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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
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Summary

The Pacific Northwest National Laboratory's[a] Surface Environmental Surveillance Project (SESP) is an ongoing effort to design, review, and conduct monitoring both on and off the Hanford Site. To these ends, the SESP conducted a chemical pathway analysis that consisted of three phases: 1) identification of chemicals of concern; 2) modeling the offsite fate, transport, exposure, and relative human-health risk posed by the identified chemicals of concern; and 3) ranking and prioritizing the chemicals of concern and exposure media.

The selection of the chemicals of concern was based on extensive examination of established databases and reports documenting onsite environmental pollutant concentrations and onsite human-health-risk assessments/screening assessments. A list of the chemicals of concern is provided in Table S.1.

Table S.1. Identified Chemicals of Concern

Ammonia
Aroclor 1248 (a polychlorinated biphenyl)
Arsenic
Benzo(a)pyrene
Beryllium
Bis(2-ethylhexyl)phthalate
Carbon tetrachloride
Chloroform
Chromium
Chrysene
Fluoride
Manganese
Nitrate
Nitric acid
Sodium
(1,1,1,2)Tetrachloroethane
Trichloroethylene

A modified version of the Modular Risk Analysis methodology was incorporated into the design of the model used for this analysis. A bounding-type pathway analysis/exposure assessment was performed that used the highest observed onsite concentration for a given chemical of concern. The fate and transport of the chemicals of concern were modeled using the Multimedia Environmental Pollutant Assessment System (MEPAS) code. Using the various exposure pathways, the offsite cancer incidence and hazard quotient were calculated. Using the same transport and exposure pathways, a retrospective pathway analysis was performed to estimate what onsite concentrations would be required in the soil (at the areas of contamination) for each chemical of concern identified (and other routinely detected chemicals occurring onsite) that would be required to obtain an estimated offsite human-health risk of 1.0E-06 cancer incidence or 1.0 hazard quotient. Thus, the different inputs/outputs provide a range of potential offsite exposure from Hanford Site-derived nonradiological chemicals occurring: 1) highest detected concentration of a chemical of concern and 2) onsite concentration required to elicit a 1.0E-06 cancer incidence or 1.0 hazard quotient offsite.

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This SESP chemical pathway analysis did not examine ecological risks from nonradioactive chemicals at this time. Furthermore, this chemical pathway analysis should be considered preliminary and performed only to provide information to make decisions on environmental monitoring. The model results have not been field validated nor has a detailed uncertainty analysis been performed on the developed model. This analysis was not designed to be a comprehensive, detailed, current-state, human-health-risk assessment but is intended to aid in the ranking and prioritization of analytes and media monitored.

This analysis indicates that current nonradiological chemical contamination occurring on the site does not pose a significant offsite human-health risk. The highest cancer incidence to the offsite maximally exposed individual was from arsenic (1.76E-10); the highest hazard quotient was chromium(VI) (1.48E-04). The most sensitive pathways of exposure were surfacewater and aquatic food consumption. The combined total offsite excess cancer incidence was 2.09E-10 and the estimated hazard quotient was 2.40E-04. Of the 17 identified chemicals of concern (see Table S.1), the SESP does not currently (routinely) monitor for the following: arsenic, benzo(a)pyrene, bis(2-ethylhexyl)phthalate, and chrysene.

Results from the retrospective analysis demonstrated that it was possible for only three (arsenic, bis[2-ethylhexyl]phthlate, and chloroform) of the identified chemicals of concern could actually occur in onsite soil at concentrations high enough to cause a 1.0E-06 excess cancer incidence or a 1.0 hazard index for a given offsite pathway of exposure. During the retrospective analysis, 20 other chemicals were also evaluated; of those, only vinyl chloride and thallium could occur in concentrations high enough to reach the targeted offsite risk values.

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The authors wish to thank John W. Buck for his assistance in the early study-design development phase and peer review of this report; to Ted Poston for his valued input to this report, and to Gariann Gelston for graphics support. The authors wish to give special thanks to the editing and report production support provided by Beverly V. Johnston, Denice A. Carrothers, Sharon M. Daly, Kathy R. Neiderhiser and Rose M. Watt.

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1.0 Introduction

The Pacific Northwest National Laboratory Surface Environmental Surveillance Project (SESP) conducts onsite and offsite environmental monitoring for the U.S. Department of Energy. As part of this monitoring effort, the SESP analyzes air, surfacewater, sediment, agricultural products, vegetation, soil, and wildlife to assess both onsite and offsite environmental impacts and offsite human-health exposures from Hanford Site-derived hazardous material. The objectives of the SESP activities are to 1) verify that doses resulting from Hanford Site operations through environmental exposure pathways remain low, 2) provide an indication of changes in environmental conditions that potentially increase or decrease the chance of public exposures, and 3) provide public assurance that the radiological and nonradiological chemicals and potential exposure pathways are understood and receive appropriate attention.

This nonradiological chemical pathway analysis was designed to aid the SESP in meeting the above-identified objectives by 1) ensuring that the selection of surveillance parameters (such as environmental media, sampling location, and chemical constituents) are chosen in a manner that is scientifically sound and cost efficient and 2) identifying specific nonradiological chemicals of concern for the Hanford Site. This report documents the findings from this SESP nonradiological chemical pathway analysis.

To understand the fate, transport, exposure, and human-health risk associated with nonradiological chemical contamination, this report gives extensive background information in Chapter 2.0. The approach taken in the analysis of the various media is given in Chapter 3.0. The results of the analysis are provided in Chapter 4.0, followed by a discussion of those results in Chapter 5.0. The conclusions are provided in Chapter 6.0. The references cited in the text are presented in Chapter 7.0 and a bibliography of noncited reference material is given in Chapter 8.0. Six appendixes are provided to aid the reader in understanding various aspects of the mathematics used in the analysis and the source terms and analytes monitored.

2.0 Background

The following is a description of the study area and the regulated waste sites. These are followed by a discussion of past practices and associated sources of contamination occurring on the Hanford Site. Information on factors controlling the chemical fate, transport, and exposure in the environment is also provided, along with discussion on the potential exposure pathways to humans at different receptor locations. Information on current and past nonradiological chemical-monitoring activities is also provided, followed by a description of the Multimedia Environmental Pollutant Assessment System (MEPAS) code.

2.1 Study Area

The Hanford Site, located in south-central Washington state, is approximately 1450 km^2 of semi-arid shrub-steppe, located approximately 11 km north of the confluence of the Yakima and Columbia rivers (Figure 2.1). For many years, the Hanford Site was dedicated to the production of plutonium for national defense. The defense production resulted in the accumulation of approximately 1.4 billion cubic meters of hazardous (both radioactive and nonradioactive) liquids and solids (EPA 1989). The operations at the Hanford Site resulted in the release of a wide variety of chemicals to the environment. Currently, the site's mission is in the management and cleanup of the resulting wastes.

2.2 Regulated Waste Sites

The Hanford Site has approximately 1400 inactive waste-disposal and unplanned release sites that are regulated under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Thompson 1991). There are also 64 Resource Conservation and Recovery Act of 1979 treatment, storage, or disposal units (Thompson 1991). Other environmental pollution releases are regulated by the National Pollutant Discharge Elimination System and the National Emission Standards for Hazardous Air Pollutants.

2.3 Past Practices and Associated Sources of Contamination

2.3.1 100 Areas

The 100 areas contain nine reactors that were used in the production of plutonium: B, C, D, DR, F, H, KW, KE, and N reactors. Numerous support facilities are associated with the reactors, including water-treatment plants, water-storage tanks, raw water-intake structures, process sewers, underground sewage-disposal systems, and powerhouses (oil or coal fired) (Stenner et al. 1988). Except for N Reactor that used oil-fired boilers, all of the other reactors used coal-fired boilers and had large areas for coal storage and fly ash/clinker disposal (Stenner et al. 1988).

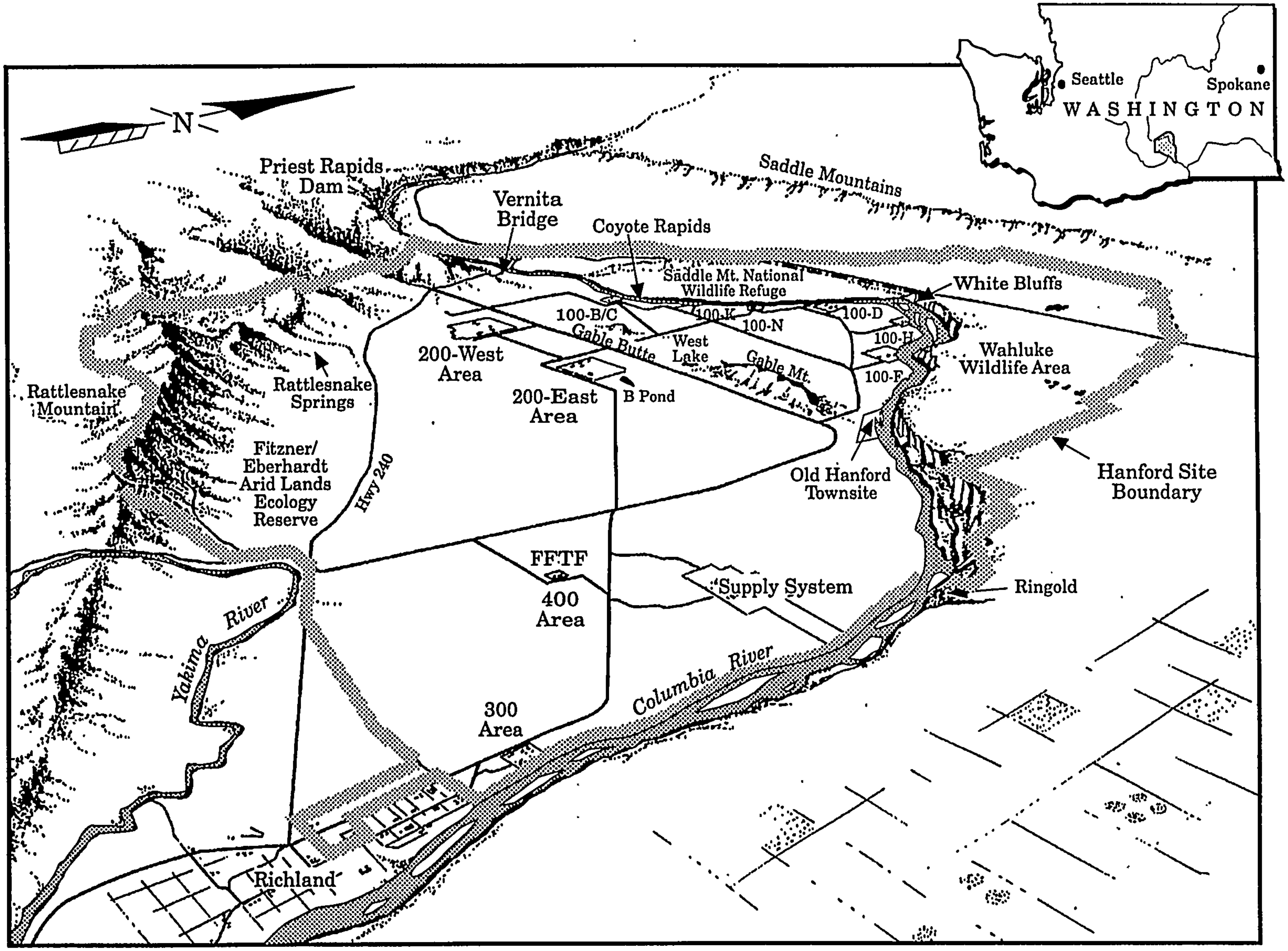

Figure 2.1. U.S. Department of Energy's Hanford Site and Surrounding Areas

The N Reactor was a dual-purpose reactor used not only in the production of plutonium but also to feed steam to an 860-MW electricity generating plant. The N Reactor cooling water was designed to be recycled after its use. The other reactors were for single-purpose production and used "once-through" cooling. Water drawn from the Columbia River was treated with alum, sulfuric acid, and chlorine before entering the reactor core as a coolant to remove heat, film buildup, and scale from the fuel elements (Stenner et al. 1988; Becker 1990; Gray and Becker 1993). To prevent corrosion of the piping and the aluminum surfaces of the fuel elements, sodium dichromate was also added to the water (Stenner et al. 1988; Becker 1990; Gray and Becker 1993). Other chemicals used during production included

- copper sulfate and chlorine to control algae growth in retention basins and settling ponds
- oxalic acid, nitric acid, and chromic acid to decontaminate the "dummy" fuel elements that were used as spacers
- sulfuric acid to keep water at a desired pH (Stenner et al. 1988; Becker 1990; Gray and Becker 1993).

The 100 areas contain 22 operable units (OUs), categorized into the following four groups: 1) source units, 2) cooling-water-treatment units, 3) buried and solid waste units, and 4) groundwater units (Stenner et al. 1988; Gray and Becker 1993). Source units and cooling-water-treatment units comprise areas that received liquid effluent from the reactors (such as reactor coolants, decontaminated waste streams, effluents from ruptured fuel-storage areas) and areas that received wastewater effluents from water-treatment plants located at the 100-N and 100-K areas (Gray and Becker 1993). Radiologically contaminated liquid wastes were discharged to engineered waste-disposal facilities (such as ponds, french drains, cribs, ditches, trenches, and reverse wells) (Stenner et al. 1988; Gray and Becker 1993).

Buried and solid waste units are areas that received radioactive solid waste, failed reactor wastes, and contaminated equipment. Solid waste was buried underground (in trenches, caissons, and tunnels) or on concrete pads for retrievable storage (Gray and Becker 1993). Trenches primarily contained failed pieces of equipment placed in storage containers (concrete, wooden, or metal). "Dry" waste consisted of contaminated paper, rags, filters, soil, disposable supplies, small pieces of equipment, etc., placed in boxes, and backfilled with approximately 2.4 m of soil (Stenner et al. 1988; Gray and Becker 1993).

Groundwater units are found beneath source units, where liquid waste discharged to the surface or below the surface migrated to the water table, resulting in a contaminated groundwater plume.

2.3.2 200 Areas

The 200 areas were used for chemical separations and waste management. The original separations plants (B, T, and U) are located in the 200 areas. Facilities located in the 200 East Area include the Plutonium-Uranium Extraction (PUREX), B, and Semiworks plants. The principal chemical-processing plants in the 200 West Area include the U, S, T, Reduction/Oxidation, and Plutonium Finishing (Z) plants.

200 East Area--Processes that occurred at the PUREX Plant included the separation of uranium, plutonium, and neptunium from irradiated uranium fuel. This was accomplished by first removing the fuel cladding with an ammonium fluoride-ammonium nitrate solution. The fuel was dissolved in nitric acid (Stenner et al. 1988; Becker 1990; Gray and Becker 1993). Uranium, plutonium, and neptunium were separated from the fuel with an organic solvent, called tributyl phosphate (in a kerosene dilutant). B Plant also separated plutonium from irradiated uranium fuel and used a bismuth phosphate process, where the aluminum fuel jacket was dissolved in a solution of sodium hydroxide-sodium nitrate solution. Once the protective jacket was removed, the fuel elements were dissolved in nitric acid. The plutonium was then recovered after a series of chemical extractions and ion exchanges using various chemicals (such as sodium bismuthate, sodium nitrate, sodium dichromate, oxalic acid, hydrofluoric acid, ammonium nitrate, potassium hydroxide, hydrogen peroxide, and ammonium sulfate). The Semiworks Plant was first a pilot plant for the reduction-oxidation process and then later used as a pilot plant for the PUREX process. The Semiworks Plant was also used in the recovery of ^{90}Sr and ^{137}Cs for shipment to the Oak Ridge National Laboratory. The Semiworks Plant is decommissioned (Stenner et al. 1988).

