for the aggregate of all radioactive and chemical materials within the Hanford Site boundary, that is, the Hanford Site post-cleanup end state. This assessment should not make assumptions or otherwise

Figure 4. Assessment Concept

develop this Hanford Site baseline for waste disposal. However, some effort may be needed to compile US Ecology, Seimens, and Washington Public Power Supply System data. If interim disposal is planned with no defined permanent disposition, the assessment will regard the interim method as permanent disposal. As the disposal planning baseline changes during the course of the multi-year cleanup effort, the assessment process in Figure 3 must be repeated for each scenario to determine the impact of the planned disposals on the affected people. Figure 4 graphically summarizes this assessment concept.

The right sector of Figure 4 represents the modules shown in Figure 3. Calculations in each module are performed for each scenario shown in the left sector of Figure 4. Assessing risk for all scenarios in this fashion constitutes one execution or one iteration of the assessment process. The assessment process is executed for each composite set of Hanford Site-wide waste disposal decisions as shown in the top sector of Figure 4. As that decision set is revised, another execution iteration must be performed. It seems apparent that this assessment should be used to support the decision-making process and as a strategic planning tool. In this context, the assessment process becomes a powerful effectiveness measure for Hanford Site cleanup and overall risk reduction.

CRCIA is complete when the effects on people and other receptors have been estimated for each scenario and for the Hanford Site composite set of waste disposal decisions as each revision in the planned final end state emerges.

1.1 Hanford Materials and Contaminants (Sources and Inventories)

CRCIA addresses all radioactive and chemical materials and wastes within the Hanford Site boundaries. It will include in its source term information on any potentially harmful chemicals introduced or released as a consequence of remediation work or Hanford operations, including new Hanford Site missions. These

combined sources of potential future contamination, called the composite source term, include but are not limited to the sources documented in the DOE approved Hanford Site listings of special nuclear materials, waste sites, waste discharges, and related data bases and documentation. It is important that the assessment use the same source term data as used in DOE's development of the Hanford Site-wide approved remediation and disposal solutions. Failing to maintain this consistency introduces mismatches with DOE's planning base which may jeopardize the relevance of the assessment's results. If disagreements develop on the usability of DOE's source term information, guidance must be requested from the CRCIA Board. Completeness of the source term information provided for this assessment must be verified to the satisfaction of the CRCIA Board.

Since the primary pathway through which contaminants are reaching the Columbia River is the groundwater underlying the Hanford Site, it is crucial to this assessment's results to understand the contaminant burden potentially to be introduced into Hanford's groundwater from all sources. The assessment must include source term information from the Supply System facility, the US Ecology low level waste site, and the Seimens nuclear fuel facility. While these entities are responsible for contaminants originating from their operations, DOE is responsible to determine the cumulative groundwater contaminant load in estimating effects. Chemical and nuclear materials and waste historical background information related to the organizations referenced will be sought.

Materials and wastes continue to arrive at Hanford. These become a part of the composite source term. Information must be obtained to estimate the extent of future shipments to Hanford and their intended disposition. Assessment results will be updated as estimates of future inbound shipments are changed. Permitted discharges to the groundwater and the river must be included in the composite source term.

The composite source term will also include estimates of those contaminants which have already escaped containment or are in an indeterminate state, such as buried solid waste. If DOE's approved planning includes remediation work to recover uncontained contaminants, this assessment will treat them as contained materials in their post-remediation state. However, if recovery is not planned, contaminants will be treated as part of the source term already in, or moving to, the ground water (see Subsection 1.3 below and Appendix II-A, Section 3.0 for transport requirements).

As an aid in the source term definition effort, especially for estimating uncontained contaminants, the analysts are encouraged to consider chemical mass balance estimating methods. Calculations using known reactor operations data and chemical processing information can be of help in estimating undocumented waste discharges. This approach is also useful as an aid in validating source term information (see Appendix II-C, Section 3.0).

Analysis work throughout the assessment will use source term information as available from DOE's characterization work as well as the radioactive decay daughter products commensurate with the long time periods needed for loss of containment, transport to the river, and uptake from the river into and through the pathways to the receptors. Similarly, assessment analyses will include reasonably expected chemical compound breakdown and recombinations into new substances typical with the irrigation, soils, river chemistry, and prevailing agricultural chemicals in the section of the Columbia River being assessed.

1.2 Containment Failure and Contaminant Release

A reasonable paraphrase of a primary goal of the Hanford cleanup project is to retrieve, as necessary, and contain radioactive and chemical materials for a period deemed sufficient to assure safety for the people and organisms who might otherwise be adversely affected by exposure to these materials. Determining the period of containment and rate of contaminant escape are the subjects of the requirements in this section.

To maintain the assessment's consistency with the data supporting the Hanford Site waste disposal decisions, the assessment will use the same period of containment and the same estimated leakage rate as used in the disposal decision process, for example, as used in environmental impact statements. The decision documents usually include strategic planning products, budget proposals, and 5-10 year plans. If information is not available from these preferred sources, performance assessment calculations will be made as a part of this assessment's analysis effort.

Leakage rate will vary with time as containment deterioration worsens and surrounding soils become more saturated. Since these factors influence eventual contaminant concentrations and effects, it is important that these rate estimates be obtained with good levels of certainty as discussed in Appendix II-C, Section 2.0.

1.3 Transport Mechanisms and Pathways to the Columbia River

This section addresses requirements concerning two different but related matters. One issue is transport of contaminants downward through the soil to the groundwater beneath the containment device or, if the wastes were not contained, the point of free discharge at the surface. The soil above the groundwater is called the vadose zone. The other issue is the movement of the contaminated groundwater toward the Columbia River. In both cases, travel times, contaminant type, amounts, and concentrations are of great interest. Each will change over a wide range as time passes and as different climate and river characteristics change.

It is to be noted that while groundwater is considered the primary pathway by which contaminants reach the Columbia River, other pathways are not to be omitted unless their contribution can be shown to be negligible in accordance with the dominance principle. The assessment is to determine the impact sustained from river and riparian zone contamination regardless of the contaminant pathway to the Columbia River. Section 1.4 addresses the transition of groundwater into river water. That sub-section points out the importance to the assessment of realizing that in the riparian zone bordering the river contamination can potentially reach wildlife and people in undiluted groundwater.

Assessment requirements for vadose zone information include both vertical transport times and estimates of contaminants which have been free within the vadose zone since their initial discharge during reactor operations and chemical processing. In both vadose zone and groundwater contaminant migration estimates,

the analyst will consider the likelihood of mobility changes resulting from chemical modification of the contaminant such that its solubility and sorption characteristics are altered.

Airborne contaminant migration to the Columbia River will also be considered, including airborne deposition on agricultural land which, in turn, is washed into the river by irrigation. Similarly, contaminants from direct discharges to the river will be included.

CRCIA requirements for groundwater movement information include travel times, contaminant presence, quantities, and concentrations. Correlations must be made between the locations of groundwater paths and geographical locations of potential contaminants in surface or vadose containments so the composite groundwater chemistry effects on migration can be estimated.

With regard to groundwater total contaminant load, contributions will be included from the Supply System facility, the US Ecology low level waste site, and the Siemens nuclear fuel facility, even though these entities are environmentally responsible for contaminants from their facilities.

Use of the Hanford Site consolidated groundwater model is encouraged provided that model is consistent with CRCIA requirements. It is especially important that the groundwater modeling for this assessment be responsive to the principles of balanced management of dominance, uncertainty, and fidelity, as well as being seamlessly compatible with other CRCIA modeling such as groundwater-to-river water transition models for the riparian zone and contaminant entry into the Columbia River.

1.4 Contaminant Entry into the Columbia River

The requirements in this subject area are especially challenging, principally because of two general considerations. First, in reality, the groundwater enters the Columbia River in a most irregular, heterogeneous fashion which will be difficult to legitimately generalize with most modeling techniques. Yet failure to explicitly recognize the actual entry locations, volumes, and rates results in omission of critical habitat linkages to undiluted, or slightly diluted, potentially contaminated groundwater. An example is the upwelling in the river bottom of groundwater through known salmon spawning beds. River bottom surveys to identify areas of upwelling seem unavoidable. Similarly, surveys of the riparian zone for points where the groundwater comes to the surface is important. In view of these considerations, any modeling assumptions implying an instantaneous, homogeneous entry of groundwater into the main body of the Columbia River are unacceptable for defining local impact.

The second consideration making this a difficult segment of the assessment is that groundwater enters the riparian zones where a large percentage of the river-dependent terrestrial life obtains its water. It is important to understand the relationships between groundwater aquifers beneath the Hanford Site and seeps, springs, wetlands, and free standing surface water in the riparian zone. A spatial description of each plume or point of discharge is also necessary. Overlapping plumes must be evaluated.

The dynamics of river flow patterns, storm run-off, dam operations, and river bank and riparian zone erosion add yet another dimension of difficulty to this assessment task. Field work will likely be needed to provide necessary information. Some approximations will have to be made. Managing the assessment in accordance with the principles of dominance, balanced uncertainty, and fidelity will be especially important in designing and conducting this work.

1.5 Fate and Transport of Columbia River-Borne Contaminants

Requirements in this section address the modeling of how the contaminants mix in the main body of river water. That is, the locations of deposits (fate) of sediments and dissolved contaminants must be determined as well as their redistribution when transported by storms or seasonal river changes in flow. Generalizations which assume instantaneous, homogeneous mixing and dilution, while simplifying the assessment task, are not acceptable because they mask potential linkages between contaminant hot spots and critical river locations such as aquatic habitats, and extractions of water for drinking or irrigation. The mixing of groundwater, potentially carrying contaminants, into the main body of the Columbia River is known to be slow and is not complete for perhaps tens of miles downstream of the point of introduction.

These requirements deal primarily with two methods of contaminant transport in the main body of Columbia River water. One is mixing of river water and groundwater potentially contaminated with dissolved radionuclides and chemicals. The other is suspended solids, mostly sediments, some of which have a great affinity for contaminants. Suspended sediment is continually settling, especially where flow rates are low. Sediment settles in holes and quiet water regions of the Columbia River, such as in sloughs and behind large rocks on the river floor. Runoff from storms and seasonal weather changes alters quiet water, sometimes dramatically, and resuspends the sediments, carrying them downstream to more permanent settling spots, perhaps behind dams (especially McNary Dam) or in areas periodically dredged for shipping.

Dissolved contaminants may remain at worrisome concentrations far enough downstream from the point of groundwater influx to encounter municipal water intakes or irrigation water systems. Even at dilute levels, mechanics such as irrigation, water treatment equipment, and hydroelectric turbines provide opportunities for reconcentration of dissolved contaminants. Such opportunities will be identified and evaluated for significance. Locations conducive to sediment accumulation and ecosystem habitats will be evaluated.

For either dissolved contaminants or sediments, little can be realistically concluded about these potential problems without knowledge of the river's flow characteristics, especially groundwater influx points (addressed in the previous section), turbulent regions and quiet areas. Columbia River bottom topological mapping surveys will almost certainly be required, as will seasonal changes.

