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# Evaluation of Aquatic and Riparian Receptor Impacts at the 100-N Area: Literature and Data Review

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September 2003

Prepared for
Fluor Hanford, Inc.

Pacific Northwest National Laboratory
Richland, Washington 99352

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# Summary

Past operations at the Hanford Site's 100-N Area resulted in the release of radiological and chemical contaminants to the soil column, local groundwater, and ultimately to the near-shore environment of the Columbia River. Cleanup of the 100-N Area is proceeding under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). As part of the CERCLA process, specific activities associated with the cleanup are provided in a record of decision. One of the activities for the 100-NR-2 Operable Unit requires that "*DOE will conduct an evaluation of aquatic and riparian receptor impacts from contaminant discharges at the groundwater/river interface and will coordinate with ongoing efforts…The evaluation will include a literature search and an evaluation of existing data*."

At the request of Fluor Hanford, Inc., Pacific Northwest National Laboratory conducted a literature search and data evaluation for aquatic and riparian receptors at the 100-N Area. This report presents those findings and includes a summary of ongoing and planned work evaluating 100-N Area receptors by Hanford Site contractors. Over 220 reports and technical documents were identified and reviewed. The documents were sorted and prioritized with special attention given to reports most relevant to 100-N Area receptors.

This report provides a brief overview of 100-N Area operations, describes the literature review process, provides information of biological resources at the 100-N Area, discusses potential threatened and endangered species issues, summarizes the contaminant data for the 100-N Area, reviews risk/dose assessments specific to the 100-N Area, summarizes modeling efforts for the 100-N Area groundwater/river interface, and lists ongoing and planned evaluation of aquatic and riparian receptors at the 100-N Area.

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The authors wish to acknowledge Brad Fritz (PNNL) and Vernon Johnson (Fluor Hanford, Inc.) for their valuable peer review. In addition, Jane Borghese (Fluor Hanford, Inc.,) and Mike Thompson (DOE/RL) provided valuable historic and technical guidance. Launa Morasch provided editorial review and Kathy Neiderhiser provided text processing.

# Contents


Summary ..... iii
Acknowledgements ..... v
Introduction ..... 1
Objectives ..... 2
Overview of 100-N Area Operations and Environmental Monitoring ..... 2
Literature Review Process ..... 6
Biological Resources and Environments Found at the 100-N Area ..... 7
    Riparian Environment ..... 7
    Riparian Biota ..... 8
    Historical Review of 100-N-Springs Shoreline ..... 13
    Aquatic Environment ..... 18
    100-N Area Threatened or Endangered Species Issues ..... 20
Contaminant Data Literature Summary ..... 21
    Contaminant Data for Riparian Environment ..... 25
    100-N Area Springs Monitoring Prior to Installation of Riprap (pre-1984) ..... 25
    100-N Area Springs Monitoring Subsequent to Installation of Riprap (post-1984) ..... 29
    Contaminant Data for Riparian Biota ..... 32
    Contaminant Data for Aquatic Environment ..... 39
    Contaminant Data for Aquatic Biota ..... 43
    Contaminant Trends in Non-Biological Samples Near the 100-N Area ..... 44
        Strontium-90 ..... 44
    Contaminant Trends in Biota Near the 100-N Area ..... 46
        Canada Geese ..... 47
        Carp ..... 47
Dose and Risk Assessments for 100-N Area Receptors ..... 49
Modeling Efforts for Groundwater and River Interactions ..... 52
    Other Reports Potentially Useful for 100-N Area Riparian and Aquatic Assessments ..... 52
Overall Summary from Literature and Data Review ..... 53
References ..... 57
Appendix A – Excel Spreadsheet of Documents for the 100-N Area Receptor Literature Review ..... A.1
Appendix B – Maximum Concentrations of Radionuclides and Metals in Wildlife, Vegetation, Soil, and Water Samples, 1970 to Present ..... B.1
Appendix C – Draft Ecological Assessment Process ..... C.1

# Figures


1 Aerial View of the Columbia River Shoreline and the Hanford Site 100-N Area ..... 1

2 The Hanford Site and Surrounding Area ..... 3

3 Conceptual Model of 100-N Area Radiological Contaminants in the Liquid Waste Disposal Facilities, Vadose Zone, and Groundwater ..... 5