200 West Area--U Plant was one of the first fuel-separation facilities built at the Hanford Site, but it was never used for that purpose; it was converted to recover uranium from stored radioactive waste by dissolving the waste in a nitric acid solution and removing the uranium with an organic solvent (tributyl phosphate in a kerosene dilutant) (Stenner et al. 1988). Operations at T Plant were similar to those at B Plant. T Plant is now used to repair and decontaminate equipment (Stenner et al. 1988; Gray and Becker 1993). The Plutonium Finishing (Z) Plant included a plutonium laboratory (231-Z), a finishing operations facility, and facilities for the processing of scrap plutonium materials and preparation of plutonium products. Plutonium was recovered from scrap, using a process called recouplex, to form a plutonium nitrate solution. This was achieved by dissolving solids in a solution of nitric and hydrofluoric acids and extracting plutonium with a tributyl phosphate-carbon tetrachloride solvent. Other chemicals were also used in the recovery of the purified plutonium nitrate solution, which included aluminum nitrate and aluminum fluoroxide nitrate (Stenner et al. 1988).

The 200 East and West areas contain 43 OUs grouped into one of four categories:

- tank farms--Highly radioactive and hazardous chemical byproducts were stored underground in single-shell tanks or double-shell tanks.

- process liquids--Radioactive and hazardous liquid waste was disposed to the ground in cribs, ditches, trenches, and ponds. In addition, some process liquid was discharged into reverse injection wells that were drilled down to or very near the groundwater table. (These disposal practices resulted in surface soil and groundwater contamination.)

- buried wastes--Radioactive dry wastes, contaminated drums, equipment, and limited amounts of liquid wastes were placed in numerous burial grounds.

- support services--Sites contaminated from byproducts of coal-burning, laundry, and maintenance facility operations are in this category (Stenner et al. 1988; Becker 1990; Gray and Becker 1993).

Releases from the separations processes are categorized as 1) high-activity aqueous solutions; 2) low-activity aqueous solutions; 3) nonaqueous solutions; 4) gaseous effluents, including particulate material; and 5) solids (Stenner et al. 1988; Gray and Becker 1993). Most of the nonaqueous liquid waste was usually disposed of by trenching and backfilling. Solid wastes (decontamination rags and failed equipment) were boxed and buried in trenches. Gaseous effluents were vented to the atmosphere, usually following various forms of treatment and filtration. Disposal of aqueous waste depended on the level of the contamination. Highly contaminated liquid waste was stored in underground single-shell or double-shell tanks. There are 149 single-shell and 28 double-shell tanks buried in the 200 areas (Becker 1990; Gray and Becker 1993). Less-contaminated liquid waste was disposed to the ground in cribs and allowed to seep through the soil column. Some of the pollutants sorbed onto soil particles, while others migrated to the groundwater table. Most of the cooling water and steam condensate was discharged to engineered artificial ponds and permitted to seep downward through the soil column to the unconfined aquifer.

2.3.3 300 Area

This area is located approximately 5 km north of Richland, Washington and covers approximately 1.5 km^2 (370 acres). Facilities in the 300 Area were used to support the fabrication of reactor fuel. A process called "coextrusion" was used to fabricate the fuel elements for N Reactor. The process bonded zirconium cladding and the uranium-silicon fuel core together in one extrusion process. Chemicals used in this process included trichloroethylene (used to remove lubricants) and nitric acid (used to dissolve the copper jacket after fuel elements were extruded into "bullets"). A zirconium end cap was brazed onto the fuel bundle with beryllium. Other chemicals used in the milling process included nitric acid, sulfuric acid, and copper sulfate (Stenner et al. 1988; Becker 1990; Gray and Becker 1993). Forms of waste were predominantly liquid in nature and consisted primarily of cooling water, dilute caustics, and pickling rinses (Becker 1990).

Up until 1971, wastes containing low concentrations of uranium from fabrication of fuels used in single-purpose reactors were discharged to two settling ponds a few hundred meters from the Columbia River (Foster et al. 1961). Wastes containing chemical solutions and low-level radioactive liquids from nearby research laboratories were also disposed to these ponds. Liquid waste was permitted to seep through the soil column to the shallow unconfined aquifer below. These ponds also received low-level radioactive liquids and chemical solutions used in research laboratories located in the 300 Area (Becker 1990).

The 300 Area contains five OUs that can be grouped into one of two categories: 1) process liquid-liquid waste disposals from fuel-fabrication operations or 2) buried and solid waste (Stenner et al. 1988; Gray and Becker 1993).

2.3.4 400 Area

The Fast Flux Test Facility is located in the 400 Area. This facility was constructed to test fuels and materials for advanced nuclear technology. The facility is unique, in that it is cooled by recirculating liquid sodium metal (Becker 1990; Gray and Becker 1993). The 400 Area also contains septic tanks and hazardous materials-handling facilities. Wastes generated in the 400 Area were properly packaged and disposed in the 200 areas.

2.3.5 1100 Area

This area was and still is used as a central warehouse, vehicle maintenance, and transportation distribution center. Chemicals disposed at the 1100 Area included, but not limited to, paints, antifreeze, battery acid, pesticides, and organic solvents (DOE 1990). There are four OUs located in the 1100 Area that can be grouped into one of the following two categories: 1) voluntary and involuntary liquid waste releases or 2) voluntary and involuntary solid waste releases.

2.3.6 Hanford Site Groundwater

As mentioned, many of the OUs function as sources that contribute to groundwater contamination beneath the site. It is estimated that, from 1944 to 1989, approximately 444 billion gallons of liquid were discharged to the ground through disposal trenches, cribs, and ponds (Freshley and Thorne 1992). The primary pollutants found in the numerous plumes located onsite include nitrate, fluoride, chromium, cyanide, carbon tetrachloride, chloroform, trichloroethylene, ^{3}H ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, ^{137}Cs, and uranium (Dresel et al. 1993). Following is a brief summary of the sources of these contaminants.

Nitrate contamination can be attributed to process-condensate liquid wastes and the use of nitric acid in the decontamination and chemical-reprocessing operations that were discharged to the ground (Dresel et al. 1993). The fluoride contamination is due primarily to the use of aluminum fluoride nitrate in the 200 Areas that was subsequently disposed in trenches and cribs (Dresel et al. 1993).

Chromium contamination can be attributed primarily to the use of sodium dichromate in the 100 areas. Cyanide contamination results primarily from the use of ferrocyanide disposed in the BY cribs located in the 200 areas. Carbon tetrachloride contamination is due primarily to the extensive use of this substance for Plutonium Finishing (Z) Plant operations and its subsequent disposal to the ground. Chloroform contamination appears to be associated with the carbon tetrachloride plume found in the 200 areas and may be a result of biodegradation of carbon tetrachloride. Trichloroethylene was a common industrial solvent used as a degreasing compound. This chemical can be detected in the 100, 200, 300, and 600 areas (Dresel et al. 1993).

All of the radionuclides noted above can be attributed to plutonium-production processes, wherein uranium and many other chemicals became irradiated. Detailed descriptions of each of the engineered disposal systems described above for the operational areas (100, 200, 300, 400, and 1100) can be found in Stenner et al. (1988).

2.4 Factors Influencing Fate and Transport of Chemicals and Potential Pathways of Exposure to Humans

Exposure is defined as the interaction of an organism with a physical or chemical agent of interest (EPA 1989). Thus, exposure can be quantified as the amount of chemical or physical agent available for absorption at the organism's exchange boundaries (i.e., dermal contact, lungs, gut, etc.). An exposure pathway is identified, based on 1) examination of the types, location, and sources (contaminated soil, raw effluent, etc.) of contaminants occurring on the site; 2) principal release mechanisms; 3) probable environmental fate and transport (including persistence, partitioning, and intermediate transfer) of contaminants of interest; and, most important, 4) location and activities of the potentially exposed populations (EPA 1989). Mechanisms that influence the fate and transport of a chemical through the environment and that are the determining factors influencing the amount of exposure one might receive at various receptor locations are listed below. These were considered during the design phase of this chemical pathway analysis:

- transportation (e.g., migrate downstream in solution or on suspended sediment, or travel through the atmosphere)
- physical or chemical transformation (e.g., deposition, precipitation, volatilization, photolysis, oxidation, reduction, hydrolysis; if radionuclide, it may decay)
- biological transformation (e.g., biodegradation)
- accumulation in the receiving medium (e.g., an environmental sink, such as a chemical sorbed strongly in the soil column).

The following summarizes the types of human-exposure pathways considered during this chemical pathway analysis (Figure 2.2):

- direct contact with contaminated air plume, resulting in possible dermal absorption of contaminants; dust and air inhalation of contaminated plume; ingestion of fugitive dust
- fugitive dust offsite deposition onto crops, livestock, and wildlife used as food
- consumption of crops and livestock that are irrigated or drinking water that is contaminated; consumption of fish, ducks, mussels, and other aquatic or terrestrial wildlife that frequent the river
- consumption of wildlife that migrate on and off the Hanford Site
- use of surfacewater for bathing, showers, drinking, cooking, etc., possibly leading to ingestion of contaminants or absorption of contaminants through mucus membranes and dermal contact.

Hydrogeologic investigations performed by Dresel et al. (1993) and three-dimensional modeling studies done by Wurstner and Devary (1993) demonstrate that the southward migration of groundwater flow from the Hanford Site (200 East Area tritium plume) is diverted eastward and discharges into the

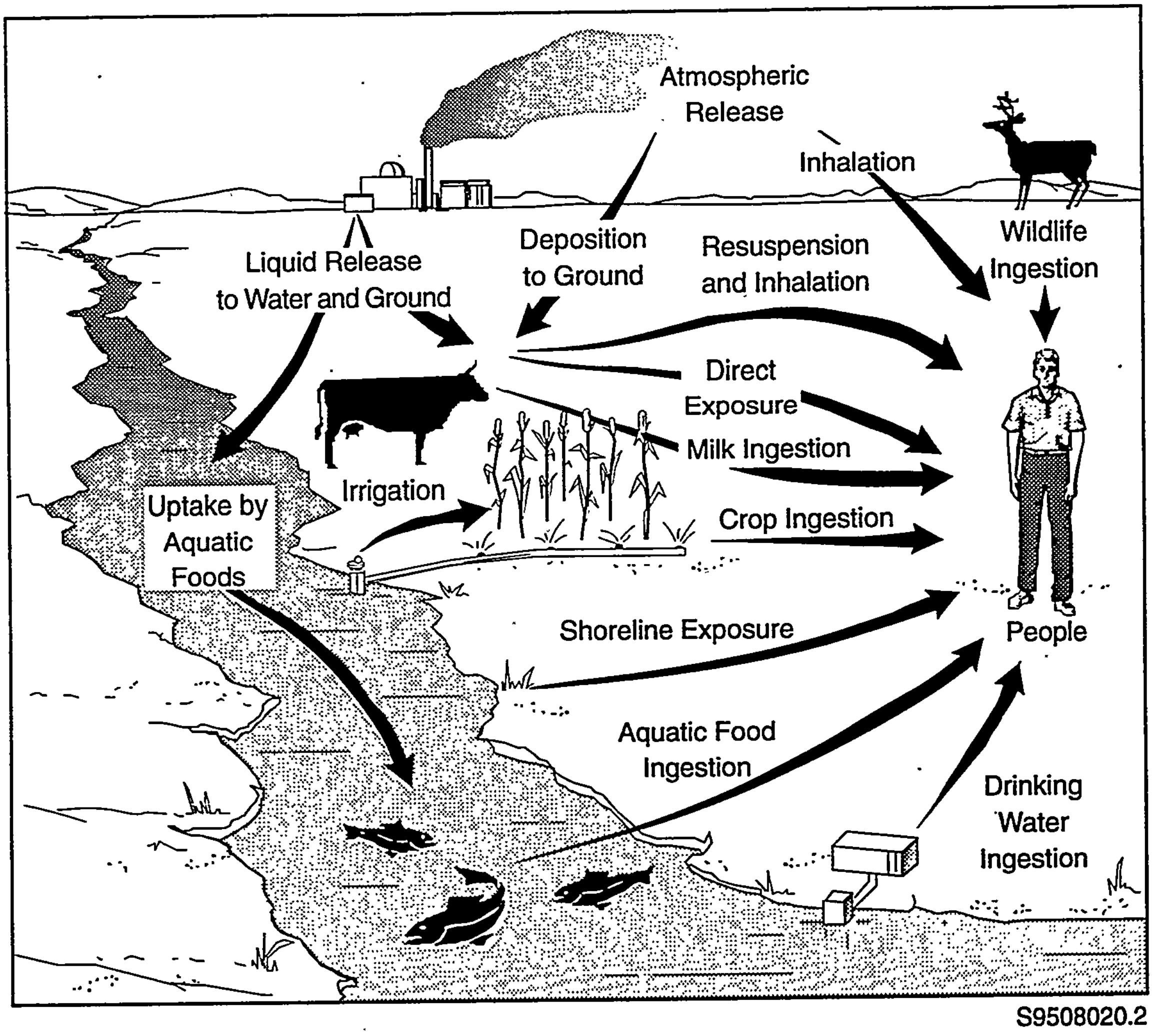

Figure 2.2. Exposure Pathways to Humans

Columbia River before reaching wells located in the city of Richland. Therefore, the residential consumption of contaminated groundwater is not currently a viable route of exposure to the public and was not included in this chemical pathway analysis. However, groundwater transport to other viable exposure media (i.e., surfacewater) was included in this analysis.

2.5 Summary of Current and Past Environmental Monitoring

Currently, the SESP monitors for nonradiological chemicals only in surfacewater, sediments, and air. The project does not routinely monitor for nonradiological chemicals in farm products, wildlife, soil, and vegetation. However, special studies conducted in the past focused on nonradiological analytes and exposure media. A description of current SESP sample collection and analysis is provided in Bisping (1995). The results of routine monitoring, sampling, collection, and results can be found in the *Hanford Site Environmental Report* for the calendar year of interest (e.g., Dirkes et al. 1994). It should be noted that the scope of routine monitoring may vary from year to year. Listings of all nonradiological analytes routinely monitored for by media and analytes monitored for during special studies are provided in Appendix A (Tables A.1 and A.2).

2.5.1 Air

The SESP monitors for nonradiological chemicals in ambient air onsite, but does not monitor offsite ambient air levels. Offsite (nonradiological) ambient air is not monitored at this time because onsite levels are not appreciably high and Hanford Site contamination would be expected to decrease with distance from the source. Results of monitoring by ten air samplers on the Hanford Site and analyzed for volatile organic compounds (e.g., halogenated alkanes and alkenes, benzene, and alkylbenzenes) during 1994 are provided in Dirkes and Hanf (1995). In summary, all measured volatile organic compounds in 1994 were well below occupational maximum allowable concentrations (Dirkes and Hanf 1995). A special SESP report (Patton et al. 1994) provides information on ambient air concentrations at the Hanford Site and concludes that levels were similar to background ambient air levels.

2.5.2 Surfacewater

Currently, the SESP monitors offsite surfacewater and sediments from various locations along the Columbia River: at Priest Rapids Dam, Hanford Reach, Richland Pumphouse, and McNary Dam (Dirkes and Hanf 1995). In 1994, Columbia River sampling for metals and anions were generally similar both upstream and downstream of the Hanford Site and were in compliance with applicable primary drinking water standards (Dirkes and Hanf 1995). Volatile organic compounds were generally less than analytical detection levels. Also, samples were collected in 1994 from seven Columbia River shoreline springs. The shoreline springs represent the primary route of Hanford Site-derived contaminants released to the river. There is no significant overland flow of water from the Hanford Site to the Columbia River and air deposition is not a significant mechanism of transport to the river. Therefore, transportation of contaminants via riverbank springs or groundwater intrusion (upwelling) would be the most sensitive indicator of Hanford Site-derived impacts on the Columbia River. The 1994 monitoring results showed that chromium and nitrate in the 100-D Area spring were the only nonradiological contaminants measured in riverbank springs that exceeded drinking water standards (Dirkes and Hanf 1995).

A special study (Dirkes 1990) reported the results of analyses for over 250 nonradiological constituents in riverbank springs along the Hanford/Columbia River boundary (see Appendix A). The results from that special study are discussed by Dirkes (1990) and indicate that nonradiological contaminants were generally undetectable in the spring water. Columbia River contaminant concentrations, outside the immediate mixing zone (spring/river mixing zone), were well below established drinking water standards.