Requirements in this section also deal with chemical recombinations between potential contaminants and the prevailing river chemistry in the area being evaluated. Some synergism of Hanford and off-site contaminants may occur in the Columbia River, causing a greater cumulative impact.

1.6 Critical Habitat and Uptake Locations

This section specifies the requirements for identifying the important locations of plant and animal habitat, for both aquatic and river-dependent terrestrial life, where uptake of contaminants is probable because of the river's deposits discussed in the previous section. Identification of other critical locations, such as municipal water intakes, is also required.

Critical locations are defined, for these purposes, as those places where the entry of contaminants into the food chain and other exposure pathways are most likely to occur. This section is especially important to the assessment as the analysis performed here links the contaminant hot spots to the biological/social/economic webs developed in the sections to follow.

The requirements for this subject area in Appendix II-A, Section 6.0 contain references to the species of interest having been selected and available to help guide the search for habitat and critical locations. Without doubt, a number of the key species can be identified simply on the basis of interest from societal groups and proximity to Hanford and the Columbia River. However, the identification of critical locations is very likely to show that certain aquatic and dependent terrestrial species are potentially in harm's way because of their position in the ecosystem web. If it is found that their exposure and ensuing impact is likely to be severe, those species may be added to the species-of-interest list. Selection of the species of interest is the subject of the next section. The search for critical locations should not depend solely on a predetermined set of species to be evaluated.

A point emphasized in these requirements is the necessary search and discovery of habitat located at points of upwelling of undiluted groundwater in the Columbia River. Discovery of active salmon spawning beds in gravels through which chrome-laden groundwater is entering the Columbia River is an example. Similarly, seeps and springs carrying undiluted groundwater to the surface and through the riparian zone into the Columbia River need to be identified if those areas contain important habitat or species.

1.7 Receptors and Exposure Pathways

This section contains those requirements dealing with the development of exposure web models which realistically define the pathways or mechanisms by which receptors of interest become exposed to contaminants.

Receptors, as defined for this assessment, include humans and human population groups as do other assessments. CRCIA, however, goes further to include as a candidate receptor any species, resource, or environmental function occupying a key juncture in the ecosystem web which, if lost, produces a significant loss or impact to the ecosystem, including potential impact to humans. Selecting all such candidates for the

receptors-of-interest list is likely to be impossible until the model of the ecosystem web is complete or the habitat for the candidate species (or its supporting food chain) is found to coincide with a contamination hot spot as discussed above.

CRCIA also includes as receptors those humans and groups projected to suffer any other adverse health effects including but not limited to cancer. It is also important to include as species those which by virtue of different cultural life styles may be susceptible to exposures and effects not otherwise encountered. Native Americans and other ethnic or minority life styles, such as migrant farm workers, are in this category. Also included as candidate receptors are river-dependent economic groups such as irrigation supported agriculture, commercial fishing, hydroelectric workers, and river transportation industries (barges and support services like dredging operations).

Another important requirement is that receptor in this assessment will include the culture of the affected peoples. If Native Americans, for example, must relocate to avoid untenable exposure from contaminants, this would be considered a serious impact to their culture and their quality of life. If the economy of the Tri-Cities (Richland, Pasco, and Kennewick, Washington) is impacted (for example, by bad water) so as to adversely affect the quality of life of the residents, CRCIA would regard the Tri-Cities culture as a receptor.

Given this perspective, this section requires that both the process for selection of receptors be defined as well as development of models of the related physical, biological, social, cultural, and economic webs of dependency on the Columbia River through which contaminants might reach, and expose the selected receptors over time.

1.8 Dose Assessment

With the selection of receptors to be evaluated and the exposure pathway models developed which relate the receptors to potential sources of contamination, the requirements in this section address the calculation of the dose estimated to be sustained by the receptors. The intent in this section is only to determine dose, that is, level of exposure. Identification of the effects or impact from having received that dose is the subject of the next section.

As a general rule, accepted risk assessment practices will guide the analyst in making dose calculations. However, the CRCIA Team expressed several concerns about these accepted practices to which the analysts must be responsive. For example, unless specific predator and prey feeding habits for a species are unknown and unknowable, calculations must not be overgeneralized. An example is categorizing animals only by weight and ignoring distinctions in diet, activity patterns, and habitat. Similarly, Native American scenarios will be developed and used as will specialized exposure scenarios for other groups such as farm workers. Aside from the conceptual requirements the reader will find in this section, explicit requirements remain to be developed by the analysts and discussed with the CRCIA Board.

A major point of concern in this area is the exposure which may be sustained in short as well as over long time periods by one or multiple generations. Determining mutagenic effects, which is of great interest, will likely be impossible unless dose calculations are performed with this effect in mind. The analysts will note in this regard that several of the candidate receptors are members of small gene pools which may tend to magnify mutagenic effects.

1.9 Receptor Impact and Tolerance Assessment

The requirements in this section address the effects or impact expected to be sustained by the species of interest resulting from the exposure calculated in the previous section. Tolerance assessment refers to some impact threshold below which effects can be tolerated with no unacceptable or irreversible effect. Above such a threshold, unacceptable harm may occur to the species, group, or culture under study. Without an understanding of both the impact of the dose received and the level of tolerance to that impact, useful conclusions will be difficult to draw.

Tolerance assessment is one of the key objectives of CRCIA, that is (from the Statement of Purpose): Evaluate the sustainability of the Columbia River ecosystem, the interrelated quality-of-life, and the viability of socio-economic entities for the period that Hanford materials and contaminants remain intrinsically hazardous.

As pointed out earlier, care must be taken by the analyst not to dismiss as unimportant an effect which may be important from a cultural perspective simply because popular analytical approaches disregard such effects. The seriousness of respecting cultural values can best be illustrated by pointing out that, when in dispute, these matters are settled only through government-to-government negotiations between the sovereign nations of the Native Americans and the U.S. Government.

Appendix II- A, Section 9.0 requires evaluation of a number of potential adverse effects to determine if dose levels are expected to be sufficiently high to cause them. However, the analyst is cautioned not to regard this list as exhaustive. The analyst should also expect that unanticipated effects will be identified, or at least inferred, by elevated exposure levels of certain contaminants. The discussion in the Principles and General Requirements section also provides guidance in this matter.

1.10 Assessment Scenarios: Columbia River, Climate, Geological, and Political Changes

As discussed in Section 1.0 above, the assessment addressed in Sections 1.1 through 1.9 is to be performed for each of several scenarios. Most of the foregoing requirements were written from the perspective of the conditions observed today and accepted as normal. However, the Columbia River, climate, area geology, and even the regional cultural and political conditions change, and especially in view of the protracted time scale

for which Hanford contaminants remain dangerous, these scenario changes should be expected to be major. The requirements in this section specify that the assessment be performed for changes which can reasonably be expected to occur.

Appendix II-A, Section 10.0 lists scenarios in categories generally expected to change pivotal factors in the assessment from what is seen today as normal. For example, a climate change which substantially increases the rainfall in the Hanford area would presumably make a dramatic change in the volume of contaminants reaching the Columbia River as well as the time necessary for them to reach the river. In another example, on a time scale of several hundred or thousands of years, the present dams on the Columbia River would likely be removed, would deteriorate and fail, or at least would have to have major desilting dredging performed. Any of these probabilities would remobilize large accumulations of contaminants in the sediments. Also considering the time scale involved, entirely new governments and/or political structures are inevitable, bringing with them potentially major changes affecting the materials and wastes at Hanford.

In view of the speculative nature of these scenarios and the expense of modifying the assessment for each, a recommended study set of the most credible scenarios must be winnowed from a broader list of candidate scenarios and proposed to the CRCIA Board for approval.

1.11 Hanford Site Disposition Baseline

As Figure 4 in Section 1.0 above shows, CRCIA is to be performed maintaining as great a consistency as possible with each set of Hanford Site-wide cleanup/disposal decisions and with each subsequent revision. In other words, whatever may be the collection of DOE documents which, at any given time, constitutes what may be considered to be the approved Hanford Site post-cleanup end state, there will be a corresponding CRCIA assessment of resultant impact. Because the various documents might be based on different assumptions, a comparison with those used in CRCIA is essential.

In the event no officially recognized end state plan exists for the overall Site, the CRCIA analysts will develop, with DOE's recommendations, the most credible surrogate end state information available. CRCIA Board approval of such surrogate information is essential.

It is particularly important that the analysts use the estimates of containment durability (time to failure and leakage rates) found in approved end state plan documents. However, transport time through the vadose zone to the Columbia River and dose levels will all be calculated in accordance with CRCIA requirements.

2.0 How Good the Impact Assessment Results Must Be

This section consists of requirements which specify the fidelity of the assessment results. Fidelity, as discussed above in the section on Principles and General Requirements, is used in this assessment in the same sense it is used in high fidelity sound reproduction, that is, it expresses the degree to which the reproduction (the assessment in this case) faithfully represents the actual performance (reality), overcoming any intrusion of factors which introduce distorting noise or bias.

Appendix II-B lists these requirements in four subject areas: (1) achieving sufficient assessment sensitivity to detect any potential adverse effects/impact, (2) ensuring seamless consistency across all models and calculation modules, (3) selecting the study set of factors and the specific fidelity requirements for the candidate factors discussed in Appendix II-A, Sections 1.0 through 9.0, and (4) ensuring software characteristics meet assessment needs.

2.1 Fidelity of Detecting Harmful Effects

These requirements specify that the assessment must be designed and conducted well enough that if an adverse effect is occurring or will occur, the assessment will identify or predict it. Deciding what constitutes an impact is discussed in the Principles and General Requirements section. It should also be kept in mind who the users of the assessment results are expected to be and for what purposes would they use the results (see Introduction).

Applying such a qualitative concept as fidelity to modeling and calculation tasks requires the use of what one regards as important. Relative importance, or value, is rooted in one's culture and lifestyle. What is seen as an impact to which the assessment must be sensitive is very much a matter of who the affected peoples are and what is important to them. Especially for this reason the CRCIA Board's guidance or approval must be sought in matters of this kind.

Two general factors will be frequent threats to needed fidelity. One is the fineness of definition in determining the timing of contaminant releases, groundwater migration rates, food chain and other pathway assimilation rates, and eventually, the duration and intensity of the exposures — especially combinations of exposures. The second factor is that it may be difficult to resolve the large geographic area being assessed into elements that are fine enough to detect contamination hot spots and the degree to which they coincide with critical uptake locations such as municipal water intakes and favored habitat. These are particularly critical considerations to the assessment and must be dealt with effectively.

In keeping with the principle of dominance (see Principles and General Requirements above), resources may not always be sufficient to support enough assessment work to include all the factors necessary to detect all impact for all the selected receptors of interest. Difficult choices may have to be made between assessing all potential impact or all receptors of interest. The CRCIA Board must make these decisions. However, the analysts will develop and use trade study methods to define the choices to be presented to the Board.

2.2 Model Integration and Consistency

These requirements are aimed at ensuring the insightful integration of the many assessment models and calculations such that overall fidelity is not degraded. For example, unless uncertainty is managed with consistency across all models, detection of important effects may be needlessly masked by the error band surrounding the final results. As discussed in Section 1.0 above (see Figure 3), the assessment task modules, especially those involving modeling and calculations, are highly dependent on one another. If output of one module is inadequate to properly enable the next module to function, fidelity will be lost to the overall assessment results. Seamlessness must be achieved across module boundaries. For instance, mass and momentum must be conserved between vadose zone models and groundwater models. This is an illustration of why the analysts must be cautious in accepting results and tools from other studies.