4 Reported Annual and Cumulative Releases of Strontium-90 to the Columbia River from the 100-N Area ..... 5

5 Vegetation Communities and Shoreline Substrate Near the 100-N Area ..... 9

6 Geological Cross Section Through 1301-N Liquid Waste Disposal Facility and the Adjacent River Channel ..... 14

7 100-N Area Spring Zones Sampled During the Early Years of the Environmental Monitoring Program ..... 16

8 Riprap Boulders Along the 100-N Area Shoreline, 1997 ..... 16

9 Diagram of Seep Well Installed in 100-N Springs Riprap ..... 17

10 Location of Groundwater or Seep Wells in the 100-N Area ..... 35

11 Strontium-90 Concentrations in Seep Wells and Water-Table Elevation in Groundwater Well Nearest the Central Portion of the Groundwater Plume ..... 36

12 100-N Area Shoreline Sampling Sites ..... 38

13 Maximum Concentrations of Tritium and Strontium-90 in Near-Shore and Cross-River Columbia River Water Samples Collected Near 100-N Area, 1993 to 2002 ..... 45

14 Strontium-90 and Tritium Concentrations in the Riverbank Spring Near Well 199-N-8T ..... 45

15 Tritium Concentrations in 100-N Area Riverbank Spring 8-13 ..... 46

16 Strontium-90 Concentrations in Canada Goose Eggshells Collected on the Hanford Reach of the Columbia River Between 1985 and 2001 ..... 48

17 Strontium-90 Concentrations in Adult Carp Carcass Samples Collected Near and Distant to the 100-N Area, 1989 to 2003 ..... 48

# Tables


1 Sorting Criteria for the 100-N Area Riparian and Aquatic Receptor Literature Search ..... 7

2 Plant Species Found in the 100-N Area Cribs, 1994 ..... 10

3 Plant Species Found Near 100-N Area Riverbank Springs, 1994 ..... 11

4 Bird Species Observed During Winter Shoreline and Riparian Surveys, 1994-1997 ..... 12

5 Total Bird Abundance Recorded During Winter Bird Surveys Near 100-N Area, 1997-2001 ..... 13

6 Reptiles and Amphibians Found on the Hanford Site ..... 14

7 Fish Species in the Hanford Reach of the Columbia River ..... 19

8 Sediment Classifications Used for the 2002 Field Mapping of 100-N Area Substrate ..... 20

9 Maximum Concentration Radionuclides in Soil and River Sediment Near the 100-N Area, 1993 to Present ..... 21

10 Maximum Concentrations of Radionuclides in Wildlife Samples Collected Near the 100-N Area, 1993 to Present ..... 22

11 Maximum Concentration of Radionuclides in Vegetation Samples Collected Near the 100-N Area, 1993 to Present ..... 23

12 Maximum Concentration Radionuclides in Water Samples Near the 100-N Area, 1993 to Present ..... 27

13 Maximum Concentration of Metals, Anions, and Volatile Organic Compounds in Riverbank Springs Near the 100-N Area, 1994 to Present ..... 28

14 Maximum Concentration of Metals, Anions and Volatile Organic Compounds Measured in the Columbia River Near the 100-N Area, 1994 to Present ..... 30

15 Maximum Concentration of Radionuclides in Soil and River Sediments Near the 100-N Area, 1993 to Present ..... 32

16 Maximum Concentration of Radionuclides in Fish Samples Around the 100-N Area, 1993-Present ..... 33

17 Maximum Concentration of Metals in Wildlife Samples Collected Near the 100-N Area Riverbank Springs, 1997 ..... 34

18 Maximum Concentration of Metals in Vegetation Samples Collected Near the 100-N Area Riverbank Springs, 1997 ..... 35

19 Average Concentrations of Strontium-90 and Tritium in Columbia River Water, Riverbank Spring Water, Drinking Water, and Rooting Zone Groundwater Collected Near the 100-N Area, 1993 to Present ..... 42

# Introduction

As part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup process at the Hanford Site's 100-N Reactor area, the 100-NR-1 and 100-NR-2 record of decision (ROD) identifies specific activities for selected remedies at the 100-NR-2 Operable Unit (DOE 1995a; DOE 1995b). One of these activities is related to aquatic and riparian receptors, specifically; "*DOE will conduct an evaluation of aquatic and riparian receptor impacts from contaminant discharges at the groundwater/river interface and will coordinate with ongoing efforts. DOE shall submit information to Ecology within 5 years of this ROD. The evaluation will include a literature search and an evaluation of existing data. Laboratory testing and studies of ecological receptors (e.g., through bioassays or injury assessments) and their habitat (e.g., pore water sampling) may be required*."