Sediment-monitoring results in 1994 for metals (and other inorganics) along the Hanford Reach and at McNary Dam were not significantly different from those at the background location at Priest Rapids

Dam, with the exception of chromium. Chromium concentrations in sediments along the Hanford Reach appeared to be slightly elevated when compared to Priest Rapids and McNary dams (Dirkes and Hanf 1995).

A special study was conducted by Blanton et al. (1995) for metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, grain size, total organic carbon content, and radionuclides in sediments from established SESP routine sediment-sampling locations (Priest Rapids Dam, Hanford Reach, and McNary Dam). The Blanton et al. (1995) study reported that concentrations of polycyclic aromatic hydrocarbons were very low for all samples and that no polychlorinated biphenyls were noted above the minimum detection level in any sample. The highest concentrations of metals in sediments were generally found at McNary Dam monitoring sites, followed by those at Priest Rapids Dam, with no metal concentrations above the severe-effect-level guideline developed by the Ontario Ministry of the Environment (Bennett and Cubbage 1991). There are no current U.S. Environmental Protection Agency-approved freshwater sediment water-quality standards available for comparison.

2.5.3 Wildlife Monitoring

Very limited nonradiological wildlife-monitoring data have been collected by the SESP in the recent past (1988 to present). In 1993, metals analyses were performed on several deer samples collected in the 200 areas and from a limited number of pigeons. The monitoring results are provided in Dirkes et al. (1994). The metals results were reported as low; however, because of the limited sample size, no definitive conclusion could be drawn in terms of overall Hanford Site deer or pigeon population health or relative metals concentrations.

2.6 Identified Chemicals of Concern

Prior to the completion of this SESP chemical pathway analysis, a draft report by Napier et al. (1995) was issued as a part of the Columbia River Comprehensive Impact Assessment (CRCIA) that identified chemicals of concern for the Columbia River. The CRCIA-identified chemicals of concern are considered preliminary--the issued report is in a first draft; a final report is in progress. The purpose of the CRCIA report was to "...determine if enough contamination exists in the Columbia River to warrant cleanup actions under applicable environmental regulations" (Napier et al. 1995). In the CRCIA report, a risk-based screening analysis was performed to identify substances occurring on the Hanford Site in quantities that could pose a significant threat to human or ecological health. In meeting the objectives of both SESP and CRCIA studies, two different lists of chemicals of concern were generated that met each project's objectives. However, because the two reports have somewhat different lists of chemicals of concern, a discussion of these differences is provided in Chapter 5.0 of this report.

2.7 Analysis Tool for Chemical Pathway Analysis

The chemical pathway analysis is based on output from the MEPAS code (Droppo et al. 1993). MEPAS is a physics-based, multimedia transport- and risk-computation code that is used to assess human-health impacts from actual and potential releases of both hazardous chemicals and radioactive materials. (Multimedia refers to multiple environmental transport and exposure media.) The MEPAS code follows U.S. Department of Energy/U.S. Environmental Protection Agency/U.S. Nuclear Regulatory Commission risk-assessment guidance as it evaluates the release of contaminants into the environment; their movement through and transfer between various environmental media (i.e., surfacewater, subsurface [vadose and saturated zones], overland [surface soil], and atmospheric); exposure to surrounding sensitive receptors via inhalation, ingestion, dermal contact, and external dose; and risk from carcinogens and hazard from noncarcinogens. By design, MEPAS is a comprehensive hazard-assessment tool that provides risk assessments that meet or exceed requirements for the remedial investigation/feasibility studies required by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. Additional information on MEPAS and its application can be obtained from Droppo et al. (1989, 1993), Buck et al. (1991, 1995), and Whelen et al. (1995).

MEPAS takes the nontraditional approach of integrating all major exposure pathways into a single public-health computational tool. MEPAS employs an integrated approach that couples source, contaminant release, migration, and fate for environmental media (groundwater, surfacewater, air) with exposure routes (inhalation, ingestion, dermal contact, external dose) and risk/health consequences for radiological and nonradiological carcinogens and noncarcinogens (Figure 2.3).

The MEPAS code is made up of seven calculation modules: source-term emission, overland-flow transport, vadose-zone transport, groundwater transport, surfacewater transport, air transport, and risk-estimate computation. The MEPAS source-term-emission module computes contaminant-loss rates for overland flow, suspension, volatilization, and infiltration. The soil-suspension rate is based on wind speed, roughness, and soil type, along with other parameters. This module also computes the infiltration rate, evapotranspiration, and overland water volume for the source, given local climatic data.

The overland-flow-transport module is based on precipitation that is in excess of infiltration and evapotranspiration. This excess then runs off the site, carrying contaminated soil with it. Overland-flow transport is computed using a modification to the Universal Soil Loss Equation (Whelan et al. 1992).

The vadose-zone-transport module computes the contaminant flux rates to the underlying layers using a one-dimensional advective-dispersive equation for contaminant movement. The solutions to the advective-dispersive equation are computed using an analytical approach, but when the results of one layer are combined with the next layer, a numerical integration is used.

The groundwater-transport module uses a one-dimensional advective/three-dimensional dispersive equation for computing the concentrations at a given receptor well. Like the vadose-zone-transport module, the solution for the saturated zone is analytical, but a numerical integration is used to combine it with the contaminant flux rates from the vadose-zone-transport module.

The surfacewater-transport module computes the concentration at a given river receptor using the contaminant flux from either the overland-flow-transport or the groundwater-transport modules. This module uses river-flow velocities, discharge rates, and dimensions to compute mixing and dilution of the concentration from the point of entrance to the river to the receptor location.

The air-transport module computes the concentration in the area encompassed by a 75-km radius (however, the module is not limited to this distance). This module uses terrain, joint frequency, and

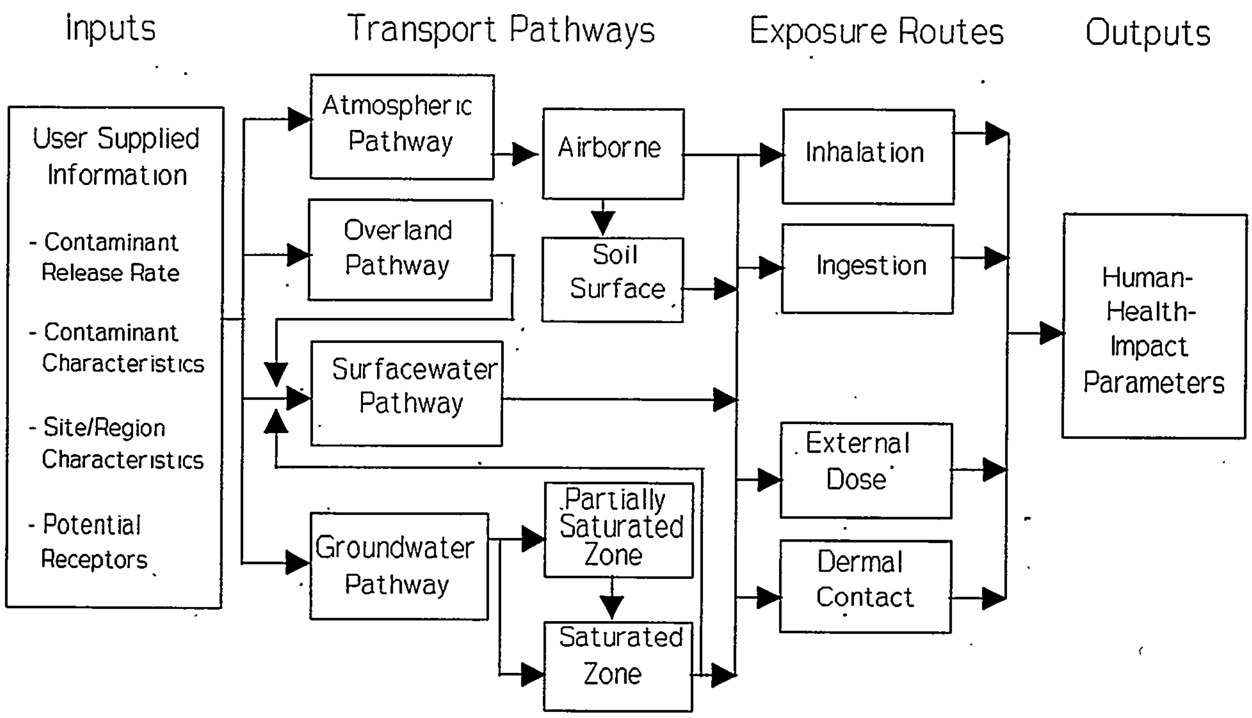

Figure 2.3. MEPAS Overall Structure

climatic parameters to compute the Gaussian-distributed concentration in the 75-km radius. This module also computes the deposition of these contaminants in the same area.

The risk-estimate-computation module calculates risk for exposure at the daily exposure rate using cancer-risk estimates of the National Academy of Sciences (1972, 1980, 1988) and EPA (1989). Hazard quotients are computed for noncarcinogenic chemicals. This module also uses a chemical properties database that contains the cancer-potency factors, reference doses, and slope factors required by this module.

Throughout its development and subsequent application, Pacific Northwest Laboratory subjected the methodology to thorough external evaluation. Extensive review by the scientific community fostered and confirmed the validity and usability of MEPAS (Whelan et al. 1988; Buck et al. 1989; EPA 1988; Intera 1992).

3.0 Approach

This chapter describes the methods and materials used in this chemical pathway analysis. The first tasks of the chemical pathway analysis were to identify what chemicals should be examined (i.e., chemicals of concern) and to obtain suitable source-term data regarding these chemicals. After accomplishment of these tasks, the fate and transport of these chemicals to various offsite receptors were modeled using the MEPAS code. The estimated human-health impact from offsite exposure to selected chemicals of concern was also calculated using MEPAS. Exposure scenarios used in calculating offsite risk were adopted from U.S. Environmental Protection Agency risk-assessment guidance (EPA 1989). A bounding-type chemical pathway analysis was performed, wherein the fate, transport, and human-health risk was not only estimated using the maximum onsite source-term data reported for the Hanford Site but a retrospective analysis was performed, wherein the model was used to predict onsite chemical concentrations in the soil necessary to obtain an offsite risk of 1.0E-06 cancer incidence or a 1.0 hazard index at various offsite receptors. A diagram depicting the conceptual design of this chemical pathway analysis is provided in Figure 3.1.

3.1 Development of Source-Term Information and Selection of Chemicals of Concern

This SESP chemical pathway analysis is based on source-term data reported in the literature through February 1, 1994. At the time this pathway analysis was initiated, information concerning source-term concentrations and geographic distribution of chemicals (nonradiological) at the Hanford Site was very limited. The historical information concerning concentrations and volumes of nonradiological contaminants used and disposed at the Hanford Site was also incomplete. No reference document or electronic database existed that encompass the scope of nonradiological contamination occurring at the Hanford Site. Process information (as described in Section 2.2) and purchase order records were useful in developing "laundry" lists of chemicals used onsite but did not provide information as to the concentration of chemicals occurring on the site.

A listing of onsite chemicals was found in Klem (1990). Other documents that provided similar listings included Riley et al. (1992) and Fowler et al. (1993); however, they do not provide area-specific chemical concentrations (i.e., source-term data).

A list of the chemicals of concern was compiled, based on review of literature and electronic databases providing information on past and current chemical releases, inventories, and known sources of environmental contamination occurring at the Hanford Site. A list of the chemicals of concern for the Hanford Site was developed, based on human-health risk assessments performed as part of the onsite characterization of OUs located in the 100, 200, 300, and 1100 areas and on professional judgment when onsite residential or industrial worker exposure scenarios and human-health-risk assessment information was not available. The primary sources of information on source-term data used in this chemical pathway analysis come from limited field investigation (LFI) study reports, qualitative risk-assessment (QRA) study reports, remedial investigation/feasibility study (RI/FS) reports, and aggregate area management study reports. The risk assessments reported for individual OUs (i.e., LFIs, QRAs) are very conservative and utilize the maximum groundwater and soil

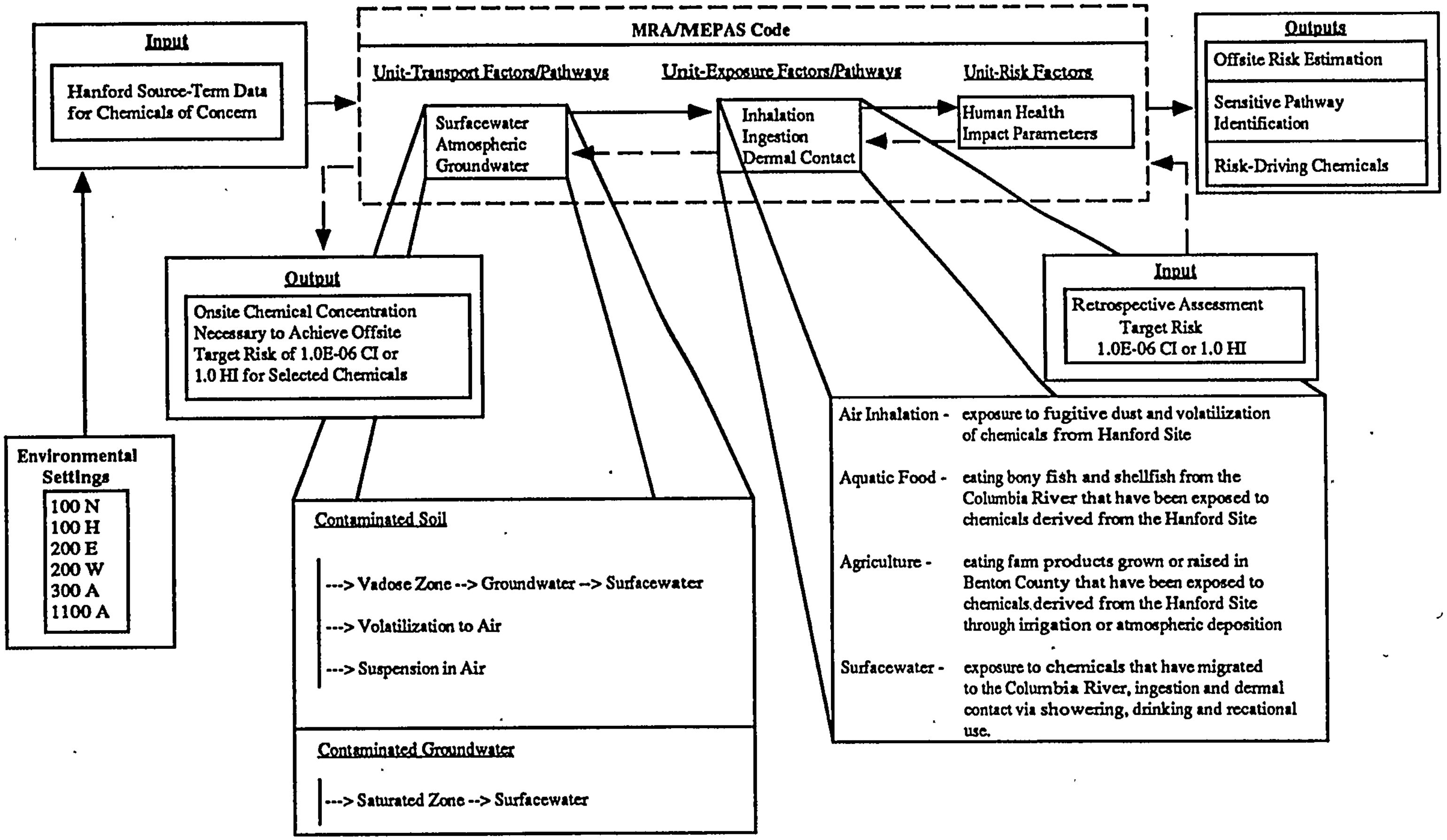

Figure 3.1. Conceptual Design of Chemical Pathway Analysis

concentrations encountered during field investigations, regardless of the depth at which the concentration occurred. This conservative approach was also incorporated into this analysis (i.e., maximum soil and groundwater concentrations encountered were used). Descriptions of the reports mentioned above are found in Napier et al. (1995). Also, the CRCIA project developed a compendium of data on Columbia River contamination (Eslinger et al. 1994).