2.3 Selecting Factors for Assessment: The Study Set

This section deals with the fidelity requirements which apply to respective modules of the assessment addressed in Appendix II-A and Sections 1.0-1.9 above. Topics include:

- ◆ Screening candidate contaminants to identify those having the most dominant effects
- ◆ Development and use of transport models to preserve the needed sensitivity to timing and location (see Section 2.1 above)
- ◆ Search, discovery, and modeling of the most important habitat and uptake locations
- ◆ Receptor selection and exposure pathway web modeling
- ◆ Chemical and radiological dose calculation for single and multiple contaminants
- ◆ Selecting dominant effects

2.4 Assessment Software Requirements

This section contains the requirements to be observed in using commercial modeling software and in developing unique software for this assessment. The section specifies that software specifications will be prepared, that software verification and validation be performed, and that a software quality assurance plan be prepared and implemented.

2.5 Assurance of Assessment Quality

A concept of assessment quality will be developed which includes the principles of fidelity, management of uncertainty, dominance, the development of CRCIA standards, and required results. These topics have all been addressed previously. In addition, workable concepts for the management and reconciliation of work scope and funding must be developed in keeping with the principle of dominance yet ensuring that the most important assessment work is accomplished to high professional standards. Particular attention will be directed to validation of all models used in the assessment.

An assessment quality assurance plan will be prepared which defines how quality is to be infused into the assessment and maintained. The CRCIA Board must approve the quality assurance plan.

3.0 Analytical Approach and Methods

The requirements in this section address the matters of concern related to how the assessment is to be designed and technically conducted. Management of the assessment is discussed in Section 4.0. The requirements in this section are provided in Appendix II-C. They are categorized into seven groups: (1) ensuring that the factors contributing most to actual exposures/effects are always considered in any assessment task, (2) ensuring that assessment uncertainty is always known, quantified, consistent among all assessment tasks, and responsive to the needs of those who will use the results, especially Hanford decision-makers, (3) ensuring that the assessment be designed as a single, integrated set of seamless tasks which together form a logical, robust architecture for long term use of the assessment tools, (4) developing and implementing meaningful data quality criteria which draw upon the best features of the data quality objective process, (5) selecting and using assessment methods which capitalize on the progress made in the risk assessment field but are not subject to its limitations, (6) verifying assessment models and results, and (7) identifying new development efforts needed in assessment methods.

3.1 Identification and Management of Dominant Factors

Ensuring that the assessment effort is always focused on the most important contributors to contamination impact is the subject of this section. This is the first principle defined in the Principles and General Requirements section. Often project efforts are prioritized in terms of a chronological sequence of tasks or favored alternative solutions; funding and staff skills are allocated accordingly. The requirements in Part II reject such approaches. Rather, it is required that methods be developed to identify the dominant factors in this assessment based upon sensitivity study methods, parametric analysis methods, or related techniques. While it is clear that smaller contributors to impact must be set aside, it is critical that the methods be adequate to preclude leaving out any major contributor. If useful, analysts are encouraged to visit advanced design organizations in other industries where such methods are more commonly found than in nuclear or environmental fields.

3.2 Identification and Management of Uncertainty

Appendix II-C, Section 2.0 provides the requirements in this subject area. Uncertainties exist, for example, in how well the Hanford cleanup methods will contain the wastes, in our capability to forecast changes in climate, cultural, and economic scenarios, and in how well this assessment will be conceived, designed, funded, and technically executed. Uncertainty is addressed as a principle (see the Principles and General Requirements) because its management is pivotal to credible results and economy of resources required.

Allocation of the maximum acceptable level of uncertainty in the assessment's results is an approach often used, that is, each of the assessment's models and calculation tasks would be allocated ceiling values of uncertainty based upon the acceptable level of the results. Inability of any task to meet its allocation would then suggest a reallocation of either allowable uncertainty or funding to the more difficult tasks.

Other methods should be considered such as those in the National Council on Radiation Protection and Measurements Commentary No. 14 (National Council on Radiation Protection and Measurements. 1996. *A Guide for Uncertainty Analysis in Dose and Risk Assessments Related to Environmental Contamination*. NCRP Commentary No. 14, Bethesda, Maryland).

Uncertainty is highly dependent upon the dominant factors discussed above. For example, if offending levels of uncertainty reside among factors of little significance, then their uncertainty is also insignificant.

Methods will be developed to identify and manage uncertainty consistently across all of the assessment tasks. The CRCIA Board will approve the methods planned to be used.

3.3 Analytical Architecture and Integration

A simple example of an architecture for this assessment is shown in Figures 3 and 4 of Section 1.0. That architecture was developed only to organize an approach for capturing and communicating the requirements in Part II of this document. That architecture may not be the approach preferred by the analysts. It is essential, however, that an approach be conceived and understood by all those involved in this assessment. The CRCIA Board will review the recommended architecture for the assessment.

The fundamental concept preferred in developing this architecture is to identify all the assessment's necessary functions and arrange them in hierarchical form, partitioning upper level functions into subfunctions to the extent necessary to assure clarity and completeness. Dependencies among functions must be defined to assure the right information is generated for the right recipients. Such an architecture is not only useful in planning and sequencing assessment tasks, but it defines the necessary conditions for compatibly integrating all the assessment's tasks.

3.4 Data Quality

Development of data quality criteria for the assessment is essential. For example, it seems unlikely that there could be much success in managing uncertainty as discussed in Section 3.2 without control of data quality. Data quality requirements are found in Appendix II-C, Section 4.0. Like many areas in Part II of this document, Appendix II-C, Section 4.0 provides little more than a conceptual framework for data quality requirements. It is left to the analysts to complete the definition of the assessment's data quality requirements for the CRCIA Board's approval. The best practices from the data quality objective process should form the basis for CRCIA data quality criteria. Criteria will include identification of data gaps, data verification and validation, data acquisition, and data quality management.

3.5 Assessment Methods

Some assume the CRCIA analysis is a risk assessment in the same sense as the practices that have emerged in response to EPA's environmental literature. The analyst is cautioned against this conclusion. It has been stressed many times in this document that the CRCIA Team believes conventional risk assessments to be inadequate, especially with respect to cultural considerations (see Problem Statement in

the Introduction section). If the analysts' intellectual perspective on this analysis is that of a conventional risk assessor, much of the needed innovation is unlikely to emerge. By all means, the experience accumulated in the risk assessment field should be drawn upon, and so should it be with radionuclide and chemical migration performance assessments methods, parametric and sensitivity analyses, mutagenic investigation methods, and many more. The requirements in this section reflect the concern expressed by several members of the CRCIA Team that the methods essential to this assessment's management of dominance, uncertainty, fidelity, and cultural impact would simply be ignored in favor of another conventional risk assessment. The analysts must design this assessment to take advantage of the best current practices but be limited by none of the popular approaches. The CRCIA Board will be kept informed and must approve the assessment approaches and design alternatives under consideration.

3.6 Verification

In discussing the required fidelity of the assessment to faithfully reflect reality without distortion (Section 2.0), the requirements for model validation were mentioned as one element of assuring the assessment's quality. A quality assurance plan was specified as a requirement in that section. Planning in response to the requirements in this section will be included in that plan. The requirements in this section address the need to be able to verify all the elements of the assessment. Among those matters to be addressed in this area are: (1) use of peer reviews, (2) field data collected especially for verification purposes, (3) use of historical and ongoing monitoring data, (4) results of climatic trending studies, (5) medical research of toxicity correlations.

3.7 Analysis Research and Development Needs

Research and development efforts will be identified to extend existing analytical methods and develop new techniques as needed to meet the requirements of this assessment. Advancing of the state-of-the-art is preferable, in most cases, to abandoning key objectives of this assessment. However, financial sponsorship of such development work will be sought from national grant programs and other sources. Use of CRCIA funding for these purposes will be considered only as a last resort.

Development of the R&D needs will be done as an integral part of the assessment planning and design effort. To the extent that assessment funds are needed for R&D, the CRCIA Board will approve the R&D candidates along with the assessment design.

3.8 CRCIA Standards, Regulations, and Guidelines

See "Standards" in the section on Principles and General Requirements.

4.0 Conducting and Managing the Assessment

This section is a brief summary of the requirements for conducting and managing the assessment found in Appendix II-D.

Paramount among the features of the management structure specified is the new public involvement paradigm this approach represents. Day-to-day management of the assessment work is carried out by a board composed of representatives from the people and socio-economic groups which, if the potential river contamination materializes, will be affected by Hanford's cleanup and disposal decisions. As a result, for the first time, cleanup effectiveness is assessed under the management of the people who are potentially affected. This effectiveness assessment is done objectively in a spirit of service and teamwork with DOE and its contractors in support of effective cleanup decision making which protects the people, ecosystems, and cultures dependent on the Columbia River.

Appendix II-D requirements address the management and CRCIA decision roles to be performed by those affected groups who accept the invitation to be represented on the Board. Since the Columbia River corridor to be assessed extends to the estuary at the Pacific Ocean, the representatives on the Board may become numerous. For practical day-to-day management purposes, the requirements provide for a hands-on Executive Board, consisting of those more closely related to the Hanford Site. Several sovereign governments will be represented on the Board. Participation does not abrogate any sovereign rights.

Funding would be provided by DOE through the Congressional appropriations process. Competition for scarce cleanup resources is on a merit basis. This means allocation of funding for assessment work would be expected to be in proportion to the value returned to the cleanup effort by the assessment's results. CRCIA deliverables are estimates of contaminant levels reaching receptors in and through the Columbia River, the sources of those contaminants within the Hanford Site, and the effects on the receptors resulting from exposure to the contaminants.

In collaboration with the Board, DOE would appoint an experienced Project Manager whom the Board would establish as the Executive Administrator and advocate of CRCIA. DOE would provide routine support services such as conference rooms, subcontracting services, clerical support and publishing services. While a DOE contractor would perform virtually all the assessment work through a senior manager dedicated to CRCIA, Board members are expected to perform significant management tasks such as developing CRCIA budget proposals, some of the higher level resource loaded schedules, and evaluating assessment technical problems and choices. Board members also are expected to review preliminary technical results and present progress reports to DOE, Hanford Site project leaders, and constituent stakeholder groups. Because most of the Board members are not likely to have technical experience, the Board may, from time to time, hire the independent technical expertise needed.

The Board is actively accountable to its constituencies through periodic progress reviews and an outreach program. The Board also is accountable to DOE and its contractors for providing technical results from the assessment needed to support cleanup decision making.

Realizing that this paradigm introduces a new way of doing business at Hanford, an implementation period is to be planned which allows — for an interim period — conduct of assessment work under existing practices with the CRCIA Team acting in its current advisory role.