At the request of Fluor Hanford, Inc., Pacific Northwest National Laboratory (PNNL) conducted a literature search and data evaluation for aquatic and riparian receptors at the 100-N Reactor area (Figure 1). Numerous environmental surveillance activities have taken place at the 100-N Area from pre-construction to present. Some of these activities were specific studies of the 100-N Area environment, and some had broader spatial scales but included samples from the 100-N Area.

For the purposes of this review, receptors are defined as anything that can be affected by a pollutant. The receptor can be biota (e.g., reed canarygrass) or abiotic (e.g., soil or riverbank spring water). An

**Figure 1**. Aerial View of the Columbia River Shoreline and the Hanford Site 100-N Area (2002)

impact is defined as any observed parameter in the receptor that may have been changed by exposure to a pollutant or physical process in the environment caused by operations at the 100-N Area. For this report, the discussion of receptor impact will be limited to the impact to biota.

# Objectives

The objectives of this effort included the following items:

- Conduct a literature search on the environment of the riparian zone and the aquatic and riparian receptor impacts at the 100-N Area.

  This effort focused on producing a list of the literature, specific to the 100-N Area, that is available in scientific papers, technical reports, Hanford Site annual reports, and letter reports. To the extent possible, a brief summary of the document was written with more detailed summary information provided for the reports deemed most likely to be useful for future 100-N Area evaluations.

- Evaluate existing data for aquatic and riparian receptors in the 100-N Area.

  The data evaluation process involved compiling lists of species of biota observed in the 100-N Area, producing summary tables for contaminant data for two time periods, and providing selected trend plots for contaminants of concern where sufficient data were available.

- Identify ongoing and planned work involving aquatic and riparian receptors at the 100-N Area by other Hanford Site contracts.

A letter describing the identified and planned work will be sent to Fluor Hanford Inc. The work was identified from a series of personal contacts with staff at the U.S. Department of Energy (DOE) Richland Operations Office and Hanford Site contractors.

# Overview of 100-N Area Operations and Environmental Monitoring

The 100-N Area is located in the northern part of the Hanford Site adjacent to the Columbia River in south-central Washington State (Figure 2). The 100-N Reactor was constructed during 1958 to 1963 and operated continuously from 1963 to 1987 for the dual purpose of producing materials for nuclear weapons and steam for the generation of electrical power at the Washington Public Power Supply System Hanford Generating Plant (DOE 1997; DOE 2002a). Full production at the 100-N Area started in January 1962. The reactor was placed in cold standby in February 1987 and the final shutdown order was issued in September 1990. The 100-N Reactor was unique among the nine Hanford Site production reactors in its use of a heat-exchange cooling system that greatly reduced the release of contaminants to the river environment compared to the single-pass reactors. The primary coolant (de-ionized water) was passed