A chemical was placed on the SESP list of chemicals of concern if it had a 1.0E-06 cancer incidence or a 1.0 hazard index or greater health risk from onsite-exposure estimates reported in the literature as described above. The selection criterion chosen was based on the following assumption: a chemical detected onsite and not posing a significant health risk from a residential-use onsite-exposure scenario would not pose a significant human-health risk to offsite receptors because concentrations of the chemical would be reduced during transport offsite. When selecting chemical source-term data for the 200 areas, special allowances were made because of a lack of suitable data and insufficient onsite risk assessment information. For the 200 areas, only suspect chemicals that had source-term data available were chosen, based on degree of toxicity and professional judgment.

3.2 Chemical Pathway Analysis

Many of the models and methodologies used during this chemical pathway analysis were based on similar technologies developed for the Programmatic Environmental Impact Statement (PEIS) (Short and Smith 1995), the Hanford Remedial Action Environmental Impact Statement (HRAEIS) (Whelan et al. 1995), and the Nevada Test Site (Gelston et al. 1995) during development of the baseline environmental management report (DOE 1995a). In particular, the models and methods used during this chemical pathway analysis were based on methods and results from the PEIS and HRAEIS studies. Both studies used the modular risk-analysis (MRA) methodology and the MEPAS code. The MRA methodology is described in several Pacific Northwest National Laboratory reports, including Strenge and Chamberlain (1994), Whelan et al. (1994, 1995), and Gelston et al. (1995), and is depicted in Figure 3.1.

One of the key assumptions in the MRA methodology is that it assumes the conditions of linearity exist within the modeled system, in that output results are linear to the input (i.e., when the input doubles [e.g., contaminant concentration in a given medium], the output doubles as well [e.g., concentration of risk]). Sensitivity analyses were conducted for the different source types and environmental settings to develop these linearities.

The MRA methodology calls for the development of unit-transport factors, unit-exposure factors, and unit-risk factors, all of which are developed with the aid of the MEPAS code. The elegance of the MRA approach is that by assuming the conditions of linearity, the assessment can be divided into compartments that can be implemented concurrently or independently. Although such flexibility was not necessary for the success of this analysis, it allows this SESP chemical pathway analysis to be a living document, in that source-term data can be updated as new information becomes available without having to redo the entire chemical pathway analysis. In fact, many of the unit-transport, unit-exposure, and unit-risk factors developed for the PEIS and the HRAEIS were utilized during this analysis. In addition, the work performed during this analysis and for future monitoring efforts will provide valuable information back to the PEIS and HRAEIS studies, which can also be viewed as living documents.

The following is a further explanation of the unit factors.

- unit-transport factor--The unit-transport factor is the environmental fate and transport component of the MRA. The unit-transport factor is the product of the unit mass (i.e., 1 g) of a contaminant that is transported through various (appropriate) media to the exposure medium (surfacewater, groundwater, soil, or air). The unit-transport factor is represented as the environmental concentration per unit mass of contaminant (i.e., [g/g]/g) (Gelston et al. 1995; Whelan et al. 1995).

- unit-exposure factor--The unit-exposure factor represents the exposure medium and pathways connected with the unit contaminant environmental concentration (Strenge and Chamberlain 1994). The unit-exposure factor is the product of a given environmental concentration at a receptor (unit mass [1 g] per unit quantity of medium [m^2, m^3, L, kg]), the exposure pathways (ingestion rate, inhalation rate, or exposure duration), and associated health-impact factors (reference dose factor, slope factor, etc.). The units are risk or hazard index per unit medium concentration (risk/[g/g], hazard index/[g/g]) (Gelston et al. 1995).

- unit-risk factors--A unit-risk factor is the product of the two appropriate unit-transport factors and unit-exposure factors. To estimate the risk from a contaminant at a given receptor, the appropriate unit-risk factor is multiplied by the source inventory (Gelston et al. 1995). The unit-risk factor analysis is intended to provide a quantitative estimate of health impacts per unit concentration of contaminant in a given medium. The health impact at the receptor for carcinogenic chemicals is the lifetime cancer incidence from intake received during a defined exposure duration. For noncarcinogenic chemicals, the health impact was estimated, based on the calculated hazard index, which is the ratio of the daily intake of the reference dose (evaluated for inhalation and ingestion routes).

In summary, assuming the conditions of linearity, environmental concentrations are linearly proportional to the strength (i.e., concentration) of the waste at the source (i.e., Hanford Site). Similarly, subsequent exposure, dose, and risk calculations are then dependent on the strength of the waste at the source and calculations can be performed under unit environmental conditions described above (Whelan et al. 1994). Figure 3.1 illustrated where the MRA method fits into the overall approach used in this chemical pathway analysis. Appendix B provides information on the mathematical calculations associated with the linearity assumption.

3.3 Input Parameters, Scenarios, and Assumptions

Many of the environmental input parameters (i.e., environmental setting, uptake factors, transport coefficients, etc.) used in the MEPAS code to generate the unit-transport factors and unit-exposure factors for the PEIS (Short and Smith 1995) were considered to be appropriate for use in this chemical pathway analysis. The following subsections provide information on the input parameters, scenarios, and assumptions incorporated into this chemical pathway analysis.

3.3.1 Bounding Hanford Site Source-Term Data and Offsite Risk Estimates

A bounding-type chemical pathway analysis was performed. Model-predicted chemical fate, transport, exposure, and relative risks were obtained using maximum source-term data concentrations for the Hanford Site. In addition to this traditional type of assessment, where effects are predicted from environmental media concentrations, a retrospective chemical pathway analysis was also performed, wherein human-health-impact parameters (i.e., cancer incidence or hazard index) are held constant and model-predicted environmental media concentrations are determined. This type of approach allows for effective comparisons to be made between Hanford Site-derived source-term data versus targeted human-health-impact parameters.

This approach will help place Hanford Site model-predicted results into perspective and aid in prioritizing and ranking the chemicals of concern, the media, or the exposure pathways to be monitored. The retrospective pathway analysis will also provide a benchmark against which field-monitoring data can be compared to determine the relative environmental consequences likely imposed for a given medium concentration.

3.3.2 Waste Site Dimensions

The dimensions of waste sites used in this analysis (i.e., 100, 200 areas, etc.) was 100 x 100 x 10 ft (length by width by height). However, during the development of the MRA methodology for the PEIS, it was demonstrated that the dimensions of the waste site modeled did not influence the offsite receptor (temporally far field) concentrations. Therefore, the dimensions of the waste site modeled could have been larger or smaller and the concentrations at the receptor would have been the same. The important factor to be considered was the source-term concentration of the chemical.

3.3.3 Environmental Settings

Environmental setting information consists of site-specific data (i.e., properties of the partially saturated zone, climatological data, longitudinal and transverse dispersivity, etc.) required as input into the MEPAS code to model contaminant transport through multimedia (atmospheric, surfacewater, and groundwater). Five different environmental settings for the Hanford Site were used in this chemical pathway analysis to model contaminant transport: 100-H, 100-N, 200 East, 200 West, and 300 areas (Figure 3.2). The environmental setting data used in this SESP chemical pathway analysis is described in detail in Schramke et al. (1994).

3.3.4 Transport Pathways, Receptor Locations, and Exposure Pathways

Onsite source-term information obtained from the data review provided concentrations for contaminated soil and groundwater. During this analysis, the transport of chemicals of concern from onsite contaminated soil and groundwater were modeled to various offsite receptors using the transport pathways shown in Figure 3.3.

Chemicals that were found occurring in both media (soil and groundwater) were modeled using all the pathways; otherwise, only the representative pathway was modeled. Because of the limited rainfall, the geologic conditions occurring at the Hanford Site, and the relative distance from onsite sources to offsite exposure-point receptors, the potential pathway of overland flow to surfacewater was not evaluated.

The transport pathways identified above were used in conjunction with the offsite-receptor-exposure pathways given in Figure 3.4.

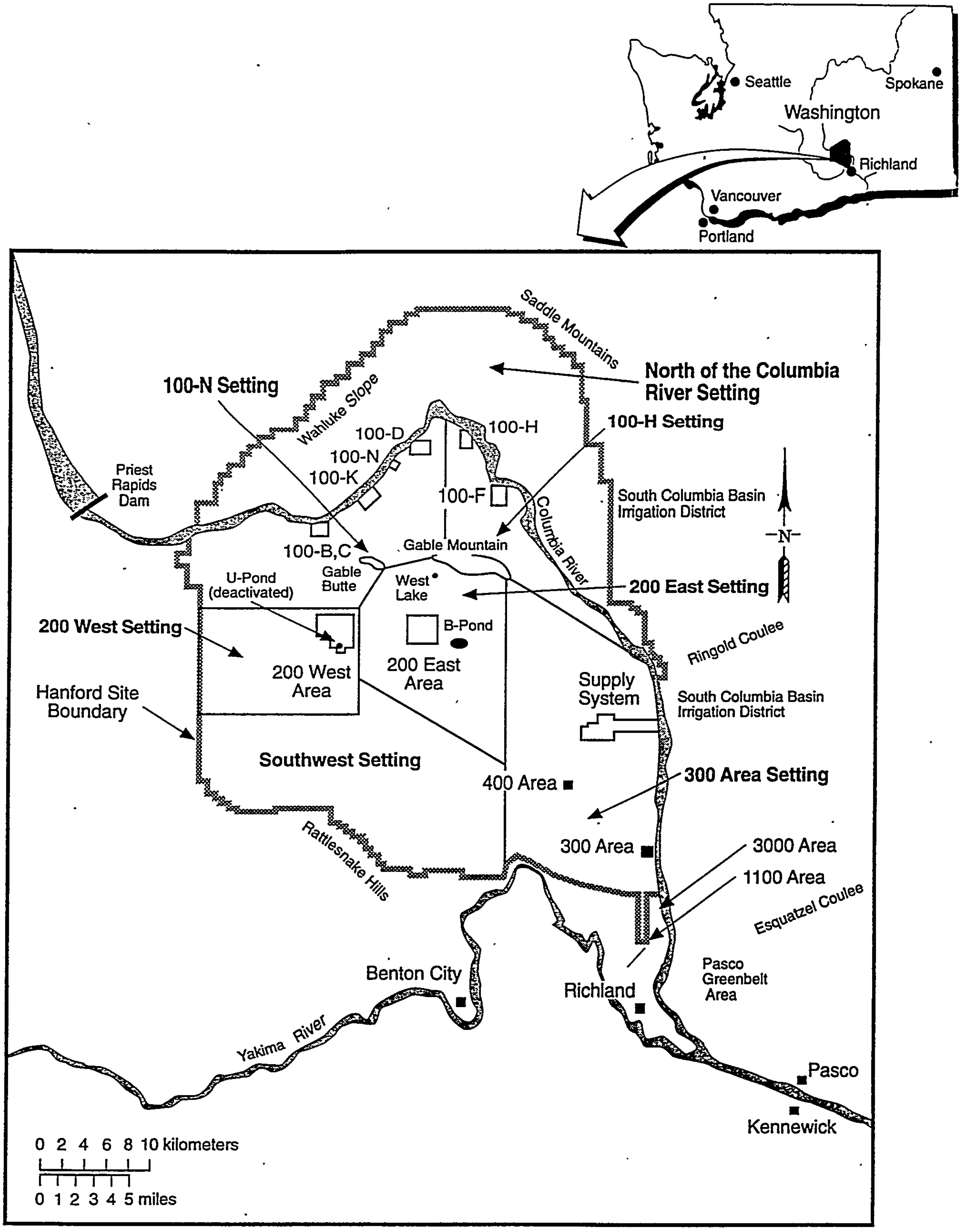

Figure 3.2. Map of the Hanford Site Showing Setting Boundaries for Which MEPAS Input Data were Developed (modified from Newcomer et al. 1992)

Hanford Site Contaminated Media -->	*Transport Pathway --> -->*	*Receptor Exposure Media*
Contaminated Soil -->	Vadose Zone --> -->	Groundwater Well
Contaminated Soil -->	Vadose Zone --> Groundwater --> -->	Surfacewater
Contaminated Soil --> -->	Volatilization to Air --> -->	Air
Contaminated Soil --> -->	Suspension in Air --> -->	Air
Saturated Zone --> -->	Groundwater Well --> -->	Groundwater Well
Saturated Zone --> -->	Surfacewater --> -->	River

Figure 3.3. Illustrated Contaminant Transport Pathways

Exposure Media -->	*Exposure Routes and Scenarios*
Air/Surface Soil -->	Inhalation and Soil Ingestion
Air/Surface Soil -->	Crops --> Ingestion
Air/Surface Soil -->	Crops --> Animals --> Ingestion
Surfacewater -->	Ingestion
Surfacewater -->	Fish/Shellfish --> Ingestion
Surfacewater -->	Irrigation --> Crops --> Ingestion
Surfacewater -->	Animals --> Ingestion
Surfacewater -->	Bathing --> Ingestion
Surfacewater -->	Recreation --> External Exposure
Surfacewater -->	Recreation --> Ingestion

Figure 3.4. Offsite-Receptor Exposure Pathways and Scenarios (Droppo et al. 1989)

The receptor locations are representative of 1) surfacewater at the Richland Pumphouse (surfacewater- and aquatic-food-consumption-exposure pathways), 2) ambient air concentrations occurring at the city of Richland (atmospheric pathway), and 3) agricultural products grown in Benton County (agriculture pathway).

3.3.5 Exposure Scenarios

The exposure scenarios used in this chemical pathway analysis are modeled after those reported in EPA (1989) and those developed in Strenge and Chamberlain (1994) and the DOE (1995b). This SESP chemical pathway analysis used a combination of residential, agricultural, and recreational exposure scenarios developed for Whelen et al. (1995). Specific numerical calculations, assumptions, and full descriptions of exposure scenarios used for the pathways are described in Strenge and Chamberlain (1994).

The MEPAS code (using the MRA methodology) was used to model the transport of chemicals of concern from the 100, 200, 300, and 1100 areas to offsite receptor points. The transport of these chemicals offsite was modeled and human-health risks were generated from the predicted offsite concentrations.

Criteria used to evaluate human-health risks included calculations of cancer incidence and hazard index for the maximally exposed individual. The maximally exposed individual represents a hypothetical individual who is exposed to all available exposure pathways for extended periods of time, and represents a very conservative estimation of human-health risk. The risk values reported in this chemical pathway analysis are for the maximally exposed individual.

4.0 Results

4.1 Hanford Site Chemicals of Concern and Source-Term Data

During the data review performed for this chemical pathway analysis, a listing of the chemicals of concern and their maximum onsite chemical concentrations were found (Table 4.1). This information was used as source-term data in the MEPAS code to model offsite chemical transport and to estimate human-health effects. Provided in Appendix C is a listing of chemicals of concern, waste-disposal sites, reported chemical concentrations, and referenced data sources. The chemical concentrations listed in Appendix C met the screening criteria used in selecting the chemicals of concern (i.e., posed at least a 1.0E-06 cancer incidence or a 1.0 hazard index from various onsite exposure scenarios).