Appendix II-A

What the Assessment Must Include

Appendix II-A

What the Assessment Must Include

The Columbia River Comprehensive Impact Assessment (CRCIA) examines the process of exposure and harmful effects of Hanford-derived contaminants in the Columbia River to humans, ecosystems, and cultures. The requirements in this appendix define what factors must be included in assessing river impact in order to understand this process. These factors, compiled for each segment of the exposure process and variant scenarios (Section 1.0 through 10.0), constitute the all-inclusive set of candidates to be considered in the assessment. They are winnowed to a manageable study set as discussed in Appendix II-B.

An acceptable comprehensive assessment must examine Hanford Site materials and contaminants, their containment and eventual release, and their transport and entry into the Columbia River. The assessment must also examine potential receptors, their exposure to Hanford-derived contaminants in the Columbia River, and impact resulting from the estimated levels of exposure. The assessment must either include the specified candidate factors, or, if a factor is not included, the assessment must contain an evaluation that explains why the factor was not included.

The factors required to understand the process of exposure and harmful effects (described in Sections 1.0 to 9.0 of this appendix) are based on current environmental conditions and the disposition baseline for Hanford Site radioactive and hazardous materials (described in Section 11.0 of this appendix). Variations from the current conditions are described in Section 10.0 of this appendix. The extent to which each factor is to be assessed, that is, how well the analysis is to be performed, is defined in Appendix II-B. How the assessment should be conducted is defined in Appendix II-C. How the assessment should be managed is defined in Appendix II-D.

1.0 Hanford Materials and Contaminants (Sources and Inventories)

The requirements in this section call for all contamination sources within the boundaries of the Hanford Site to be considered in a composite source term for assessing impact to the Columbia River. The impact of the entire inventory of radioactive and hazardous materials is required. This includes materials which are not contained, such as those contaminating the vadose zone of the Hanford Site. It also includes materials managed by entities other than the U.S. Department of Energy (DOE), such as US Ecology Incorporated and the Siemens Nuclear Fuels. The inventory shall include estimates of future materials whether imported to the Hanford Site or generated on the site. This section requires the analyst to show that the list of potential contaminants used in the assessment is complete. This section also requires the analyst to rank all candidate contaminants in accordance with CRCIA criteria developed to screen contaminants by their potential contribution to harmful effects. The ranking will enable the assessment effort to always focus on the dominant contaminants regardless of the level of resources allocated to CRCIA (see Appendix II-B).

An overview of the requirements in this section is:

- (A1.0-1) All existing and potential contaminants and contaminant sources must be identified, characterized, and ranked for significance of potential impact. The characterization shall include atomic or molecular composition, mass, and location. It also shall include reactivity, solubility, and mobility. Materials shall be defined clearly enough to support tracing their movement through the media along their pathway to the Columbia River.
- (A1.0-2) A composite source term shall be established that captures all potentially harmful radioactive and hazardous materials and contaminants on or near the Hanford Site.
- (A1.0-3) A method to demonstrate and document completeness of the list of inventory sources and compositions used in the assessment shall be developed.

Approximately three and a half additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

2.0 Containment Failure and Contaminant Release

The requirements in this section call for assessment of potential contamination of the Columbia River expected to result from eventual containment failure. Radionuclides and hazardous chemicals are contained during disposal operations by some form of engineered containment. Over time, all containments will eventually allow leaks into the surrounding soil, air or water as containment fails. The analyst must determine when containment failure is projected to occur. The analyst also must determine the rate at which contaminants are projected to be released when containment fails.

An overview of the requirements in this section is:

- (A2.0-1) A projected time of containment failure shall be determined based on the method of containment selected in the approved disposal plan. If the disposal plan includes defensible estimates of containment durability, these will be used.
- (A2.0-2) The projected rates of release (progression of containment deterioration) shall be determined based on the approved disposal plan.
- A2.0-3) Determination of release rates shall consider external migration rates in adjacent soils.

- (A2.0-4) Candidate containment failure scenarios that span the range of possibilities shall be established.

An additional page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

3.0 Transport Mechanisms and Pathways to the Columbia River

The requirements in this section call for transport of Hanford-derived contaminants to the Columbia River to be assessed. Existing transport models will be used to the extent that they satisfy the following requirements. An overview of the requirements in this section is:

- (A3.0-1) Contaminant transport through the vadose zone to groundwater shall be assessed.
- (A3.0-2) Contaminant transport through the groundwater to the Columbia River shall be assessed.
- (A3.0-3) Transport characteristics of geologic formations, such as the Hanford formation and Ringold Formation, shall be established to the degree needed to support the assessment.
- (A3.0-4) All other pathways of Hanford-derived contaminants to the Columbia River shall be considered. This shall include but is not limited to atmospheric releases, direct discharges, and transport of contaminants to the Columbia River by contaminated humans, plants, and animals.
- (A3.0-5) Migration rates to and concentrations in the Columbia River of all contaminants shall be determined including estimates of holdup periods in travel time calculations.
- (A3.0-6) Uncertainty in travel times and contaminant concentrations at the point of introduction to the Columbia River shall be assessed.
- (A3.0-7) Transport of contaminants through all potentially dominant pathways from the source term to the Columbia River shall be assessed. See Principles and General Requirements and Appendix II-B for definition of "dominant."
- (A3.0-8) Chemical forms and physical characteristics of radionuclides, such as solubility and sorption rates, shall be considered to the extent that migration rates are affected. This consideration shall include probable modifications of the original contaminants' characteristics as contact is made with soils, groundwater chemistry, and other contaminants.

(A3.0-9) Decay of radionuclides during transport shall be evaluated.

Approximately three additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

4.0 Contaminant Entry into the Columbia River

The requirements in this section call for the determination of the entry locations and flux of contaminants as they enter the river.

Model and geological/hydrological description requirements must be established for introduction of Hanford-derived contaminants into the Columbia River through groundwater. The rates and locations of contaminant influx to the river must support investigations to determine potential contaminant distribution in the river. (Section 5.0 of this appendix).

Currently, the Hanford Site groundwater discharges into the Columbia River through seeps, springs, river bottom (for example, gravel substrate), and potentially as surface water during storms. Contaminants in dissolved, colloidal, and particulate form, enter the river through these paths.

Contaminated groundwater mixes with surface water. The groundwater contamination concentrations are eventually diluted to bulk river concentrations. Mixing begins in porous river bottom and is complete at a currently unspecified distance downstream from each given entry point.

Some of these contaminants can compromise the health of the river ecosystem. For example, early life stages of fish are susceptible to the toxic effects of hexavalent chromium which enters the gravel substrate of the Columbia River bottom. Section 6.0 of this appendix addresses the mapping of habitat critical locations to contaminant concentrations.

Groundwater influx, though difficult to quantify, must be defined. If generalizations are used instead of field data, potentially high concentrations in critical locations may be missed. Groundwater influx locations must be identified, the groundwater at those locations characterized, and the groundwater and expected contaminant loading quantified. The relationship between groundwater influx and river flow (for example, dam operations) must be established. The hydraulic conductivity at a given location greatly affects the amount and concentration of contaminant entering the river at that location.

An overview of the requirements in this section is:

(A4.0-1) Groundwater and surface water interactions shall be evaluated.

- (A4.0-2) The interface with the Columbia River, including seeps, springs, and sub-surface influx into the river, shall be evaluated to support the assessment of biota exposures in the riparian zone and near the river bottom as required in Section 8.0 of this appendix.
- (A4.0-3) The groundwater interface with the Columbia River, seeps, springs, and sub-surface influx shall be evaluated to support assessment of contaminant distribution in the river.
- (A4.0-4) Valid interfaces shall be defined between groundwater transport assessment and the assessment of groundwater introduction into the Columbia River.

Approximately three additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

5.0 Fate and Transport of Columbia River-Borne Contaminants

The requirements in this section describe how the assessment must represent the way the contaminant distribution in the river evolves. The Columbia River redistributes contaminants to habitat where the contaminants may injure humans, ecosystems, and eventually cultures. It transports a large amount of water and a much smaller but significant amount of suspended solids (sediment). Some contaminants concentrate on the sediment particles, making them primary dose contributors in some situations.

Suspended sediment is continually settling, especially where flow rates are low. Sediment settles in holes and quiet water regions of the river, such as in sloughs and behind large rocks. Sediment settled on the river bottom can also be resuspended and carried downstream. Dissolved contaminants are carried by the river without settling out. Contaminants that dissolve out of the sediment are carried with the river water.

As slowly flowing groundwater approaches the river channel, it passes through the river bottom into the main body of the river. Contaminant concentration varies as it approaches and passes through the river bottom. Lateral mixing into the main body of the river is slow and not complete for perhaps tens of miles below the point of introduction into the river. Higher contaminant concentrations, resulting from high groundwater concentrations, persist along river streamlines emanating from contaminated groundwater influx points, until the mixing with the less contaminated river water is complete. The concern is redistribution of contaminants to critical locations where they may contact humans, plants, and animals at harmful concentrations and periods of time. Critical locations are defined in Section 6.0 of this appendix.

An overview of the requirements in this section is:

- (A5.0-1) The fate assessment of river-borne contaminants (locations of sediment deposits) shall support exposure and dose assessment.
- (A5.0-2) The transport assessment of river-borne contaminants shall support exposure and dose assessment.
- (A5.0-3) Hot spots (contaminant concentrations) in the Columbia River which result from slow mixing of high concentration contamination sources with river water and suspended solids shall be assessed.
- (A5.0-4) All Hanford contamination in the Columbia River environment that has the potential to significantly contribute to habitat or drinking water contamination shall be evaluated.

Approximately five additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

6.0 Critical Habitat and Uptake Locations

The requirements in this section call for identifying candidate locations of plant and animal life where contaminants are likely to enter exposure pathway webs. This includes habitats of both aquatic and river-dependent terrestrial life. The requirements also call for other critical locations, such as municipal water intakes, to be identified.

An overview of the requirements in this section is:

- (A6.0-1) Candidate habitat locations within the study area shall be identified.
- (A6.0-2) Cleanup impact on critical locations shall be assessed. See Section 11.0 of this appendix.
- (A6.0-3) The spatial representation scheme shall support realistic representation of exposure to contaminants that occur at critical locations.
- (A6.0-4) Any habitats within the study area that are considered high priority or sensitive by the State of Washington shall be accounted for. Habitats critical to the well being of plant and animal species that are classified as threatened, endangered, or sensitive by the State of Washington, the State of Oregon, the Federal Government, and/or the Indian Nations shall be evaluated.

- (A6.0-5) Suspect areas with unknown characteristics shall be evaluated.
- (A6.0-6) All available sources of information shall be cataloged and included in databases to the extent needed to meet assessment objectives.

Approximately two additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

7.0 Receptors and Exposure Pathways

The requirements in this section call for the identification of candidate receptors from which the receptors of concern (the study set) will be selected (see Appendix II-B). The requirements in this section also call for definition of the pathways through which receptor exposure potentially could occur. Examples of ways receptors may be exposed to contaminants include ingestion, inhalation, dermal exposure, or external radiation exposure.

The requirements in this section suggest some candidate receptors. Additional candidates will be identified upon determination of their criticality to other species because of their essential position in the web of ecosystem relationships.