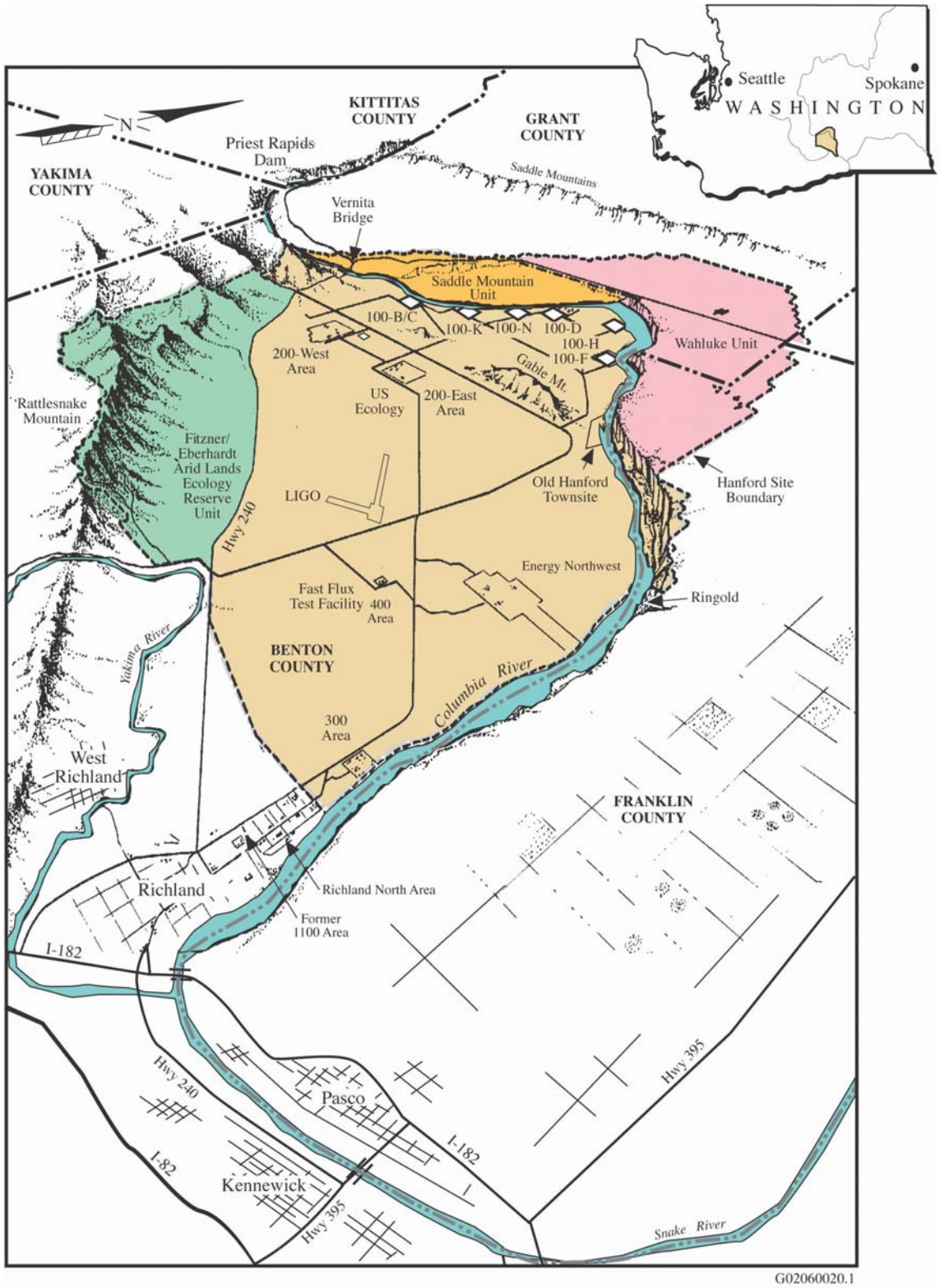


**Figure 2**. The Hanford Site and Surrounding Area

through the N Reactor multiple times (roughly 100 cycles, based on a 1% continuous replacement), and this resulted in higher levels of some radionuclides in the coolant water compared to the Hanford Site's single-pass reactors.

When the 100-N Reactor was operating, contaminated water from the primary cooling loop of the reactor, as well as water from other reactor-related sources, was directed to the 1301-N (operated from 1963 to 1983) and the 1325-N (1983 to 1991) liquid waste disposal facilities (LWDF) located on the bluff above the Columbia River. These LWDF were concrete basins with unlined drainage trenches. The LWDF were the major liquid effluent sources and released radiological and chemical contaminants to the vadose zone, groundwater, and ultimately to the Columbia River riparian and aquatic environment. All liquid waste discharges to the LWDF ceased in January 1992. During operations, non-radioactive secondary cooling water was disposed directly to the Columbia River. Solutions used to regenerate ion-exchange columns used in the river water treatment plant were disposed to the 1324 N/NA pond.

Summarizing environmental data at the 100-N Area over the weapons production period of the Hanford Site is challenging because changes in operational activities greatly influenced environmental concentrations. During the early operations at the 100-N Reactor (1963 to 1973), the other eight Hanford Site reactors were all cooled using the single-pass method (i.e., not heat exchanged) and were the dominant source of Hanford-derived chemical and radionuclides in the Columbia River. With the closure of the final single-pass reactor in 1971, the 100-N Reactor was the only production reactor operating. Although the direct discharge of radionuclides and chemicals to the river was minimal, substantial volumes of contaminated water were discharged to the LWDF. This resulted in dispersal of contaminants from the soil column under the LWDF to the actively flowing riverbank springs on the 100-N Area shoreline. Production operations at the 100-N Reactor ended in 1985, with a dramatic decrease to the volume of water discharged to the LWDF, which greatly reduced the number and discharge volumes at the 100-N Area riverbank springs. A conceptual model of the 100-N Area contaminants in the LWDF, vadose zone, and groundwater is shown in Figure 3.