Table 4.1. List of Chemicals of Concern and Maximum Onsite Concentrations

	Maximum Concentration in Soil (mg/kg)				Maximum Concentration in Groundwater (mg/L)			
	100 Areas	200 Areas	300 Area	1100 Area	100 Areas	200 Areas	300 Area	1100 Area
Ammonia	(a)	(a)	(a)	(a)	0.75	(a)	(a)	(a)
Arsenic	47	(a)	23.3	(a)	0.01	(a)	(a)	(a)
Benzo(a)pyrene	0.81	(a)	27	(a)	(a)	(a)	(a)	(a)
Beryllium	4.7	(a)	3.3	(a)	(a)	(a)	(a)	(a)
Bis(2-ethylhexyl)phthalate	(a)	(a)	(a)	25,046	0.011	(a)	(a)	(a)
Carbon tetrachloride	(a)	52.27	(a)	(a)	(a)	7	(a)	(a)
Chloroform	(a)	(a)	(a)	(a)	0.053	1	(a)	(a)
Chromium	610	(a)	960	(a)	2.09	(a)	(a)	(a)
Chrysene	(a)	(a)	43	(a)	(a)	(a)	(a)	(a)
Fluoride	(a)	(a)	(a)	(a)	1.3	(a)	(a)	(a)
Manganese	(a)	(a)	(a)	(a)	0.18	(a)	(a)	(a)
Nitrate	(a)	1136.36	(a)	(a)	170	450	(a)	(a)
Nitric acid	(a)	128.97	(a)	(a)	(a)	(a)	(a)	(a)
PCBs	0.13	(a)	19.5	65.29	(a)	(a)	(a)	(a)
Sodium	(a)	1420.45	(a)	(a)	(a)	(a)	(a)	(a)
Trichloroethylene	(a)	(a)	0.39	(a)	0.019	(a)	(a)	(a)
(1,1,1,2)Tetrachloroethane	(a)	(a)	1.1	(a)	(a)	(a)	(a)	(a)

(a) Not detected or below risk-screening level.

This analysis found the most useful source-term data to come from the LFI reports, QRAs, and RI/FS reports. However, many of the onsite OUs have not had LFIs performed. For example, no LFIs were completed for any of the OUs in the 200 areas at the time this analysis was initiated. There was no suitable risk information available for the 200 areas; therefore, the chosen chemicals of concern were based on professional judgment and availability of suitable source-term data.

A listing of chemicals used during the retrospective risk assessment are given in Table 4.2. The retrospective risk assessment is a backcalculation of chemical concentrations required in onsite soil to achieve target human-health risk for a given individual chemical of 1.0E-06 cancer incidence or 1.0 hazard index for noncarcinogenic chemicals at various offsite receptors. The list of chemicals provided in Table 4.2 is much broader in coverage than the list of identified chemicals of concern in Table 4.1 and is intended to place additional conservatism into this chemical pathway analysis by including chemicals that were not identified as chemicals of concern but considered to be detected frequently on the site. The selection of chemicals provided in Table 4.2 was based on observations made during the data literature review and on professional judgment and is intended to be representative of the types of chemicals often encountered in the 100, 200, and 300 areas.

Since the completion of this analysis, two reports were published that compiled and summarized much of the nonradiological (and radiological) chemical contamination source-term data available for the Hanford Site: the environmental restoration disposal facility report (DOE 1994) and the CRCIA report (Napier et al. 1995). The list of chemicals of concern and maximum onsite chemical concentrations provided in Napier et al. (1995) is provided in Appendix D. The maximum onsite chemical concentrations and site locations described in DOE (1994) are provided in Appendix E. The

Table 4.2. List of Chemicals Included in the Retrospective Pathway Analysis

Antimony
Aroclor 1248 (a polychlorinated biphenyl)
Arsenic
Asbestos
Barium
Benzo(a)pyrene
Beryllium
Bis(2-ethylhexyl)phthalate
Cadmium
Carbon tetrachloride
Chlordane
Chloroform
Chromium
Chrysene
Copper
Cyanide
Fluoride
Lead
Manganese
Mercury
Methylene chloride
Nickel
Nitrate
Pentachlorophenol
Selenium
Silver
Sulfate
(1,1,1,2)Tetrachloroethane
Thallium
Toluene
Tributyl phosphate
Trichloroethylene
Vanadium
Vinyl chloride
Xylenes

Napier et al. (1995) report provides an excellent summary of available chemical source-term data that were used in this analysis. Some of the information used to generate the list of chemicals of concern in the CRCIA (Napier et al. 1995) report was obtained from the research done for this SESP chemical pathway analysis; therefore, summary descriptions of referenced data sources from Napier et al. (1995) are given herein.

4.2 Identification of Sensitive Media Pathways and Offsite Human-Health Risks

One of the identified chemicals of concern (sodium) was unable to be modeled because of the lack of information required by the MEPAS code (i.e., input parameters, etc.) at the time this analysis was initiated. Therefore, sodium was not included in offsite human-health-risk estimations.

The total offsite human-health risk, along with the contributions from each chemical by exposure pathway, is provided in Tables 4.3 and 4.4 for cancer incidence and hazard index, respectively. The estimated overall human-health risk to the maximally exposed individual is 2.09E-10 cancer incidence

Table 4.3. Offsite Excess Cancer Incidence to Maximally Exposed Individual (expressed by chemical and pathway). The total offsite risk posed from all pathways summed together is also provided for individual chemicals and summation of all chemical inputs contribution.

Chemical	Air Exposure	Aquatic Foods	Agriculture	Surfacewater	Cancer Incidence
Arsenic	3.30E-17	6.04E-11	1.22E-11	1.03E-10	1.76E-10
Benzo(a)pyrene	3.86E-16	0.00E+00	2.30E-17	0.00E+00	4.09E-16
Beryllium	8.66E-18	0.00E+00	8.81E-19	0.00E+00	9.54E-18
Bis(2-ethylhexyl)phthalate	6.93E-16	6.91E-15	1.31E-11	1.24E-14	1.31E-11
Carbon tetrachloride	1.97E-19	1.19E-11	2.19E-13	8.37E-12	2.05E-11
Chloroform	(a)	1.38E-17	3.40E-17	2.31E-16	2.79E-16
Chromium(VI)	3.27E-15	(b)	(b)	(b)	3.27E-15
Chrysene	6.15E-16	0.00E+00	2.62E-17	0.00E+00	6.42E-16
Polychlorinated biphenyl (Aroclor 1260)	1.78E-16	0.00E+00	7.46E-17	0.00E+00	2.53E-16
Trichloroethylene	8.50E-21	4.17E-15	2.43E-15	1.07E-13	1.14E-13
(1,1,1,2)Tetrachloroethane	1.90E-22	(b)	(b)	1.34E-14	1.34E-14
Total Offsite Risk	5.19E-15	7.24E-11	2.55E-11	1.11E-10	**2.09E-10**

(a) The source-term data used for this chemical occurred in the groundwater only; thus, this chemical would not be exposed to the receptor through this pathway.

(b) This chemical is not classified as a carcinogen through this pathway.

Bolded value represents the total offsite cancer incidence risk to the maximally exposed individual from exposure to all viable contaminants of concern.

A hypothetical groundwater pathway was investigated and found to be below the U.S. Environmental Protection Agency action level of 1.0E-06 and is not reported here because it is not a viable pathway. See text for clarification.

Contaminants of concern that are not listed in this table are not considered to be carcinogens; therefore, they appear in Table 4.4.

Table 4.4. Offsite Excess Hazard Index to the Maximally Exposed Individual (expressed by chemical and pathway). The hazard quotient (summed hazard index values) is also provided for individual chemical and pathway and for the total of all pathways combined.

Chemical	Air Exposure	Aquatic Foods	Agriculture	Surfacewater	Hazard Index
Ammonia	(a)	0.00E+00	1.38E-12	2.08E-11	2.22E-11
Chromium(VI)	1.04E-08	5.79E-05	9.58E-06	8.05E-05	1.48E-04
Fluoride	(a)	7.32E-13	6.09E-12	2.27E-11	2.95E-11
Iron	0.00E+00	7.79E-11	2.46E-12	2.41E-12	8.28E-11
Manganese	(a)	2.69E-10	3.35E-11	1.04E-10	4.07E-10
Nitrate	2.29E-18	1.46E-05	1.32E-07	3.72E-09	1.48E-05
Nitric acid	1.19E-17	7.57E-05	6.61E-07	1.87E-08	7.63E-05
(1,1,1,2)Tetrachloroethane	1.06E-13	2.43E-07	1.54E-08	5.08E-07	7.66E-07
Hazard Quotient	1.04E-08	1.48E-04	1.04E-05	8.10E-05	**2.40E-04**

(a) The source-term data used for this chemical occurred in the groundwater only; thus, this chemical would not be exposed to the receptor through this pathway.

Bolded value represents the total offsite hazard index to the maximally exposed individual from exposure to all viable contaminants of concern.

A hypothetical groundwater pathway was investigated and found to be below the U.S. Environmental Protection Agency action level of 1.0E-06 and is not reported here because it is not a viable pathway. See discussion in text for clarification.

Contaminants of concern that are not listed in this table are not considered to be carcinogens; therefore, they appear in Table 4.3.

and 2.40E-04 hazard index. The "overall human health risk" is the sum of each individual chemical risk (i.e., the sum of all individual chemicals of concern risk estimates). The conservative estimate of offsite cancer incidence obtained for the maximally exposed individual (2.09E-10) is four orders of magnitude below the most conservative U.S. Environmental Protection Agency action level of 1E-06.

The 2.40E-04 hazard index is four orders of magnitude below the conservative U.S. Environmental Protection Agency action level of 1.0. Arsenic was the largest contributor to the cancer incidence value (84%), followed by carbon tetrachloride (10%) and bis(2-ethylhexyl)phthalate (6%). These three chemicals made up over 99% of the cancer risk to the maximally exposed individual. The surface-water-exposure pathway was found to be the most sensitive pathway for cancer incidence and contributed over 53% of the calculated risk to the maximally exposed individual. The next most sensitive pathway was aquatic food consumption, which contributed approximately 34%. Together, the surface-water- and aquatic-food-consumption-exposure pathways contributed over 87% of the cancer incidence risk to the maximally exposed individual.

The largest percent contributor to the hazard index value was chromium (assumed to be chromium[VI]), which accounted for 62% of the hazard index total, followed by nitric acid (32%) and nitrate (6%). The most sensitive pathway for noncarcinogenic chemicals was from aquatic food consumption, which contributed 61.8% to the hazard index. The second most-sensitive exposure pathway was surfacewater, which contributed approximately 33%. Together, these two pathways accounted for approximately 95% of the hazard index risk total. As previously stated, research indicated that groundwater is not a viable exposure pathway; therefore, the groundwater-exposure pathway was not included in the estimation of the total cancer incidence and hazard index offsite risk.

4.2.1 Retrospective Chemical Pathway Analysis Results

Retrospective modeling results showed that only three of the identified chemicals of concern (arsenic, bis[2-ethylhexyl]phthalate, and chloroform) could occur in soil concentrations high enough on the site to cause an offsite health risk of 1.0E-06 cancer incidence or a 1.0 hazard index for a given receptor/exposure pathway (i.e., exposure to the chemical alone without summing any other chemicals or pathways) (Table 4.5). When the chemicals provided in Table 4.2 were analyzed, only vinyl chloride and thallium were theoretically capable of occurring in soil concentration quantities that could reach the targeted health-risk criterion of 1.0E-06 cancer incidence or 1.0 hazard index (in addition to the chemicals of concern previously identified). The small number of chemicals for which it was theoretically possible to reach the U.S. Environmental Protection Agency risk-action level required that exceedingly high concentrations be present (see Table 4.5).

Table 4.5. Results of Retrospective Chemical Pathway Analysis

	Onsite Soil Concentration Required to Achieve a 1.0E-06 Cancer Incidence		
	Aquatic Foods (mg/kg)	Agricultural (mg/kg)	Surfacewater (mg/kg)
Arsenic	2.18E+02	8.47E+02	1.01E+02
Bis(2-ethylhexyl)phthalate	(a)	8.40E+02	8.87E+05
Chloroform	(a)	(a)	5.18E+05
Vinyl chloride	5.24E+05	(a)	5.76E+04
	Onsite Soil Concentration Required to Achieve a 1.0 Hazard Index		
	Aquatic Foods (mg/kg)	Agricultural (mg/kg)	Surfacewater (mg/kg)
Chromium(VI)	4.68E+04	2.83E+05	3.36E+04
Thallium	1.34E+04	(b)	(b)

(a) Unable to achieve onsite concentration to reach target risk value of 1.0E-06 cancer incidence through this exposure pathway.
(b) Unable to achieve onsite concentration to reach target risk value of 1.0 hazard index through this exposure pathway.

5.0 Discussion

The results of this chemical pathway analysis suggest that chemical contaminants known to occur on the Hanford Site do not currently pose a significant offsite human-health risk. The results from the retrospective analysis also suggest that soil concentrations necessary onsite to elicit an offsite human-health risk for a given pathway are very large and the current maximum onsite soil concentrations found during the literature search do not approach these levels (see Tables 4.1 and 4.2). For many of the identified chemicals of concern, we demonstrated that the chemical could not occur in concentrations high enough in onsite soil to reach concentrations required to achieve the target health-risk value of 1.0E-06 cancer incidence and 1.0 hazard index. When selecting chemical source-term data for the 200 areas, special allowances were required because of a lack of suitable data and insufficient onsite human-health-risk-assessment information. For the 200 areas, only suspect chemicals that had source-term data available were chosen, based on degree of toxicity and professional judgment. Furthermore, sodium was identified as a chemical of concern during this analysis but was not included in the offsite human-health-risk estimates because of a lack of sufficient data required by the MEPAS code.

Of the contaminants of concern, arsenic was the primary risk driver for carcinogenic health effects (contributing 84% to the risk value). It is somewhat surprising that results indicate arsenic as the primary risk driver because arsenic was not a major chemical constituent used during Hanford Site production (see Chapter 2.0). The most likely source of Hanford Site arsenic released to the environment comes from coal fly ash, a byproduct from the use of coal-fired power generators used in the 100 areas. It may also be possible that natural concentrations of arsenic in the soil from this region are abnormally high. Another possible source of arsenic contamination to the environment may be from past agricultural practices that utilized arsenic-based pesticides. However, very little information is available on the extent of arsenic contamination occurring on the Hanford Site. A definitive answer to the extent and primary sources of arsenic contamination cannot be provided at this time because of the lack of sufficient information.

Chromium was the primary risk driver for noncarcinogenic health effects (contributing 62% to the risk value). As identified in Chapter 2.0, sodium dichromate and chromic acid were heavily used during Hanford Site production, and environmental releases of this material occurred (and to some extent are still occurring today) through groundwater discharge to the Columbia River along the Hanford Reach. Historical use of these materials during production in the 100 and 200 areas may be contributing to the source of environmental chromium contamination.

It was very clear from the analysis that the most sensitive exposure pathway was from surfacewater and aquatic food consumption, contributing 87% and 95% of the risk value for cancer incidence and hazard index, respectively.

Results of the retrospective analysis demonstrated that only three (arsenic, bis[2-ethylhexyl]phthalate, and chloroform) of the identified chemicals of concern could occur in onsite soil concentrations high enough to reach the target human-health-risk parameters of 1.0E-6 cancer incidence or 1.0 hazard index for a given individual pathway of exposure (i.e., no summing of multiple pathways or multiple risks from different chemicals). There were three pathways of exposure that could possibly reach the target health-risk value: surfacewater, aquatic foods, and agricultural exposure pathways, with the surfacewater pathway dominating.

Approximately 20 analytes that were not identified as chemicals of concern were also examined during the retrospective analysis (see Table 4.2). Of these, only two (vinyl chloride and thallium) were potentially capable of attaining concentrations necessary to reach the targeted human-health-risk parameters.

The U.S. Environmental Protection Agency-established (EPA 1989) carcinogenic and noncarcinogenic screening benchmarks for SESP-identified chemicals of concern are provided in Appendix F. The risk-based concentrations are provided for various media (i.e., tapwater, ambient air, fish, and soil) and are based on the 1.0E-06 cancer incidence or 1.0 hazard index. The information presented in Appendix F, Table F.1 will aid the reader in screening the SESP-monitoring results to determine if concentrations present in any given medium are such that they may pose a human-health risk (i.e., if the monitored concentration is above the established benchmark, then the carcinogenic/noncarcinogenic health risk exceeds 1.0E-06 or 1.0 from exposure to the measured medium).