An overview of the requirements in this section is:

- (A7.0-1) An all-inclusive, internally consistent set of receptors shall be identified to include river-dependent humans, plants, animals, and groups whose activities bring them into contact with river corridor resources. These activities include but are not limited to sustenance, recreational, commercial, religious, and cultural practices. The term receptor also includes the culture of affected population groups (for example, the Yakama Indian Nation and Hispanic migrant farm workers) as well as the economic viability of commercial groups (for example, agriculture and river barge transportation). This requirement includes those candidate receptors who come into contact with river resources even though they may be a considerable distance from the river corridor under study. Examples include those coming into contact with commercially marketed fish, wide-ranging animals that drink at the river, water fowl, distributed municipal water, irrigation water, wind-blown sediments, and hydroelectric parts or equipment.
- (A7.0-2) All interactions with river resources that may lead to contaminated habitat, food, or receptors and that contribute to exposure levels shall be evaluated.

- (A7.0-3) All humans, animals, and plants that use habitat in the study area shall be considered as candidate receptors.
- (A7.0-4) Pathway webs shall be developed which capture the relationships of the candidate receptors to river resources. Different relationship webs may be needed for each type of potential impact such as health effects, economic effects, and cultural practices. All such webs are expected to embody many of the river ecosystem relationships.
- (A7.0-5) Intrusion scenarios which result in potential contaminant transport into the river corridor shall be evaluated for both humans and biota.
- (A7.0-6) Exposure mechanisms related to airborne contaminants shall be evaluated for both humans and biota.

Approximately three additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

8.0 Dose Assessment

The requirements in this section address the calculation of the dose which results from potential exposure of the receptors to Hanford-derived contaminants.

Dose in individual biota is the presence over time of toxicant concentrations or energy deposition rates in the tissues of a selected receptor. The dose characterization needed varies with receptor role. If a particular biota category is of interest only as a contaminant carrier, simple mass uptake adequately characterizes dose. However, additional properties are needed to define the impact resulting from that dose. Contaminant uptake events that affect economic or socio-cultural groups must be identified.

Doses from past exposures can be obtained by sampling and measuring the receptors. Future doses must be estimated based on exposure models.

Dose calculations shall be made for each of the selected receptors of concern. The receptors of concern comprise a set selected from the candidate receptors (see Section 7.0 of this appendix). The requirements that describe the process to select receptors of concern are in Appendix II-B. After the receptors of concern set is developed, changes will probably seldom be needed. However, dose calculations may be constrained in some fiscal years to only a portion of the receptors of concern by CRCIA resource limitations. If dose calculations cannot be made for all receptors of concern, a subset will be defined using the requirements of dominance (see the Principles and General Requirements and section Appendix II-B).

An overview of the requirements in this section is:

- (A8.0-1) Radiation and chemical doses shall be calculated for each of the receptors of concern for all contaminants in the dominant contaminants set.
- (A8.0-2) Dose calculation scenarios will be defined for each receptor group having different activities in relationship to river resources and potential exposure. Examples include different scenarios for fishery and related river workers, farm workers where irrigation water is used, Native Americans, Tri-Cities residents, and metropolitan area industrial and office workers. Age and gender shall be considered in establishing absorption or uptake rates.

Approximately six additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

9.0 Receptor Impact and Tolerance Assessment

The requirements in this section translate receptor dose into adverse effects. Both current and future dose and effects from Hanford-derived contaminants must be assessed.

An overview of the requirements in this section is:

- (A9.0-1) Acute health effects shall be assessed.
- (A9.0-2) Chronic health effects including delayed health effects and cumulative effects from multiple exposures shall be assessed.
- (A9.0-3) The full range of genetic effects shall be assessed in all affected populations.
- (A9.0-4) The impact to community, tribal, and other populations' quality of life shall be assessed. This includes impact to jobs, housing, produce markets, and recreational opportunities.
- (A9.0-5) The impact to tribal quality of life shall be assessed, including but not limited to:
 - (a) Restrictions on access to ancestral lands and heritage resources
 - (b) Interruption of transfer of educational and spiritual knowledge within the community and between generations
 - (c) Protection of cultural and religious values and sacred landscapes

- (d) Degree of effort being expended to preserve or restore culturally important sites and resources within the study area
- (e) Sustainable economic and environmental practices
- (f) Access to open spaces
- (g) Visual and aesthetic impact to landscape
- (h) Trust in governing institutions
- (i) Cost of avoiding exposure and illness

Approximately six additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

10.0 Assessment Scenarios: Columbia River, Climate, Geological, and Political Changes

Sections 1.0 through 9.0 of this appendix define requirements to comprehensively assess potentially adverse effects of Hanford-derived contaminants in the Columbia River. These requirements are to be applied to:

- ◆ Current or normal conditions
- ◆ Hypothetical but probable or credible scenarios

The requirements in this section specify the development of candidate scenarios that span all possibilities. Appendix II-B provides the requirements for winnowing these candidates to the most credible study set.

The normal scenario assumed in the preceding sections is defined by parameters that change either very slowly or unpredictably and constitute present-day expectations. While the preceding sections are based on a normal scenario, future scenarios must also be considered. Because all the possible combinations of scenarios would lead to an unworkable number of assessment cases, the number of scenarios must be limited. The set of scenarios to be included in the assessment are those that involve the largest impact of Hanford contaminants to the Columbia River.

An overview of the requirements in this section is:

- (A10.0-1) A set of scenarios that depict the maximum impact from Hanford shall be defined.
- (A10.0-2) Credible scenarios with parameters that depict increased consequences from Hanford contaminants shall be evaluated to establish a set of scenarios for use in a comprehensive assessment.
- (A10.0-3) The limited set of scenarios to be evaluated shall include waste containment performance corresponding to the current Hanford Site disposition baseline for cleanup. See Section 11.0 in this appendix.
- (A10.0-4) The limited set of scenarios to be evaluated include potential demographic changes for the river corridor area under study.
- (A10.0-5) Scenarios to be assessed shall include but are not limited to:
 - (a) Scenarios that depict the groundwater recharge rate in a way that the maximum impact from Hanford is assessed. Examples are climate change, future site uses including irrigated agriculture, and river channel changes.
 - (b) Scenarios that depict contaminant dilution by groundwater or Columbia River water in a way that the maximum impact from Hanford is assessed. Examples are flood and drought scenarios, upgradient injection or extraction, disposition of present or new dams, and geologic events.
 - (c) Scenarios that depict enhanced remobilization of sediment in a way that the maximum impact from Hanford is assessed. Examples are future dredging, disposition of present or new dams, and river channel changes.
 - (d) Scenarios that depict potential changes in receptors. Examples are future Hanford land use scenarios, Hanford Site accident scenarios, transportation accident scenarios, demographic scenarios, economic scenarios, institutional evolution scenarios, and cultural evolution scenarios.
- (A10.0-6) Scenarios to be evaluated include but are not limited to:
 - (a) Scenarios that involve increased inventories of dangerous materials at Hanford. An example is a projected future plutonium repository.
 - (b) Scenarios that depict the impact of newly introduced foreign species. An example is the introduction of Northern Pike.

- (c) Scenarios that depict loss of institutional control over the Hanford Site after various time periods. The full range of probable times for loss of institutional control shall be evaluated.
- (d) Scenarios that depict loss of cleanup funding
- (e) Scenarios that depict the future production of plutonium and other new missions for the Hanford Site
- (f) Scenarios that depict ecosystem changes

Approximately two additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

11.0 Hanford Site Disposition Baseline

The requirements in this section call for the Columbia River impact assessment to be consistent with the current definition of the Hanford Site after all cleanup and waste disposal actions are complete and institutional controls cease. Because this may be a very long period of time, an assessment is also needed for the transition period when operations are in process.

As the strategic planning changes which defines the Hanford Site post-operations end state, the assessment must be updated.

An overview of the requirements in this section is:

- (A11.0-1) A complete disposition baseline shall be documented for purposes of the assessment.
- (A11.0-2) The assessment shall be consistent with the current revisions of the Hanford disposition baseline.
- (A11.0-3) The impact from actual and proposed remedial actions shall be assessed for compatibility with target, end-state conditions.
- (A11.0-4) The retrieveability of new waste forms that are part of either interim or permanent remedies and which affect the Columbia River shall be assessed.

Appendix II-B

How Good the Impact Assessment Results Must Be

Appendix II-B

How Good the Impact Assessment Results Must Be

The requirements in this appendix call for the assessment to be performed in accordance with the principles of fidelity, dominance, and management of uncertainty as specified in the Principles and General Requirements section. As used here, fidelity carries the same meaning that it does in high fidelity sound reproduction. It expresses the faithfulness of reproduction of the actual performance without adding distorting noise or bias which may obscure the more delicate but crucial sounds. To be useful for addressing public and regulator concerns, the assessment results must have acceptable fidelity, in other words, an acceptably low level of error, distortion, and bias. Idealized Hanford impact simulations must be shown to capture the essential factors of the actual situation. Fidelity also must encompass the lowest impact levels of concern to stakeholders and regulators.

Applying the principle of dominance requires the selection of the largest contributors to contaminant impact from among the demonstrably complete set of candidates specified in Appendix II-A. All potentially harmful Hanford-derived materials and contaminants must be included as candidates. This appendix specifies that the most dominant must be selected as contaminants of concern.

Consistent treatment of uncertainty throughout the assessment is indispensable to controlling quality or how good the impact assessment must be. For example, inattention to uncertainty of some field data collection effort may relegate all the assessment's data to unacceptably poor levels. Fidelity of assessment results could become so poor because of uncertainties in just one area of the assessment that actual impact to some receptors may be obscured.

An overview of the requirements in this appendix is:

- (B0.0-1) Impact assessment fidelity shall be adequate for the assessment uses and users, either those directing the Hanford cleanup effort or those affected by its results. See "Uses and Users" in the Principles and General Requirements section.
- (B0.0-2) The impact assessment shall provide the range of impact values which bracket uncertain impact with high probability. For example, it may be decided that the results must be able to show that, with 95 percent certainty, 99 percent of all impact has been identified.
- (B0.0-3) An explicit, documented definition and validation of model structure and parameters shall be established and maintained current with model and parameter revisions.
- (B0.0-4) Overall assessment uncertainty objectives shall be consistent with the applicable definition of the post-cleanup Hanford Site end state.
- (B0.0-5) Projected assessment quality shall be acceptable to the Columbia River Comprehensive Impact Assessment (CRCIA) Board. See Appendix II-D.

1.0 Fidelity of Detecting Harmful Effects

The requirements in this section call for the assessment calculations to represent actual conditions. Decisions on the acceptability of generalizations or deviations from reality must be made with an understanding and a concern for the people potentially affected by Hanford derived contaminants. Their cultural perspective and values are the only moral measures of the acceptable fidelity. Fidelity must be treated as a serious factor which requires major investments of time to gather information about the ecosystems and population groups in the study area.

One fidelity concern is identification of the periods of highest exposure, which correspond to the periods when peak contaminant concentrations reach the Columbia River. The evaluation of the ability of models with to predict peak exposure levels is particularly important.