5.1 SESP Environmental Monitoring

Provided in Appendix A is a list (see Table A.1) of chemicals of concern identified by this analysis compared to analytes currently monitored by the SESP and to analytes that were monitored during special studies (see Table A.2). The results of SESP routine monitoring (i.e., not a special study), sampling, and collection can be found in the *Hanford Site Environmental Report* (i.e., Dirkes et al. 1994) for the calendar year of interest (monitoring scope may vary from year to year). Of the 17 identified chemicals of concern listed in Table 4.1, the SESP does not currently monitor for the following: arsenic, benzo(a)pyrene, bis(2-ethylhexyl)phthalate, chrysene. Of these chemicals, SESP monitored for all of them during one or more special studies (see Appendix A). The SESP currently (routinely) monitors for over 50 analytes in one or more media (air, water, or sediment) that were not identified as chemicals of concern during this analysis (see Appendix A).

Provided in Table 5.1 is a listing of the identified chemicals of concern, along with notations of chemicals being currently monitored for by the SESP, that have been monitored by the SESP in the recent past, and those determined from the retrospective analysis.

Of the identified chemicals of concern that SESP monitored for in 1994, only two were reported to be above background level or an established quality-control benchmark: chromium and nitrate in the 100-D Area spring were measured in concentrations above established drinking water standards (Dirkes and Hanf 1995). Also, concentrations of chromium in sediments from the Hanford Reach in 1994 were found to be slightly elevated when compared to background concentrations (Dirkes and Hanf 1995). All other identified chemicals of concern and other nonradiological chemicals currently monitored for were measured in concentrations that were either nondetectable or below established quality standards or benchmark concentrations.

Table 5.1. Identified Chemicals of Concern

	1994 Monitoring	Special Study Monitoring	Retrospective Analysis
Ammonia	*		
Antimony^	*	*	*
Aroclor 1248 (a polychlorinated biphenyl mixture)^		*	*
Arsenic^		*	*
Benzo(a)pyrene		*	*
Beryllium	*	*	*
Bis(2-ethylhexyl)phthalate		*	*
Carbon tetrachloride^	*		*
Chlordane^		*	*
Chloroform^	*	*	*
Chromium^	*	*	*
Chrysene		*	*
Copper^	*	*	*
Cyanide^		*	*
Diesel fuel^			
Fluoride^	*	*	*
Lead^		*	*
Manganese^	*	*	*
Mercury^	*	*	*
Nitrate^	*	*	*
Phosphate^	*	*	
Silver chloride^			
Sodium	*	*	
(1,1,1,2)Tetrachloroethane^	*	*	*
Trichloroethylene^	*	*	*
Zinc^	*	*	

Bolded = SESP chemical of concern.
^ = CRCIA chemical of concern.

5.2 CRCIA-Identified Chemicals of Concern

The CRCIA-identified chemicals of concern (Napier et al. 1995) (see Appendix D) are based on very conservative screening equations. It should be noted that the CRCIA-identified chemicals of concern are considered preliminary--the issued report is a first draft; a final report is in progress. Of the CRCIA-identified chemicals of concern, 10 were not identified as chemicals of concern by this analysis: antimony, chlordane, copper, cyanide, diesel fuel, lead, mercury, phosphate, silver chloride, and zinc. Two (cyanide and trichloroethylene) were chosen, based on "continued public interest" and were not selected, based on scientific screening analysis. Of the CRCIA-identified chemicals of concern, only three were screened out, based on potential carcinogenic effects: arochlor 1248 (a polychlorinated biphenyl), arsenic, and chromium. All other chemicals were screened out, based on either exceeding the hazard index criteria, ambient water-quality criteria, or potential toxic effects to aquatic organisms. The SESP does not currently monitor for six of the CRCIA-identified chemicals of concern: arsenic, chlordane, cyanide, diesel fuel, lead, mercury, and silver chloride.

Differences in chemicals of concern identified by this analysis and those by the CRCIA are primarily attributed to one factor--the SESP study did not evaluate the potential for adverse ecological effects (i.e., toxic effects to plants and animals). Chemicals of concern chosen for this chemical pathway analysis were based solely on potential adverse effects to humans. However, it should be noted this is an area that was identified by the SESP that may warrant further investigation.

6.0 Conclusions

The fundamental question--what chemicals and media warrant monitoring--is addressed by the SESP each year through an established surveillance design-review process. The results of this chemical pathway analysis, in addition to the information from historical monitoring efforts, will aid in answering the question and the prioritization of the chemicals and media to be monitored. This chemical pathway analysis report is preliminary and is not intended to be an exhaustive examination of the current offsite human-health risks resulting from nonradiological chemical contamination occurring on the Hanford Site.

A comparison of monitoring data with the pathway and retrospective analysis results indicate that nonradiological chemical contamination occurring onsite does not currently pose a significant human-health risk. However, investigation of nonradiological chemical contamination effects to the ecosystem, either onsite or offsite, was not part of this chemical pathway analysis. Therefore, no inference can be made on the nonradiological effects to the ecosystem (i.e., flora and/or fauna).

The chemical pathway analysis results indicated that the two primary exposure pathways contributing the most to offsite human-health risk are surfacewater and aquatic food consumption.

Arsenic was identified as the primary risk driver for carcinogenic effects and chromium was identified as the primary risk driver for noncarcinogenic effects.

The following five chemicals were identified as nonradiological chemicals of concern during this analysis that are not currently being monitored for by the SESP: arsenic, benzo(a)pyrene, bis(2-ethylhexyl)phthalate, and chrysene. In addition, the following five chemicals were identified by the CRCIA, also not monitored for by the SESP: chlordane, cyanide, diesel fuel, lead, and silver chloride. Results from the retrospective analysis demonstrated that it was possible for only three (arsenic, bis[2-ethylhexyl]phthalate, and chloroform) of the identified chemicals of concern could actually occur in onsite soil at concentrations high enough to cause a 1.0E-06 excess cancer incidence or a 1.0 hazard index for a given offsite pathway of exposure. During the retrospective analysis, 21 other chemicals were also evaluated; of those, only vinyl chloride and thallium could occur in concentrations high enough to reach the targeted offsite human health risk target values.

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Appendix A

Nonradiological Analytes and Media Monitored

Table A.1. Routine Monitoring of Nonradiological Analytes

Sampling Media	Surfacewater	Air (Onsite)	Sediment
Ions			
Ammonia	*		
Bromide	*		
Chloride	*		
Cyanide ion			
Ethyl cyanide	*		
Fluoride	*		
Nitric acid			
Nitrate	*		
Nitrite	*		
Phosphate	*		
Sulfate	*		
General Chemistry			
Alkalinity	*		
Bicarbonate (as HCO3)	*		
Carbonate (as CO3)	*		
Coliform (fecal)	*		
Dissolved oxygen	*		
Hardness	*		
PH	*		
Solids residue	*		
Specific conductance	*		
Streptococci (fecal)	*		
Temperature	*		
Turbidity	*		
Metals			
Aluminum	*		*
Antimony	*		
Arsenic			
Barium	*		*
Beryllium	*		*
Cadmium	*		*
Calcium	*		*
Chromium	*		*
Cobalt	*		*
Copper	*		*
Iron	*		*
Lead			
Magnesium	*		*

Table A.1. (contd)

Sampling Media	Surfacewater	Air (Onsite)	Sediment
Metals (contd)			
Manganese	*		*
Mercury	*		
Nickel	*		*
Potassium	*		*
Selenium			
Silver	*		
Sodium	*		*
Thallium			
Tin	*		
Vanadium	*		*
Zinc	*		*
Semivolatile Organics			
1,4-Dichlorobenzene	*	*	
Acenaphthene			
Acenaphthylene			
Anthracene			
Aroclor 1242		*	
Aroclor 1248		*	
Aroclor 1254		*	
Aroclor 1260		*	
Benz(a)anthracene			
Benzo(a)pyrene			
Benzo(b)fluoranthene			
Benzo(g,h,i)perylene			
Benzo(k)fluoranthene			
Bis(2-ethylhexyl)phthalate			
Chrysene			
Dibenz(a,h)anthracene			
Fluoranthene			
Fluorene			
Indeno[1,2,3c,d]pyrene			
Naphthalene			
Pentachlorophenol			
Phenanthrene			
Pyrene			
Tributylphosphate			
Volatile Organics			
1,1,1-Trichloroethane	*	*	
1,1,2-Trichloroethane	*	*	

Table A.1. (contd)

Sampling Media	Surfacewater	Air (Onsite)	Sediment
Volatile Organics (contd)			
1,1-Dichloroethane	*	*	
1,2-Dichloroethane	*	*	
1,2-Dichloroethylene	*	*	
1-Butanol	*		
2-Butanone	*		
Acetone	*		
Benzene	*	*	
Carbon disulfide	*		
Carbon tetrachloride	*	*	
Chloroform	*	*	
cis-1,3,-dichloropropene		*	
Dichlorodifluoromethane		*	
Dichloromethane	*	*	
Hexone	*		
m,p-xylene		*	
o-xylene		*	
1,1,1,2-Tetrachloroethane	*		
Tetrahydrofuran	*		
Toluene	*	*	
trans-1,3-dichloropropene		*	
Trichloroethylene	*	*	
Trichlorofluoromethane		*	
Trichloromethane		*	
Trichlorotrifluoroethane		*	
Vinyl chloride	*		
Xylenes (total)	*		
Miscellaneous			
Asbestos			

Bold = SESP chemical of concern.

Table A.2. Special Studies of Nonradiological Analytes

	Special Shoreline Springs Study(a)	Special Sediment Study(b)	Special Trace Metal Analysis Study(c)
Metals			
Arsenic	*	*	*
Beryllium	*	*	*
Strontium	*		
Zinc	*	*	*
Calcium	*		
Barium	*	*	
Cadmium	*	*	*
Chromium	*	*	*
Silver	*		*
Sodium	*		
Nickel	*	*	*
Copper	*	*	*
Vanadium	*		
Antimony	*		*
Aluminum	*		
Manganese	*	*	
Potassium	*		
Iron	*		
Magnesium	*		
Mercury	*	*	*
Lead	*	*	*
Selenium	*		*
Thallium	*		*
Enhanced Thiourea			
Thiourea	*		
1-acetyl-2-Thiourea	*		
1-(0-chlorophenyl)-Thiourea	*		
Diethylstilbestrol	*		
Ethylenethiourea	*		
1-naphthyl-2-Thiourea	*		
N-Phenylthiourea	*		
Enhanced Pesticides			
Endrin	*	*	
Endrin aldehyde		*	
Methoxychlor	*		
Toxaphene	*	*	

Table A.2. (contd)

	Special Shoreline Springs Study$^{(a)}$	Special Sediment Study$^{(b)}$	Special Trace Metal Analysis Study$^{(c)}$
Enhanced Pesticides (contd)			
Alpha BHC	*	*	
Beta BHC	*	*	
Gamma BHC	*		
Delta BHC	*	*	
4,4-DDD	*	*	
4,4-DDE	*	*	
4,4-DDT	*	*	
Heptachlor		*	
benHeptachlor	*		
Heptachlor epoxide	*	*	
Dieldrin	*	*	
Aldrin	*	*	
Chlordane	*	*	
Endosulfan I	*	*	
Endosulfan II	*	*	
Endosulfan sulfate		*	
Chlorobenzilate	*		
DBC	*		
Lindane		*	
Volatile Organic Compounds			
Tetrachloromethane	*		
Benzene	*		
Dioxane	*		
Methylethyl ketone	*		
Pyridine	*		
Toluene	*		
1,1,1-Trichloroethane	*		
1,1,2-Trichloroethane	*		
1,1,2-Trichloroethene	*		
Perchloroethylene	*		
Xylene (o, P)	*		
Xylene (M)	*		
Methyl bromide	*		
Carbon disulfide	*		
Chlorobenzene	*		
2-Chloroethyl vinyl ether	*		

Table A.2. (contd)

	Special Shoreline Springs Study[(a)]	Special Sediment Study[(b)]	Special Trace Metal Analysis Study[(c)]
Volatile Organic Compounds (contd)			
Chloroform	*		
Chloromethane	*		
1,1-Dichloroethane	*		
1,2-Dichloroethane	*		
trans-1,2-Dichloroethene	*		
1,1-Dichloroethene	*		
Methylene chloride	*		
1,2-Dichloropropane	*		
1,3-Dichloropropenes	*		
1,1,2,2-Tetrachloroethane	*		
Bromoform	*		
Vinyl chloride	*		
Hexone	*		
Acrolein	*		
Acrylonitrile	*		
bis(Chloromethyl)ether	*		
Bromo acetone	*		
Chloromethylmethylether	*		
Crotonaldehyde	*		
1,2-dibromo-3-Chloropropane	*		
1,2-Dibromomethane	*		
Dibromomethane	*		
1,4-dichloro-2-Butene	*		
Dchlorodifluoromethane	*		
N,N-Diethylhydrazine	*		
Hydrogen sulfide	*		
Iodo methane	*		
Methacrylonitrile	*		
Methanethiol	*		
Pentachloroethane	*		
1,1,1,2-Tetrachloroethane	*		
Trichloromethanethiol	*		
Trichlorofluoromethane	*		
Trichloropropane	*		
1,2,3-Trichloropropane	*		
Diethylarsine	*		

Table A.2. (contd)

	Special Shoreline Springs Study[a]	Special Sediment Study[b]	Special Trace Metal Analysis Study[c]
Volatile Organic Compounds (contd)			
Formaldehyde	*		
Methyl methacrylate	*		
Ethyl methacrylate	*		
Acetonitrile	*		
Ethylene oxide	*		
Phenanthrene		*	
Semivolatile Organic Compounds			
Acenaphthene		*	
Acenaphthylene		*	
Analine	*		
Anthracene		*	
Benzo(a)anthracene	*	*	
Benzidine	*		
Benzo(b)fluoranthene	*	*	
bis(2-Chloroethoxy)methane	*		
bis(2-Chloroethyl)ether	*		
bis(2-Ethylhexyl)phthalate	*		
4-Bromophenyl phenyl ether	*		
Butylbenzylphthalate	*		
P-Chloroaniline	*		
P-chloro M-Cresol	*		
2-Chloronapthalene	*		
2-Chlorophenol	*		
Chrysene	*	*	
Dibenzo(a, h)anthracene	*	*	
di-n-butyl phthalate	*		
1,2-Dichlorobenzene	*		
1,3-Dichlorobenzene	*		
1,4-Dichlorobenzene	*		
3,3'-Dichlorobenzidine	*		
2,4-Dichlorophenol	*		
Diethyl phthalate	*		
2,4-Dimethylphenol	*		
Dimethyl phthalate	*		
4,6-dinitro-0-Cresol	*		
2,4-Dinitrotoluene	*		

Table A.2. (contd)

	Special Shoreline Springs Study[a]	Special Sediment Study[b]	Special Trace Metal Analysis Study[c]
Semivolatile Organic Compounds (contd)			
2,6-Dinitrotoluene	*		
di-n-octyl phthalate	*		
1,2-Diphenylhydrazine	*		
Fluoranthene	*	*	
Hexachlorobenzene	*		
Hexachlorobutadiene	*		
Hexachlorocyclopentadiene	*		
Hexachloroethane	*		
indeno(1,2,3-cd)Pyrene	*	*	
Hexachlorophene	*		
Naphthalene	*	*	
Nitrobenzene	*		
N-Nitrosodimethylamin	*		
Phenol	*		
Pyrene		*	
1,2,4-Trichlorobenzene	*		
2,4-Dinitrophenol	*		
4-Nitrophenol	*		
para-Nitroaniline	*		
Pentachlorophenol	*		
2,4,5-Trichlorophenol	*		
2,4,6-Trichlorophenol	*		
1,2,3-Trichlorobenzene	*		
1,3,5-Trichlorobenzene	*		
1,2,4,5-Tetrachlorobenzene	*		
1,2,3,4-Tetrachlorobenzene	*		
1,2,3,5-Tetrachlorobenzene	*		
Pentachlorobenzene	*		
Cresols	*		
N-Nitrosodinpropylamine	*		
Benzo(a)pyrene	*	*	
bis(2-Chloroisopropyl)ether	*		
Tributylphosphate	*		
Acetophenone	*		
Warfarin	*		
2-Acetylaminofluorene	*		

Table A.2. (contd)

	Special Shoreline Springs Study[a]	Special Sediment Study[b]	Special Trace Metal Analysis Study[c]
Semivolatile Organic Compounds (contd)			
4-Aminobiphenyl	*		
5-(aminomethyl)-3-Isoxazolol	*		
Amitrole	*		
Aramite	*		
Amine	*		
Benz(c)acridine	*		
Benzene, Dichloromethyl	*		
Benzemethoil	*		
P-Benzoquinone	*		
Benzyl Chloride	*		
2-Sec-Butyl-4,6-Dinitrophenol	*		
Chloroalkyl ethers	*		
1-chloro-2,3-Epoxypropane	*		
2-cyclohexyl-4,6-Dinitrophenol	*		
Dibenzo(a,h)acridine	*		
Dibenzo(a,j)acridine	*		
7H-Dibenzo(c,g)carbazole	*		
Dibenzo(a,e)pyrene	*		
Dibenzo(a,h)pyrene	*		
Dibenzo(a,i)pyrene	*		
2,6-Dichlorophenol	*		
Dihydrosafrole	*		
3,3'-Dimethoxybenzidine	*		
P-Dimethylaminoazobenzene	*		
7,12-Dimethylbenz(a)anthracene	*		
3,3'-Dimethylbenzidine	*		
Thiofanox	*		
Alpha, Alpha-Dimethylphenethylamine	*		
Dinitrobenzene	*		
Diphenylamine	*		
Ethyleneimine	*		
Ethyl methanesulfonate	*		
Fluorene		*	
Isosafrole	*		
Malononitrile	*		
Malphalan	*		

Table A.2. (contd)

	Special Shoreline Springs Study[(a)]	Special Sediment Study[(b)]	Special Trace Metal Analysis Study[(c)]
Semivolatile Organic Compounds (contd)			
Mathapyrilene	*		
Matholonyl	*		
2-Methylaziridine	*		
3-Methylchloroanthrene	*		
4,4-'-Methylenebis (2-Chloroaniline)	*		
2-Methyllactonitrile	*		
Methyl methanesufonate	*		
2-Methyl-2 (Methylthio) Propionaldehyde-0-(Methylcarbonyl) Oxime	*		
Methylthiouracil	*		
1,4-Naphthoquinone	*		
1-Napthylamine	*		
2-Napthylamine	*		
N-Nitrosodi-N-butylamine	*		
N-Nitrosodiethanolamine	*		
N-Nitrsodiethylamine	*		
N-Nitrosomethylethylamine	*		
N-Nitroso-N-methylurethane	*		
N-Nitrosomethylvinylamine	*		
N-Nitrosomoropholine	*		
N-Nitrosonornicotine	*		
N-Nitrosonopiperidine	*		
Nitrosopyrrolidine	*		
5-Nitro-0-Toluidine	*		
Pentachloronitrobenzene	*		
Phenacetin	*		
Phenylenediamine	*		
Phthalic acid esters	*		
2-Picoline	*		
Pronamide	*		
Reserpine	*		
Rescorzinol	*		
Safrol	*		
2,3,4,6-Tetrachlorophenol	*		
Thiuram	*		

Table A.2. (contd)

	Special Shoreline Springs Study[a]	Special Sediment Study[b]	Special Trace Metal Analysis Study[c]
Semivolatile Organic Compounds (contd)			
Toluenediamine	*		
0-Toluidine Hydrachloride	*		
0,0,0-Triethyl Phosphorothioate	*		
sym-Trinitrobenzene	*		
tris (2,3-Dibromopropyl)-Phosphate	*		
Chloronaphazine	*		
Hexachloropropene	*		
Kerosene	*		
Maleic hydrazide	*		
Nicotinic acid	*		
Strychnine	*		
Benzo(j)fluoranthene	*		
Benzo(g,h,i)perylene		*	
Benzo(k)fluoranthene		*	
Phosphorus Pesticides			
Tetraethylpyrophosphate	*		
Carbophenothion	*		
Disulfoton	*		
Dimethoate	*		
Methylparathion	*		
Ethyl Parathion	*		
Direct Aqueous Injection Analysis			
Hydrazine	*		
Paraldehyde	*		
Acrylamide	*		
Allyl Alcohol	*		
Chloroacetaldehyde	*		
3-Chloropropionirile	*		
Ethyl carbamate	*		
Ethyl cyanide	*		
Isobutyl alcohol	*		
N-Propylamine	*		
2-Propyn-1-0L	*		
Enhanced Herbicides			
2,4-D	*		
2(2,4,5-T) P	*		

Table A.2. (contd)

	Special Shoreline Springs Study(a)	Special Sediment Study(b)	Special Trace Metal Analysis Study(c)
Enhanced Herbicides (contd)			
(2,4,5-T)	*		
PCB Analysis			
Aroclor 1016	*		
Aroclor 1221	*		
Aroclor 1232	*		
Aroclor 1242	*	*	
Aroclor 1248	*	*	
Aroclor 1254	*	*	
Aroclor 1260	*	*	
TOC (Total Organic Carbon)	*		
TC (total carbon)	*		
TOX (total organic halogen)	*		
IC Report			
Nitrate	*		
Sulphate	*		
Fluoride	*		
Chloride	*		
Phosphate	*		
Other			
Cyanide	*		
Perchlorate	*		
Sulfide	*		
Ammonium ion	*		
Ethylene glycol	*		
Citrus red	*		

Bold = SESP chemical of concern.

(a) From Dirkes, R. L. 1990. *1988 Hanford Riverbank Springs Characterization Report*. PNL-7500, Pacific Northwest Laboratory, Richland, Washington.

(b) From 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.

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

Appendix B

Calculations for Linearity Assumption

Appendix B

Calculations for Linearity Assumption

Source-term area, mass, and concentration represent the important parameters driving the linearity associated with the Modular Risk Analysis (MRA) at Hanford. The importance of these parameters stems from the following assumptions of the assessment:

- Contaminant movement through the subsurface environment for all non-standing-water waste sites (e.g., contaminated soils) is mainly driven by precipitation, resulting in deep-drainage percolation.

- For those sites that do not contain concentration information, the source-term concentration (i.e., total concentration) will be determined from the mass reported for the waste site divided by the total volume identified for the waste site:

$$C_T = \frac{M}{V_T} = \frac{M}{A\,T} \tag{2}$$

where C_T is the total concentration (mass per total volume), M is the mass or inventory of the constituent, V_T is the total volume of contamination at the site, A is the area of contamination, and T is the thickness of the contamination. C_T is used to calculate the dissolved concentration as follows:

$$C_o = \frac{C_T}{\theta + \beta_d K_d} \tag{3}$$

where C_o is the dissolved concentration, θ is the moisture content, β_d is the bulk density, and K_d is the distribution (partition or equilibrium) coefficient for the chemical of concern.

- The contaminant mass flux from the waste site is assumed to be equal to the water mass flux times the dissolved contaminant concentration:

$$Q_c = C_o\,Q \tag{4}$$

where Q_c is the contaminant mass flux and Q is the water volumetric flux rate, defined as

$$Q = i\ A \tag{5}$$

where i is the deep drainage-percolation rate (i.e., infiltration rate, Darcy velocity, or volumetric water discharge per unit area).

Based on Equations (2) through (4), the contaminant mass flux from the waste site can be calculated as follows:

$$Q_c = \frac{M\ i}{T\ (\theta + \beta_d\ K_d)} \tag{6}$$

Based on inspection of Equation (6), the contaminant mass flux and, hence, the receptor concentration and risk for a given contaminant appear to be proportional and solely based on the mass at the waste site, assuming the same geologic setting. The mass flux will only have an impact on the receptor concentration as long as the concentration is below some limiting amount (e.g., C_o).

Although the area appears to have no impact on the resulting receptor concentrations, its effects appear in the solution to the advective-dispersive equation:

$$\frac{\partial C}{\partial t} + u_p^* \frac{\partial C}{\partial x} = D_x^* \frac{\partial^2 C}{\partial x^2} + D_y^* \frac{\partial^2 C}{\partial y^2} + D_z^* \frac{\partial^2 C}{\partial z^2} - \lambda C. \tag{7}$$

The instantaneous solution of the advective-dispersive equation for an area source in a saturated zone is as follows:

$$Ci = \delta\ X\ Y\ Z \qquad \text{where } X \equiv \text{flow direction} \tag{8}$$

in which

$$\delta = M\ /\ (R_f\ \eta_e) \tag{9}$$

$$X = \left[\frac{1}{2\ L}\right] \exp(-\lambda\ t) \left\{ \text{erf}\left[\frac{x + \frac{L}{2} - u_p^*\ t}{(4\ D_x^*\ t)^{0.5}}\right] - \text{erf}\left[\frac{x - \frac{L}{2} - u_p^*\ t}{(4\ D_x^*\ t)^{0.5}}\right] \right\} \tag{10}$$

$$Y = \left[\frac{1}{2\,W}\right] \left[\mathrm{erf}\left[\frac{y + \frac{W}{2}}{(4\,D_y^*\,t)^{0.5}}\right] - \mathrm{erf}\left[\frac{y - \frac{W}{2}}{(4\,D_y^*\,t)^{0.5}}\right] \right] \tag{11}$$

$$Z = \left[\frac{1}{H}\right] \left\{ 1 + 2 \sum_{n=1}^{\infty} \left[\exp\left[-\frac{n^2\,\pi^2\,D_z^*\,t}{H^2}\right] \cos\left[\frac{n\,\pi\,z}{H}\right] \right] \right\} \tag{12}$$

$$R_f = 1 + \frac{\beta_d\,K_d}{\eta_e} \tag{13}$$

$$D^* = \frac{D + 190\ \mathrm{cm}^2/\mathrm{yr}}{R_f} \tag{14}$$

$$D = \alpha\,u_p \tag{15}$$

$$u^* = u_p / R_f \tag{16}$$

$$v_d = u_p\,\eta_e \tag{17}$$

$$A = L\,W \tag{18}$$

where Ci is the instantaneous concentration solution to the advective-dispersive equation; δ is a mass-related constant; X, Y, and Z are Green's functions in the x, y, and z directions, respectively; R_f is the retardation factor; η_e is the effective porosity; L is the length of the waste site in the groundwater flow direction; λ is the first-order degradation/decay constant; t is time; x is the travel distance; u_p^* is the pore-water contaminant velocity; D is the dispersion coefficient; W is the width of the waste site perpendicular to the groundwater flow direction; H is the aquifer thickness; v_d is the Darcy velocity; n is the index on the summation; 190 cm²/yr equals molecular diffusion; α is the dispersivity in the x, y, or z direction; A is the area of the waste site.

The contaminant mass flux from the waste site and the instantaneous concentration are combined through the convolution integral to provide the concentration at the receptor:

$$C(\tau) = \int_0^{\tau} Q_C(t)\,C_i(\tau - t)\,dt \tag{19}$$

where $C(\tau)$ is the concentration at the receptor at time τ, and τ is the limit of the integral representing the current time associated with the concentration.

By inspection, Equations (10) and (11) illustrate that length and width of the waste site play an integral part in determining the concentration at the receptor; as a result, area may become an important variable for near-field problems. Spacially, far-field problems are those for which an area source looks like a point source. Temporally, the convolution integral of far-field problems simplifies to the instantaneous-concentration solution as presented in Equation (8).

From Whelan, G., J. W. Buck, K. J. Castleton, J. P. McDonald, C. Sato, G. M. Gelston, A. deHamer, R. J. Serne, S. K. Wurstner, and R. N. Kickert. 1995. "3.0 Calculations for Linearity." *Unit Environmental Transport Assessment of Contaminants from Hanford's Past-Practice Waste Sites, Hanford Remedial Action Environmental Impact Statement.* PNL-10233, Pacific Northwest Laboratory, Richland, Washington.

Appendix C

Source-Term Data

Appendix C

Source-Term Data

This appendix provides source-term data and waste-site locations found in the literature for all chemicals having a 1.0E-06 cancer incidence or a 1.0 hazard index or greater. Source-term data for the 200 areas are not based on the above risk-based criteria. The maximum chemical value for a given chemical in the 100, 200, 300, and 1100 areas was used as the source-term data input to the Multimedia Environmental Pollutant Assessment System (MEPAS) code.

Table C.1. Source-Term Data and Waste-Site Locations

Area	Operable Unit	Waste Site	Media	Chemical of Concern	Concentration	Reference
100	100-BC-5					QRA 100-BC-5, WHC-SD-EN-RA-006
		100-BC-5	gw	Bis(2-ethylhexyl)phthalate	0.011 mg/L	Table 3-1b Conc.
			gw	Trichloroethene	0.003 mg/L	Table 3-1b Conc.
	100-BC-1					QRA 100-BC-1, WHC-SD-EN-RA-003
		116-B-1	soil	Chromium VI	30 mg/kg	Table 3-1c
		116-B-3	soil	Chromium VI	45 mg/kg	Table 3-3c
			soil	Benzo(a)pyrene	0.097 mg/kg	Table 3-3c
		116-C-5	soil	Chromium VI	610 mg/kg	116-c-5
	100-DR-1					QRA 100-DR-1, WHC-SD-EN-RA-005
		108-D	soil	Benzo(a)pyrene	0.18 mg/kg	Table 3-1c
		116-D-1A/1B	soil	Chromium VI	41.6 mg/kg	Table 3-2c
		116-D-7/107-D	soil	Chromium VI	51.6 mg/kg	Table 3-7c
		116-DR-1/2	soil	Chromium VI	186 mg/kg	Table 3-8c
		116-DR-9 & 107-DR	soil	Arsenic	12.4 mg/kg	Table 3-11c
			soil	Chromium VI	73.4 mg/kg	Table 3-11c
			soil	Arochlor-1260	0.13 mg/kg	Table 3-11c
			soil	Benzo(a)pyrene	0.11 mg/kg	Table 3-11c
	100-HR-1					QRA 100-HR-1, WHC-SD-EN-RA-004
		116-H-1	soil	Arsenic	37.9 mg/kg	Table 3-1c
			soil	Benzo(a)pyrene	0.81 mg/kg	Table 3-1c

Table C.1. (contd)

Area	Operable Unit	Waste Site	Media	Chemical of Concern	Concentration	Reference
		116-H-7	soil	Arsenic	47 mg/kg	Table 3-4c
			soil	Chromium VI	28.3 mg/kg	Table 3-4c
		116-H-9	soil	Beryllium	4.7 mg/kg	Table 3-5c
			soil	Chromium VI	114 mg/kg	Table 3-5c
	100-HR-3					QRA 100-HR-3, WHC-SD-EN-RA-007
		100-D/DR	gw	Chromium VI	2.09 mg/L	Table 3-1c
			gw	Ammonia as N	0.75 mg/L	Table 3-1c
			gw	Manganese	0.186 mg/L	Table 3-1c
			gw	Nitrate as N	32.7 mg/L	Table 3-1c
		100-H	gw	Chloroform	0.053 mg/L	Table 3-2c
			gw	Nitrate as N	170 mg/L	Table 3-2c
			gw	Chromium VI	0.49 mg/L	Table 3-2c
			gw	Manganese	0.18 mg/L	Table 3-2c
			gw	Fluoride	1.3 mg/L	Table 3-2c
			gw	Ammonia as N	0.29 mg/L	Table 3-2c
		600 Area	gw	Arsenic	0.0115 mg/L	Table 3-3c
			gw	Chromium VI	0.17 mg/L	Table 3-3c
		100-D/DR Near River	gw	Chromium VI	0.443 mg/l	Table 3-4b
		100-H Near River	gw	Chromium VI	0.49 mg/L	Table 3-5b
		No Risk Calculation	**	Iron	15 mg/L	Table 3-5b
	100-KR-4					QRA 100-KR-4, WHC-SD-EN-RA-010
		Near River	gw	Chloroform	0.017 mg/L	Table 2-4a
			gw	Trichloroethene	0.019 mg/L	Table 2-4a

Table C.1. (contd)