An overview of the requirements in this section is:

- (B1.0-1) Assessment fidelity shall be sufficient to enable impact assessment at a level determined by the needs of affected ecosystems and cultural groups.
- (B1.0-2) Exposures and, therefore, effects vary with time over very long periods. The time at which high exposures occur is less important than the peak concentrations encountered, except to the extent that simultaneously arriving contaminants combine in their effects on receptors.
- (B1.0-3) Temporal peak width shall be accurate enough to support estimates of multi-generational exposure.
- (B1.0-4) The effect of uncertainty in the relative timing of peaks shall be considered in evaluating the uncertainty of combined (total) peak exposures. The timing of contaminant concentration peaks and their period (temporal width) shall be accurate enough in relation to each other that they adequately approximate total dose to an unspecified maximally exposed receptor generation, including the effect of individual contaminant peaks overlapping in time. See Appendix II-C, Section 2.0.
- (B1.0-5) Uncertainty in peak exposure level shall be quantified and managed to enable detection of impact relative to the criteria developed in response to the requirements specified in "CRCIA Standards" in the Principles and General Requirements section.

An additional page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

2.0 Model Integration and Consistency

The requirements in this section call for the overall assessment to conform to established physical laws and sound practice. This will help maintain the required consistency among all the subtasks and models in the assessment; for example, across geographical subdivisions.

An overview of the requirements in this section is:

- (B2.0-1) Consistency shall be maintained between boundary conditions of partitioned sub-region analyses, supporting valid and seamless integration into the overall assessment.
- (B2.0-2) Consistency shall be maintained at interfaces between models used in the assessment. Before models are designed or selected, interfaces must be defined in terms of the output data characteristics required from one model to enable the receiving model to function with consistency, for example, in uncertainty, and fidelity.
- (B2.0-3) Mass and momentum shall be conserved across the study area. This includes but is not limited to between calculations of partitioned sub-regions of the Hanford Site and river corridor downstream.
- (B2.0-4) Integration of model equations for all exposure process and harmful effects steps shall be validated before committing resources to their use.
- (B2.0-5) Consistency and seamless integration are especially important requirements which also apply to the use of data from other studies and analyses.

3.0 Selecting Factors for Assessment: The Study Set

The requirements in this section parallel the sections in Appendix II-A. The purpose of Appendix II-A is to ensure that no relevant factor is overlooked. This appendix requires that for any level of CRCIA effort, the assessment always considers the most important factors. These requirements call for the narrowing of the candidate factors specified in Appendix II-A to those which dominate potential impact to the receptors, that is from a demonstrably complete candidate set to the dominate study set.

An overview of the requirements in this section is:

- (B3.0-1) The impact assessment shall be designed so that the dominant threats to humans, cultures, and the Columbia River ecosystem are assessed and so that assessment resources and time are focused on correctly assessing the most severe threats.
- (B3.0-2) The dominant sources of harmful effects, both existing and projected, shall be evaluated.

- (B3.0-3) The assessment shall provide estimates of peak concentrations and the duration of contaminant pulses at all Columbia River locations of importance to the Hanford ecosystem and human users.

3.1 Hanford Materials and Contaminants

The requirements in this section assure that all Hanford radioactive materials and chemicals that could have an unacceptable impact are assessed. A suggested way to do this is to estimate the likely impact of contaminants and inventories with successive, iteratively refined models of the contaminant-transport-exposure-impact process.

Three additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

3.2 Containment Failure and Release

The requirements in this section call for selection of the dominant containment failure scenarios from among the candidates defined in Appendix II-A, Section 2.0. Radioactive materials and hazardous chemicals are expected to be contained after disposal following cleanup operations. They also are expected to slowly leak into the surrounding ground, water, and air when the containments eventually fail. Selection of the containment failure scenarios will be based upon credible probability of occurrence and the extent of resulting impact. To preserve CRCIA relevancy to cleanup decisions, containment performance information should come from only one source, the U.S. Department of Energy's (DOE's) approved disposal engineering plans. Only if no such documentation exists will alternate sources of information be used. This could include DOE performance requirements, or generally accepted performance estimates for the selected disposal method.

Two additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

3.3 Transport Mechanism and Pathways to the Columbia River

The requirements in this section call for selection of the transport mechanisms and pathways to the Columbia River from among the candidates defined in Appendix II-A, Section 3.0. Physical transport mechanisms are involved in the movement of contaminants from an inventory in a contaminated region or breached containment to the Columbia River. Selection of the level of detail in modeling or in choosing from among alternative mechanisms and pathways will be done using the principles of dominance, fidelity, and management of uncertainty. Pathways accounting for 95 percent of the receptors' dose shall be included for each of the scenarios in Appendix II-A, Section 10. Uncertainties may be large. If so, it may be desirable to determine the cost effectiveness of research efforts to reduce uncertainty to a level comparable with other calculations and modeling in the assessment.

An additional page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

3.4 Contaminant Entry into the Columbia River

The requirements in this section call for field data and the selection of the interface models which describe the manner and locations where contaminants enter the Columbia River. Candidates were identified in Appendix II-A, Section 4.0. While groundwater may be perceived to be the most probable pathway and entry mechanism, some scenarios may suggest other pathways to be more dominant and will require attention to other entry methods and locations. Applying the principles of dominance and fidelity to this selection process may depend on considerations such as habitat and drinking water uptake locations.

An additional page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

3.5 Fate and Transport of Columbia River-Borne Contaminants

The requirements in this section call for selection of the dominant, most credible mechanisms of contaminant concentration upon initial entry into the Columbia River. The requirements also address the rate and pattern of mixing with bulk river water, reconcentration of diluted contaminants, and redistribution of contaminated sediments. Candidate mechanisms were developed in response to the requirements in

Appendix II-A, Section 5.0. Examples of situations these requirements examine include reconcentration of contaminants in soils through years of using weakly contaminated irrigation water, reconcentration of contaminants on hydroelectric equipment which is exposed for years to large volumes of water, and the redistribution of contaminated sediments by dredging or the eventual removal of dams. Rates and patterns of mixing with bulk river water also require insightful selection from among candidate scenarios such as patterns of dam operations and cyclical river flow rates.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

3.6 Critical Habitat and Uptake Locations

The requirements in this section call for selection of dominant uptake mechanisms and locations which result in the largest contributions to receptor dose. Candidate ecosystem habitat locations and requirements to identify candidate critical uptake locations such as drinking water uptake were addressed in Appendix II-A, Section 6.0. The selections specified in this section define the interface between distributed contaminants and the biotic exposure webs, such as food chains. Matching locations of concentrated contaminants with critical uptake is key to the assessment.

Two additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

3.7 Receptors and Exposure Pathways

The requirements in this section address selection of the receptors of concern (the receptor study set) from among the candidates identified in Appendix II-A, Section 7.0. Selections must also be made from among the candidate exposure pathways such that the chosen exposure models (the pathway study set), regardless of depth of detail, always represent the most important pathways to the potentially highest impacted receptors. In addition to the candidate receptors required to be considered for selection in Appendix II-A, Section 7.0, this section also requires selection of candidate receptors if they occupy crucial positions in food chains, cultural webs, economic networks, or any other receptor dependency web. If resource allocations to CRCIA are highly constrained, tradeoffs may have to be made between assessing more receptors or a broader spectrum of contaminants, for example. In any case, the most highly impacted receptors and the most dominant exposure pathways must be selected — a balance achievable only through iterative executions of rough order-of-magnitude calculations prior to commitment of significant resources.

An additional page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

3.8 Dose Assessment

The requirements in this section address how well the dose characterization and quantification requirements in Appendix II-A, Section 8.0, must be implemented. Dose assessment provides the basis for assessing the impact because doses correlate with impact. Dose characterization approximates and simplifies dose. The dose as characterized must represent the actual or impending dose to an acceptable degree of approximation. For example, dose is characterized in part by the selected Contaminants of Concern. Dominant contaminants are selected on the basis of their contributions to dose. Simplifying approximations must be applied similarly to other factors determining dose. Dose characterization must be statistical. Dose distribution across population groups must be assessed. Because of their disproportionate contribution to impact, the dose to the most highly exposed members of a population group is important. The tails of the distributions on the side of high dose are of particular importance to values, such as equity.

3.9 Receptor Impact and Tolerance Assessment

The requirements in this section call for selection of the dominant adverse effects from among the candidates required to be considered in Appendix II-A, Section 9.0. This section also requires the adverse effects selected for evaluation (the study set) be assessed with sufficient fidelity to reveal actual conditions. Project scope limitations will constrain these choices. Unexpected potential adverse effects discovered in the course of the assessment must be identified and either included for assessment or shown to be less than the least dominant impact previously selected.

3.10 Assessment Scenarios: River, Climate, Geological, and Political Changes

The requirements in this section call for selection of the dominant scenarios from among the candidates required to be considered in Appendix II-A, Section 10.0. Dominant scenarios are chosen based on both the severity of their effects on impact and the likelihood of their occurrence. Scenarios provide stakeholders and decision makers a measure of the effectiveness of cleanup solutions.

4.0 Assessment Software Requirements

The requirements in this section call for software characteristics that meet assessment needs. The requirements in this section are:

- (B4.0-1) Software shall be designed, implemented, or procured on the basis of explicit requirements.
- (B4.0-2) Model representation of dominant contaminants and pathways shall include all elements necessary to describe dominant elements of dose.
- (B4.0-3) Verification and validation shall be performed on software.
- (B4.0-4) A Quality Assurance Plan shall be established before any software is developed or procured.
- (B4.0-5) A Software Test Plan shall be established during software requirements phase.
- (B4.0-6) Software reviews (walk-throughs) shall be held for each software module. Reviews shall include verification of software interfaces.
- (B4.0-7) Formal technical reviews shall be held at the end of the software requirements phase, the software design phase, and for analysis software integration prior to calculating assessment results.
- (B4.0-8) Software design quality shall be evaluated and reviewed for acceptability by qualified independent reviewers approved by the CRCIA Board.
- (B4.0-9) Software testing requirements shall be established during the software requirements phase.

5.0 Assurance of Assessment Quality

A concept and implementation approach to control the quality of the assessment during execution of the work shall be developed. This approach together with descriptions of the quality assurance work tasks to be done shall be published in a brief quality assurance plan. Required topics to be addressed in the plan follow and include confirmation that factors included in the assessment are the most dominant, confirmation of consistent treatment of uncertainty, and ensuring acceptable fidelity in the assessment results.

An additional page of explicit, detailed requirement for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

Appendix II-C

Analytical Approach and Methods

Appendix II-C

Analytical Approach and Methods

The requirements in this appendix specify that the Columbia River Comprehensive Impact Assessment (CRCIA) analysis process is to be designed and technically conducted so as to objectively reveal probable adverse effects. Appendix II-A, in contrast, addressed the factors to be considered in the exposure process and determination of its impact. The analysis process performance needed is driven by the quality requirements for the assessment results specified in Appendix II-B. The analysis must effectively cut through the complexity of the exposure process and the consequent adverse effects to quantify the essential, or dominant, contributors to the impact. A comprehensive impact assessment can only be realized if the analysis process performs this function. Contaminants and effects are quantitatively related by modeling.

An overview of the requirements in this appendix is:

- (C0.0-1) The analysis process design shall possess the capability to assess all impact, or threats of impact, listed in this document or discovered through the efforts of analysts and the CRCIA Board.
- (C0.0-2) The analysis process shall identify, select, and organize the dominant sources of impact, and the dominant pathways and pathway characteristics from the sources to their adverse effects.
- (C0.0-3) Models of the exposure process and consequent impact shall be validated.
- (C0.0-4) The capacity to evaluate and respond to timeliness and quality tradeoffs shall be designed into the assessment process.
- (C0.0-5) The assessment process shall manage uncertainty to achieve balanced uncertainty reduction as well as integration with management of dominant factors.
- (C0.0-6) The architecture and integration features of the analysis process shall be specified prior to commitment of the major funding.
- (C0.0-7) The assessment process shall incorporate a well defined data quality management process.
- (C0.0-8) Assessment methods that are consistent with and integrate with other impact assessment requirements shall be adopted or developed and verified.
- (C0.0-9) The assessment process shall manage verification.
- (C0.0-10) Analysis research and development needs shall be identified.

(C0.0-11) Standards will be compiled especially for CRCIA as discussed in the General Requirements Section.

1.0 Identification and Management of Dominant Factors

The requirements in this section call for the assessment to always evaluate those factors having the greatest contribution to receptor exposure and consequent impact. A comprehensive assessment must describe the dominant effects and relationships involved. By focusing on dominant factors, simplified approximations can be used in models without compromising their validity. However, representing behavior in terms of dominant factors is a two-edged sword. The representation problem is intractable without limiting the representation to dominant factors. But, failing to include a major contributor distorts the answer, perhaps seriously. While less important factors must be excluded to conserve resources, all important factors must be included for validity. Failure to distinguish between important and unimportant factors is not acceptable. Distinguishing between the two is the subject of this section.

In model formulation an iterative search for dominant process features must be done. For example, in searching through the possible factors influencing an impact to identify the essential (dominant) set, indirect, as well as direct, effects must be considered. Dependencies among receptors may affect the dominant set. For example, a receptor of concern's dependency on other receptors may cause effects on them to be propagated to the receptor of concern. Relatively small effects on several receptors of no apparent interest may be cumulative in a receptor of interest. For example, predator/prey relationships in the food web may lead to substantial cumulative dose in a receptor of concern. If such chains of effects contribute significantly to the total impact, they must be carefully preserved in representing the progression of adverse effects. Impact may also be manifested through dynamic instabilities. For example, non-linear dynamics or positive feedback can cause sudden, unexpected population collapse in a threatened ecosystem.

By definition, a set of dominant factors accounts for the bulk of the related impact, to any required degree of completeness. Any set of factors that fails to account for the impact to the required degree of completeness is not a dominant set. The most influential factors must be included in the dominant set, both for effective simplification and to meet completeness requirements. Dominant factors can take the form of pathways, relationships, contributors to, or elements of, dose or effects.

An additional page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

Conceptualization of the technical approach to the assessment must account for, if not begin with, the selection of methods and criteria with which to select the study set (dominant factors) from the candidate set (all-inclusive factors) in each module of the assessment process. For any given iteration of the assessment, all the assessment modules (see Figure C-1 below) will be included. However, the depth of detail will vary, that is, the number of factors making up the study set from each module will differ

depending on their significance to the assessment end result. The study set selection methods must determine the depth of detail in each module such that a balance in significance is struck across all modules. This becomes a key in technical direction to each module's technical leader. It also becomes key in recommending budget allocations for the modules to the CRCIA management. It should be expected that the study set size and resource allocation for each module will have to be reviewed periodically as new information and modeling provide new insight to the significant contributors to the assessment final result. It is likely to be found that the study set selection methods involve an iterative series of sensitivity studies using first coarse, then progressively better approximations (models) of exposure and impact.

Figure C-1. Management of Dominance and Uncertainty

The sources of uncertainty and their extent of contribution to the overall uncertainty of the assessment's end result also vary across the nine assessment modules. To conceptualize the technical approach to the assessment, methods must also be selected to estimate the extent of uncertainty contribution. Because technical effort and resource allocation should be made such that overall uncertainty of results is reduced, it is necessary to reduce the uncertainty from the largest contributors. Figure C-1 depicts this relationship graphically. Further, uncertainty and dominance are coupled. For example, some given factor may be very uncertain but of little consequence to the assessment results. Therefore, the technical approach must include methods which can estimate these combined effects and balance the depth of effort across the modules such that both the most important factors and the degree of uncertainty receive appropriate resources and investigative efforts.

2.0 Identification and Management of Uncertainty

The requirements in this section call for uncertainties to be identified, quantified, and managed. An appropriate level of allowed uncertainty which considers both needs and costs is to be established through interaction by analysts and the CRCIA Board. The uncertainty, or probability distribution, of exposures and biological damage depends many factors. Examples include:

Scenario Uncertainty:

- (a) Climate (recharge rate) uncertainty
- (b) Socio-economic evolution
- (c) Ecosystem evolution

Performance Uncertainty:

- (a) Performance of the cleanup approach causing the exposure
- (b) Technological uncertainty—maturity of technology and application experience
- (c) Institutional performance uncertainty

Analysis Uncertainty:

- (a) Data/parameter uncertainty
- (b) Model uncertainty

Management involves reducing those uncertainties that reduce overall impact uncertainty the most for the available money. An iterative approach, starting from a coarse initial analysis and progressing through ever more refined analyses, with uncertainty reduction at each step, is normally used. Dominant uncertainties, uncertainties that are the largest contributors to overall impact uncertainty, are addressed. Irreducible uncertainty is reached when reducing the largest sources of uncertainty is beyond the available time and resources.

Note that dominance among uncertainties is closely related to dominance as discussed in the previous section and should be treated in a unified process using, for example, the methods in National Council on Radiation Protection and Measurements (NCRP) Commentary No. 14 (1996).

Two additional pages of explicit, detailed requirements for this section have been identified from stakeholder concerns, issues, and experience. They do not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. They should be separately available by this draft's publication date for those who would like to request a copy. They will be included in the final document.

3.0 Analytical Architecture and Integration

The requirements in this section call for the assessment process to have an architecture that:

- (a) Supports iterative refinement of analysis products
- (b) Uses resources well, performing up-front scoping analyses to ensure purposeful and efficient execution of main-line tasks
- (c) Proceeds along a well-defined path to the final product
- (d) Is well integrated, using pre-defined intermediate analytical products effectively

3.1 Functional Definition of the Analysis Process

The requirements in this section call for a complete functional definition of the assessment process to be done prior to assessment planning. They also call for major intermediate assessment products to be defined, and the functions needed to produce the products to be identified.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

3.2 Internal Interfaces of the Analysis Process

The requirements in this section call for the input information categories, intermediate products, and final assessment products to be well defined during design of the assessment process.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

4.0 Data Quality

The requirements in this section call for data quality, data gaps, data acquisition, and verification and validation to be managed in a balanced way and consistent with other requirements.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to

develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

5.0 Assessment Methods

The requirements in this section describe the characteristics the analysis methods and procedures used in the assessment must have.

- (1) Assessment methods shall estimate the likelihood and severity of all the effects to be assessed.
- (2) Assessment methods shall satisfy the quality requirements in Appendix II-B.
- (3) Risk assessment methods shall be capable of detecting impact levels that affect the sustainability, robustness, and viability of the Columbia River ecosystem or stakeholder cultures.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

6.0 Verification

The requirements in this section call for the assessment process design to be properly verified before it is implemented.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

7.0 Analysis Research and Development Needs

The requirements in this section call for research and development needs for new or modified analytical methods to be promptly identified. They also call for research and development expenditures and efforts to focus on areas that make the most difference in assessment quality and assessment process performance.

Research to determine relative importance of factors which influence adverse effects will be an important part of identifying dominant assessment factors. The benefits of such research include assessment completeness and uncertainty reduction.

It is expected that, because of the delays and expense such development efforts entail, every effort will be made to incorporate the requirements for this assessment into previously planned and scheduled research efforts.

An additional half page of explicit, detailed requirements for this section has been identified from stakeholder concerns, issues, and experience. It does not appear in this draft due to insufficient time to develop an orderly presentation reasonably free of error or redundancy. It should be separately available by this draft's publication date for those who would like to request a copy. It will be included in the final document.

8.0 CRCIA Standards, Regulations, and Guidelines

The requirements in this section identify the standards to be used in the analytical process (see "Standards" in the section on Principles and General Requirements.)

- (1) The applicability of federal, State of Washington and State of Oregon laws and guidelines shall be evaluated and reported to the CRCIA Board.
- (2) Analysis methods shall be compatible with pertinent State of Washington and Oregon water regulations. Regulations such as Washington's Clean Water Act, Surface Drinking Water Act, and Model Toxins Control Act must be evaluated for applicability and relevance. The evaluation must be approved by the CRCIA Board.
- (3) The most stringent applicable standards shall be identified and applied. For example, salmon related standards shall be applied in regions where salmon are affected. This means an analytical sensitivity below 11 parts per billion of chromium (the concentration at which injury to juvenile salmon occurs) in salmon reads shall be achieved rather than 50 parts per billion as required by the clean water (human) standard.

Appendix II-D

Conducting and Managing the Assessment

Appendix II-D

Conducting and Managing the Assessment

The requirements in this section define how the assessment process is to be managed (see Figure II-D.1). They establish:

- Authority for direction of the assessment and the stakeholder roles in the directive process.
- Role of the sponsoring organization, including administration and funding.
- Responsibilities.
- Assessment planning, budget preparation, and resource allocation.
- Progress reporting to stakeholders.
- Oversight and review.
- Integration with waste disposal decision-making.
- Implementation.
- Control of changes in assessment results, planning, and budgets, as well as changes to the requirements in this document (Part II).

Figure D.1. Management of the Columbia River Comprehensive Impact Assessment

1.0 Project Direction and Stakeholder Steering Roles

A group representing the people affected by the cleanup and waste disposal decisions at Hanford, the Columbia River Comprehensive Impact Assessment (CRCIA) Board, will serve as the steering authority for the conduct of the assessment. This document, supplemented by a Board Charter, establishes and empowers the CRCIA Board. The Board manages the conduct of the assessment under the auspices of the Tri-Party Agreement and the Natural Resource Trustee Council. The requirements in this section are:

(D1.0-1) Membership of the CRCIA Board will be sought to represent:

- (a) General citizenry affected by Hanford
- (b) Persons who use the Columbia River for sustenance, commerce, or recreation
- (c) Affected Tribal governments
- (d) Tri-Party Agreement agencies
- (e) Federal and state regulators of Hanford
- (f) Federal, state, and local public health agencies
- (g) Hanford Natural Resource Trustee Council
- (h) Fish and wildlife agencies
- (i) Representatives of the affected local, state, and federal governments

Participation on the CRCIA Board does not abrogate the sovereignty of Indian Nations, state or local governments, nor does it preclude separate action.

(D1.0-2) The decision authority established for the CRCIA Board applies solely to the conduct of the impact assessment. Unless specific individuals are invited to make personal recommendations, involvement of assessment personnel in other Hanford Site decision-making activities is limited to the presentation of assessment results. Assessment results will not include judgments on the acceptability of river conditions (as opposed to portraying regulatory standards) or suggested disposal solutions. Personal recommendations must be clearly understood to be only the views of the individual and do not represent the Board or the assessment project.