Area	Operable Unit	Waste Site	Media	Chemical of Concern	Concentration	Reference
			gw	Arsenic	0.010 mg/L	Table 2-4c
			gw	Chromium	1.95 mg/L	Table 2-4c
			gw	Nitrate/nitrite	26.0 mg/L	Table 2-4c
200	200 Area	Cribs and Liquid Disposal Units	soil	Sodium	2500 kg/m^3	Northwest Area Environmental Restoration,
			soil	Nitrates	2000 kg/m^3	Performance Based Requirements
			soil	Phosphates	500 kg/m^3	Draft September 1993, DOE
			soil	Nitric acid	227 kg/m^3	
			soil	Carbon tetrachloride	92 kg/m^3	
		Groundwater	gw	Nitrate	450 mg/L	
			gw	Carbon tetrachloride	7000 μg/L	
			gw	Chloroform	1000 μg/L	
			gw	Trichloroethylene	10 μg/L	
300	300-FF-1					Phase I Remedial Investigation Report for the 300-FF-1 Operable Unit DOE/RL-92-43
		Process Trenches	soli	Beryllium	1.9 mg/kg	Table 4-15
				Chrysene	43 mg/kg	Table 4-15
				PCBs	19.5 mg/kg	Table 4-15
				Benzo(a)pyrene	27 mg/kg	Table 4-15
		South Process Pond	soil	Arsenic	23.3 mg/kg	Table 4-17
				Beryllium	3.2 mg/kg	Table 4-17
				Chromium	604 mg/kg	Table 4-17
				PCBs	14.5 mg/kg	Table 4-17

Table C.1. (contd)

Area	Operable Unit	Waste Site	Media	Chemical of Concern	Concentration	Reference
		North Process Pond	soil	Arsenic	4.3 mg/kg	Table 4-19
				Beryllium	3.3 mg/kg	Table 4-19
				Chromium	533 mg/kg	Table 4-19
				PCBs	16.3 mg/kg	Table 4-19
		Burial Ground No. 4	soil	Arsenic	7.6 mg/kg	Table 4-21
				Chromium	960 mg/kg	Table 4-21
				PCBs	2.7 mg/kg	Table 4-21
				Benzo(a)pyrene	27 mg/kg	Table 4-21
				Trichloroethene	0.39 mg/kg	Table 4-21
		Burial Ground No. 5	soil	Arsenic	5.3 mg/kg	Table 4-23
				Chromium	49.1 mg/kg	Table 4-23
				PCBs	0.468 mg/kg	Table 4-23
		North Sanitary Trench		Chromium	122 mg/kg	Table 4-25
		Filter Backwash Pond		Arsenic	12.5 mg/kg	Table 4-26
				Chromium	28.9 mg/kg	Table 4-26
				Benzo(a)pyrene	0.12 mg/kg	Table 4-26
				Chrysene	0.24 mg/kg	Table 4-26
		Ash Pits		Arsenic	5.2 mg/kg	Table 4-27
				Beryllium	1.7 mg/kg	Table 4-27
				Chrysene	0.17 mg/kg	Table 4-27

Table C.1. (contd)

Area	Operable Unit	Waste Site	Media	Chemical of Concern	Concentration	Reference
1100	1100 Area					Phase 1 Remedial Investigation Report for the Hanford Site 1100-EM-1 Operable Unit DOE/RL-90-18 Volume 1
		1100-6 Operable Subunit	soil	Bis(2-ethylhexyl)phthalate	25046 mg/kg	Table 4-13
		Pit 1 and Ephemeral Pool	soil	PCBs	4.7 mg/kg	Table 4-15
		Horn Rapids Landfill	soil	PCBs	65.29 mg/kg	Table 4-14

gw = Groundwater.

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Appendix D

CRCIA-Identified Chemicals of Concern and Identified Maximum Concentrations of Chemicals Occurring Onsite

Table D.1. List of CRCIA-Identified Contaminants of Concern[a] (From Napier et al. 1995)

In Columbia River, Groundwater,[b] Sediment, and Soil	Groundwater Plumes Away from the Columbia River[c]	Continued Public Interest
Antimony	Carbon tetrachloride	Chloroform
Aroclor 1248 (PCB)	Fluoride	Cyanide
Arsenic		Iodine-129
Cesium-134		Plutonium-239/240
Cesium-137		Technetium-99
Chlordane		Trichloroethylene
Chromium[d]		Tritium (hydrogen-3)
Cobalt-60/particles		Uranium
Copper		
Diesel fuel		
Europium-152		
Europium-154		
Lead		
Manganese		
Mercury		
Nitrate/nitrite[d]		
Phosphate		
Silver chloride		
Strontium-90		
Zinc		

(a) Direct irradiation is also identified as being of concern.

(b) Hanford groundwater within 150 meters (500 feet) of the Columbia River.

(c) Hanford groundwater farther than 150 meters (500 feet) from the Columbia River.

(d) These contaminants are also of concern in groundwater plumes away from the Columbia River but are not repeated in that list to avoid duplication.

Reference: Napier, B. A., N. C. Batishko, D. A. Heise-Craff, M. F. Jarvis, and S. F. Snyder. 1995. *Identification of Contaminants of Concern, Columbia River Comprehensive Impact Assessment*. PNL-10400 Draft, Pacific Northwest Laboratory, Richland, Washington.

Table D.2. List of Identified Maximum Concentrations of Chemicals Occurring Onsite

	Surfacewater (μg/L)	Groundwater (μg/L)		Soil (μg/kg)	Sediment (μg/kg)
Acetone	11	30	Acenaphthene	210	
Aluminum		4,810	Aluminum	26,700,000	9,350,000
Ammonia		70	Ammonia	12,800	12,000
Ammonium		1,630	Anthracene	430	
Antimony		60	Aroclor 1248 (PCB)	9,900	
Arsenic	3	17	Arsenic	47,000	75,000
Barium	48	719	Barium	672,000	120,000
Beryllium		6	Benzene	4,500	
Bis(2-ethylhexyl)phthalate		50	Benzo(G,H,I,)perylene	410	
Bismuth		(a)	Benzo(a)anthracene	940	
Boron		(a)	Benzo(a)pyrene	810	
Cadmium		31	Benzo(b)fluoranthene	890	
Calcium	35,900	302,000	Benzo(k)fluoranthene	760	
Chloride	870	122,000	Benzoic acid	1,700	
Chloroform		42	Beryllium	8,000	1,100
Chromium	22	1,950	Bis(2-ethylhexyl) phthalate	68,000	
Cobalt		8	Cadmium	1,800	2,700
Copper	22	516	Calcium	40,800,000	4,460,000
Cyanide		21	Chlordane	4,500	
1,2-Dichloroethylene		200	Chloride	1,100	
1,2-trans-Dichloroethylene		130	Chlorine	(b)	
Fluoride	150	2,080	Chromium	259,000	12,200
Hydrazine		7	Chrysene	920	
Iron	463	37,300	Cobalt	34,100	11,500
Lead		173	Copper	140,000,000	40,000
Lithium		(a)	Cyanide	1,050	
Magnesium	9,860	55,000	Dibenzofuran	130	
Manganese	23	400	Diesel fuel	2,800,000	
Mercury		9	Endrin aldehyde	3	
Methyl ethyl ketone		18	Ethyl benzene	32,000	
Methylene chloride		3,040	Fluoranthene	1,800	
Nickel	31	479	Fluorene	190	
Nitrate	480	90,000	Fluoride	4,700	
Nitrite		60,000	Fluorine	(b)	
Phosphate		3,240	Indeno(1,2,3-CD)Pyrene	520	
Potassium	2,430	11,300	Iron	33,500,000	71,000,000
Selenium		17	Kerosene	3,085,000	
Silicon		(a)	Lead	540,000	73,000
Silver		19	Lithium	(b)	

Table D.2. (contd)

	Surfacewater (μg/L)	Groundwater (μg/L)		Soil (μg/kg)	Sediment (μg/kg)
Sodium	13,800	200,000	Magnesium	11,600,000	7,600,000
Strontium		310	Manganese	839,000	578,000
Sulfate	8,600	600,000	Mercury	4,300	
Sulfide		3,000	Methyl-2-pentanone,4-	22,000	
Tetrachloroethylene		39	Methylene chloride	120	
Thallium		4	Methylnaphthalene,2-	42	
Toluene	5	3	Nickel	221,000	19,700
Trichloroethylene		24	Nitrate	30,400	
Vanadium		40	Phenanthrene	1,500	
Xylene	4		Potassium	4,980,000	1,900,000
Zinc	11	8,800	Pyrene	1,200	
			Selenium	4,200	
			Silver	1,900	2,500
			Silver chloride	17,300,000	
			Sodium	1,770,000	920,000
			Strontium	67,000	
			Strontium chloride	1	
			Sulfate	131,000	
			Titanium	(b)	
			Toluene	350,000	
			Total petroleum hydrocarbon	126,000,000	
			Vanadium	389,000	82,200
			Xylene	1,800,000	
			Zinc	309,000	397,000
			Zirconium	(b)	

(a) Chemical not detected.

(b) Chemical found at normal background levels.

Modified from Napier, B. A., N. C. Batishko, D. A. Heise-Craff, M. F. Jarvis, and S. F. Snyder. 1995. *Identification of Contaminants of Concern, Columbia River Comprehensive Impact Assessment*. PNL-10400 Draft, Pacific Northwest Laboratory, Richland, Washington.

Appendix E

Environmental Restoration Disposal Facility-Identified Maximum Nonradiological Chemicals Occurring in the 100 and 300 Areas

Table 3-9. Maximum Concentrations for Organic Compounds in 100 and 300 Area Wastes. (Sheet 1 of 3)

Compound	Maximum Concentration (μg/kg)	Waste Unit
VOLATILE ORGANIC COMPOUNDS		
1,2-Dichloroethene (Total)	1,000	316-5W 3904 Process Waste Trenches
1,1,1-Trichloroethane	6	100-D-Pond
1,1,2,2-Tetrachloroethane	3	100-D-Pond
2-Butanone	390	100-D-Pond
2-Hexanone	9	100-D-Pond
4-Methyl-2-Pentanone	11	116-B-2 Storage Basin Trench
Acetone	2,800	UN-100-N-17 Diesel Oil Supply Line Leak
Benzene	190	UN-100-N-17 Diesel Oil Supply Line Leak
Carbon Disulfide	200	116-B-5 Crib
Carbon Tetrachloride	8	116N1
Chloroform	80	316-5W 3904 Process Waste Trenches
Ethylbenzene	330	UN-100-N-17 Diesel Oil Supply Line Leak
Methylene Chloride	4,500	316-2 North (new) Pond
Tetrachloroethene	1,100	316-5W 3904 Process Waste Trenches
Toluene	150	316-2 North (new) Pond
Trichloroethene	390	618-4 Burial Ground No. 4
Vinyl Chloride	24	316-5W 3904 Process Waste Trenches
Xylenes (Total)	1,100	130-D-1 Gasoline Storage Tank
SEMI-VOLATILE ORGANIC COMPOUNDS		
4-Chloroaniline	6,300	C-sanitary trench (300 Area)
1,3-Dichlorobenzene	48	116-DR-1 Liquid Waste Disposal Trench No. 1
1,4-Dichlorobenzene	51	116-N-2 Chemical Waste Storage Tank
2-Methylnaphthalene	13,000	UN-100-N-17

Table 3-9. Maximum Concentrations for Organic Compounds in 100 and 300 Area Wastes. (Sheet 2 of 3)

Compound	Maximum Concentration (µg/kg)	Waste Unit
4-Chloro-3-Methylphenol	38	116-DR-1 Liquid Waste Disposal Trench No. 1
4-Methylphenol	1,000	C-sanitary trench (300 Area)
Acenaphthene	850	316-5W Process Waste Trenches
Anthracene	6,300	UN-100-N-17
Benzo(a)anthracene	1,800	1607-H-4 Septic Tank Discharge Pipe
Benzo(a)pyrene	27,000	316-5E 3904 Process Waste Trenches
Benzo(b)fluoranthene	2,400	1607-H-4 Septic tank Discharge Pipe
Benzo(g,h,i)perylene	3,700	316-5E 3904 Process Waste Trenches
Benzo(k)fluoranthene	760	116-H-1 Liquid Waste Disposal Trench
Benzoic Acid	1,300	316-5E 3904 Process Waste Trenches
Bis(2-ethylhexyl)phthalate	33,000	C-Sanitary Trench (300 Area)
Butylbenzylphthalate	2,600	130-D-1 Gasoline Storage Tank
Carbazole	54	116-D-1B Fuel Storage Basin, Trench No. 2
Chrysene	43,000	316-5E 3904 Process Waste Trenches
Di-n-butylphthalate	5,500	316-5E 3904 Process Waste Trenches
Dibenz(a,h)anthracene	1,700	316-5E 3904 Process Waste Trenches
Dibenzofuran	500	316-5W 3904 Process Waste Trenches
Diethylphthalate	1,000	100-D-Pond
Fluoranthene	2,900	1607-H4 Septic Tank Discharge Pipe
Fluorene	1,700	UN-100-N-17

Table 3-9. Maximum Concentrations for Organic Compounds in 100 and 300 Area Wastes. (Sheet 3 of 3)

Compound	Maximum Concentration (μg/kg)	Waste Unit
Indeno(1,2,3-cd)pyrene	1,600	316-5E 3904 Process Waste Trenches
Naphthalene	4,100	UN-100-N-17
N-Nitrosodiphenylamine	1,800	316-5E 3904 Process Waste Trenches
Pentachlorophenol	1,500	316-5E 3904 Process Waste Trenches
Phenanthrene	3,900	316-5W 3904 Process Waste Trenches
Phenol	240	100-D-Pond
Pyrene	12,000	316-5E 3904 Process Waste Trenches
PESTICIDES/AROCLORS		
4,4'-DDD	110	1607-H4 Septic Tank Discharge Pipe
4,4'-DDE	170	100-D-Pond
Aroclor-1248	10,000	316-2 North Process Pond
Aroclor-1254	6,400	190-B
Aroclor-1260	2,300	100-D Pond
Beta-HCH (Beta-BHC)	7.8	116-D-1A Fuel Storage Basin, Trench No. 1
Chlordane, Gamma-	18	1607-H4 Septic Tank Discharge Pipe
Dieldrin	21	116-D-1A Fuel Storage Basin, Trench No. 1
Methoxychlor	83	100-D-Pond
PCBs	19,500	Process trenches (300 Area)

Source: U.S. Department of Energy (DOE). 1994. *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility*. DOE/RL-93-99 Rev. 1, Richland, Washington.

Appendix F

Risk-Based Screening Benchmarks for SESP-Identified Contaminants of Concern

Table F.1. U.S. EPA Carcinogenic and Noncarcinogenic Effects Screening Benchmarks

Contaminant	Risk-Based Concentrations Tap Water (μg/L)		Ambient Air ($\mu g/m^3$)		Fish (mg/kg)		Soil (mg/kg)	
Ammonia	1000	N	100	N				
Arsenic	0.038	C	0.00041	C	0.0018	C	3.3	C
Benzo(a)pyrene	0.0092	C	0.001	C	0.00043	C	0.088	C
Beryllium	0.016	C	0.00075	C	0.00073	C	0.15	C
Bis(2-ethylhexyl)pthalate	4.8	C	0.45	C	0.23	C	46	C
Carbon tetrachloride	0.16	C	0.12	C	0.024	C	4.9	C
Chloroform	0.15	C	0.078	C	0.52	C	100	C
Chromium	180	N	0.00015	N	6.8	N	390	N
Chrysene	9.2	C	1	C	0.43	C	88	C
Fluoride	2200	N	220	N	81	N	4700	N
Manganese	180	N	110	N	41	N	2300	N
Nitrates	58000	N	5800	N	2200	N	130000	N
PCBs	0.0087	C	0.00081	C	0.00041	C	0.083	C
Tetrachloroethene	1.1	C	3.1	C	0.061	C	12	C
Trichloroethene	1.6	C	1	C	0.29	C	58	C

C = Carcinogenic effects.
N = Noncarcinogenic effects.
From EPA Region III Risk-Based Concentration Table Background Information
Smith, Roy L., February 9, 1995.