(D1.0-3) Within the Board, an Executive Board will be established. The Executive Board will conduct the hands-on management of the assessment while the full Board will establish policy and provide executive oversight of the on-going assessment activities. The full Board will meet at regular intervals as needed, monthly, for example. The Executive Board, however, will need to meet more frequently, perhaps weekly, and for longer sessions, such as a half or full business day. Additional meetings will be convened as needed.

(D1.0-4) The Executive Board will be composed of representatives of the Tri-Party Agreement agencies, the governments of the states of Washington and Oregon, the Hanford Advisory Board, and the sovereign governments of the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, and Yakama Indian Nation. This participation is essential.

Reimbursement for time and expenses may be a condition for some members' participation. The Board is authorized to make funds available from the funding authorized to CRCIA from the sponsoring organization.

- (D1.0-5) Among the responsibilities of the CRCIA Board is planning the conduct of the assessment and preparing the annual budget proposal. Both the sponsor's administrative staff and the performing contractor will assist as requested. The CRCIA Board will present and defend each CRCIA budget proposal to the sponsor's budget decision-making body and to higher authority as warranted. Definition and planning of the assessment's technical work is to be accomplished by the performing contractor under the guidance of the CRCIA Board.
- (D1.0-6) The CRCIA Board may, through the sponsoring organization, hire independent experts to advise or perform intermittent special technical tasks for the Board. Similarly, the Board will need independent peer review services which, like the technical advisors, will be acquired through the contracting capabilities of the sponsoring organization or performing organization. The experience of these advisors and peer reviewers should be from outside the Hanford and U.S. Department of Energy (DOE) community to the extent feasible considering the degree of familiarity with Hanford Site cleanup the Board feels to be essential.
- (D1.0-7) The meetings and all other business of the CRCIA Board will be open to the public. However, in view of the broad based public representation comprising the Board, it is expected that input from the public will usually be made through the appropriate representative.
- (D1.0-8) The CRCIA Board will prepare a Charter to formalize its existence, responsibilities and operations.

2.0 Roles of the Sponsoring Organization

The sponsoring organization is that group which funds and advocates accomplishing the assessment, most probably, but not necessarily, DOE's Richland Operations Office. The organization serving as the sponsor and funding agent of this assessment will defer to the CRCIA Board to manage the conduct of the assessment. The requirements in this section are:

- (D2.0-1) The sponsoring organization will keep the CRCIA Board informed of the need for funding information and budget requests. While the Board will represent the assessment project in budget reviews and related resource allocation activities, the sponsoring organization is expected to provide fair and impartial advocacy of the assessment project's needs in day-to-day funds management activities.
- (D2.0-2) The sponsoring organization will provide a senior, well qualified manager to serve as project manager within the sponsoring organization and as executive administrator within assessment activities. This person must have sufficient stature and respect within the sponsoring organization to enable authority to be delegated to him or her to act for and, in all but sensitive policy areas and funding matters, to commit the sponsoring organization to the agreements reached in

Board deliberations. In all matters, the executive administrator will reflect and advocate the Board's consensus positions and sentiments. The sponsoring organization will also provide reasonable staff support to the executive administrator.

- (D2.0-3) The CRCIA project will rely upon the sponsoring organization to provide:
- (a) General administrative services
 - (b) Meeting support services, including minutes, conference rooms, and audio/visual equipment
 - (c) Procurement and subcontracting services, including contract management of the contractor performing the assessment analytical work
 - (d) Payroll and/or expense reimbursement services for those Executive Board members whose participation is not possible without financial support
 - (e) Publishing services, including controlled document distribution and support
 - (f) Liaison and support services with other project managers and senior DOE officials to ensure integration of the CRCIA with other Hanford Site activities and decision-making

3.0 Performing Organization and Subcontractors

- (D3.0-1) The sponsoring organization in collaboration with the CRCIA Board will select and contract with the most highly qualified company available to perform the assessment. Subcontractors will also be selected in collaboration with the CRCIA Board. In all cases, contractor selection will be made so as to avoid a conflict-of-interest.
- (D3.0-2) The performing organization will be responsive to the CRCIA Board's direction through the sponsoring organization and appropriate contract provisions.
- (D3.0-3) The performing contractor is responsible to ensure that the Board acts in all matters with a grasp of the relevant technical considerations.

4.0 Conflict of Interest

- (D4.0-1) Potential or perceived conflict-of-interest will be acted upon by the Board as appropriate.

5.0 Relationship with Hanford Site Decision-Making

- (D5.0-1) In accordance with the stated purpose for performing this assessment, it is expected that the results and conclusions will be used by Hanford Site decision-makers to:

- (a) Help determine the manner in which remediation and waste disposition should be done
 - (b) Validate the waste disposition decisions already made or justify a revision in planned actions
 - (c) Provide advice and recommendations to people down river from Hanford
- (D5.0-2) In view of the intended uses of assessment results, the CRCIA Board must plan and schedule the key milestones in the assessment to yield timely information for the Hanford Site decision making process. The Executive Administrator will keep the Board advised of:
- (a) Budget preparation, review, and allocation schedules
 - (b) Hanford Environmental Impact Statement and Record of Decision schedules
 - (c) Key strategic planning activities
 - (d) Formulation efforts for other key decision documents at both the Site and project levels
- (D5.0-3) The Board will consider the use of such devices as a newsletter, flash reports, and similar tools to both advise Hanford project managers of significant CRCIA developments and also to encourage informal networking between the assessment project and the decision makers.
- (D5.0-4) The Board must constantly strive to have assessment results available which reveal the overall Hanford Site performance for each officially approved waste disposal baseline. This applies whether the expression of that baseline occurs in formal strategic planning documentation, in environmental impact statements, or in budget proposal planning assumptions.

6.0 Management and Progress Reviews

- (D6.0-1) The CRCIA Board will, with support from the sponsoring organization and performing contractor, develop and maintain a resource loaded project work plan spanning the life of the project. Currency of the work plan, progress, and problem resolution responsibilities will be reviewed regularly, perhaps monthly, by the Executive Board and reported to the full CRCIA Board.
- (D6.0-2) The CRCIA Board is responsible for the allocation of the funding provided as well as the financial state of the assessment project. The Board may appoint one of its members to serve as Financial Manager. The project work plan will be the basis for preparation of budget proposals and reports. Financial information available through the existing cost reporting systems of the sponsoring organization and performing contractor will be used as appropriate.
- (D6.0-3) The Board will ensure that resources and budgets are allocated in accordance with the results of the required sensitivity studies which are intended to identify and rank order the factors contributing most to impact to the river (See Appendix C, Section 2.0). This approach will

require that funding is allocated to the evaluation of the most dominant drivers first. This requirement is the cornerstone of financial management for the project and for defining and revising work plans.

- (D6.0-4) At the Board's discretion, gates should be defined at key junctures in the work plan schedule. The gates should define conditions to be met during the assessment which measure work progress and keep subtasks in harmony with one another. Gates also improve financial management within the project. Reporting the extent to which gate conditions are being met should be included in management reviews.
- (D6.0-5) After completion of any given work plan, literature searches will be done. This is to determine if technical work done in the past meets the needs of the work plan and the requirements of this document. If so, the results may be used in lieu of performing the work again in the CRCIA project.
- (D6.0-6) The CRCIA Board will receive a progress report presentation from the sponsoring organization and performing contractor on a regular basis, perhaps monthly. Observers, especially representatives of the sponsoring organization and Tri-Party Agreement agencies, may be invited to participate.
- (D6.0-7) The Executive Administrator and performing contractor will provide a written quarterly progress report to the Board for approval and transmission to the Tri-Party Agreement agencies and sponsoring organization.
- (D6.0-8) Periodic reviews of progress and findings will be made by the Board with the organizations represented on CRCIA Board.

7.0 Public Outreach

The CRCIA Board will remain mindful of its burden to responsibly represent the public who, through Hanford's impact on the Columbia River, are affected by the cleanup program's waste disposal decisions. The structure of the CRCIA management approach is designed to enable the public's meaningful involvement in directing the assessment. However, this will be achieved only to the extent that each Board member aggressively develops and maintains a rapport with the constituency to which he or she is accountable. The requirements in this section are:

- (D7.0-1) The CRCIA Board will develop a public outreach plan that shall include but not be limited to the following:
 - (a) Regularly provides assessment reports to interested parties informing them of the emerging insights into the present and future states of the Columbia River together with the causes of any projected impact

- (b) Provides innovative opportunities for meaningful and effective public participation in assessment project reviews

8.0 Technical Oversight

- (D8.0-1) At the discretion of the Board, periodic technical reviews will be made by independent, qualified experts. These reviews may be of the assessment project in general, of the technical approach(es) planned, or of the results obtained. Peer review comments and recommendations will be made available to anyone who requests them. The experience of the reviewers should be from outside the Hanford and DOE community to the extent feasible considering the degree of familiarity with Site cleanup the Board feels to be essential.

9.0 Implementation

The management approach prescribed for CRCIA defines a new paradigm for predecisional participation by affected people. Realizing that it will take time to adapt the supporting infrastructure, the CRCIA Board will work cooperatively with existing policies and practices while helping to develop more effective processes. Throughout the implementation period, the Board will entertain suggestions to revise and update requirements in this document. However, the basic approach and structure is considered sound. The requirements in this section are:

- (D9.0-1) Throughout the conduct of the Screening Assessment and preparation of these requirements, the CRCIA Board functioned as a stakeholder advisory team. It has been composed of the Tri-Party Agreement agencies, the governments of the states of Washington and Oregon, the Hanford Advisory Board, and the sovereign governments of the Confederated Tribes of the Umatilla Indian Reservation, Nez Perce Tribe, and Yakama Indian Nation. Implementation of these requirements broadens the membership of the Board and changes its role to management of the assessment effort.
- (D9.0-2) The existing CRCIA Team will determine when the full CRCIA Board should be formed. Probably the existing team will remain unchanged while preliminary assessment tasks are being performed. The other provisions of this appendix will be implemented on the date(s) established by the existing team or on the date this document is published as revision zero.

10.0 Control of Changes to the Assessment Project

The CRCIA Board or the Executive Board acting in the Board's behalf is the only approval authority for changes in the assessment's work plans, budget allocations, findings, or for changes to the requirements in this document, Part II. The requirements in this section are:

- (D10.0-1) Upon initial release in its final form, Part II of this document will be controlled by the CRCIA Team. It will be released as revision zero (Rev. 0). Subsequent revisions distributed by interim correspondence can be approved only by the CRCIA Board or the Executive Board acting in the Board's behalf.
- (D10.0-2) The assessment project work plan, after its initial preparation and approval by the Board, will be revised only upon approval by the Board. However, it is expected that the Board will provide the performing contractor moderate discretionary authority to make operational deviations in keeping with the provisions and spirit of this document and the work plan.
- (D10.0-3) Results from the assessment will be released only after review and approval by the Board. Findings of subsequent technical work indicating a need to update these conclusions will be approved by the Board prior to release and prior to revising earlier assessment results.

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