The operational changes at the 100-N Area and decay of short half-life radionuclides require that environmental data summaries be grouped into several time periods. The text of this report focuses on the period from 1993 to 2003 since this reflects the data most likely to reflect current conditions, i.e., 100-N Area data with minimal discharges to the LWDF. The data from 1973 to 2003 is summarized in Appendix B (100-N Area data with production operation discharges to the LWDF). Data prior to 1973 was not included in this review since the Hanford Site contaminants were primarily from the single-pass reactors and much of the data is for radionuclides with short half-lives that are no longer observable in the Columbia River environment. For this review, the primary contaminants of concern for aquatic and riparian receptors at the 100-N Area are strontium-90, tritium, hexavalent chromium, manganese, nitrate, sulfate, and total petroleum hydrocarbons. Strontium-90 has historically been the major contaminant of concern for the 100-N Area. Strontium-90 releases peaked in 1985 at roughly 8.5 Ci/yr with releases decreasing to below 0.2 Ci/yr after 1990 (Figure 4). The cumulative release of strontium-90 to the Columbia River increased markedly from 1973 to 1990 with the cumulative level reaching a plateau near 46 Ci.

Environmental monitoring at the 100-N Area occurred prior to construction, during reactor production, and continues today. The two major projects that are currently tasked with environmental monitoring at the 100-N Area are the Surface Environmental Surveillance Project (SESP) and the Near-Facility

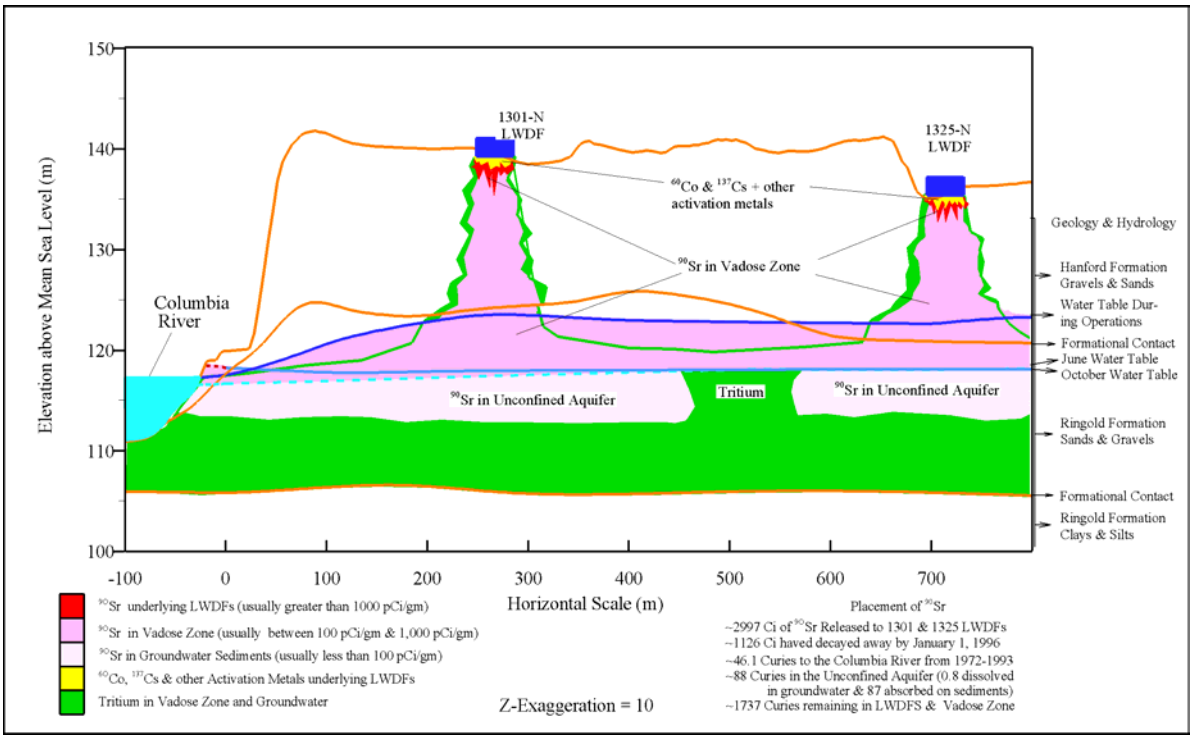


**Figure 3**. Conceptual Model of 100-N Area Radiological Contaminants in the Liquid Waste Disposal Facilities, Vadose Zone, and Groundwater (from Mike Connelly, CH2M HILL, 100-N Groundwater Workshop, August 11-12, 2003, Washington State University at Tri-Cities)

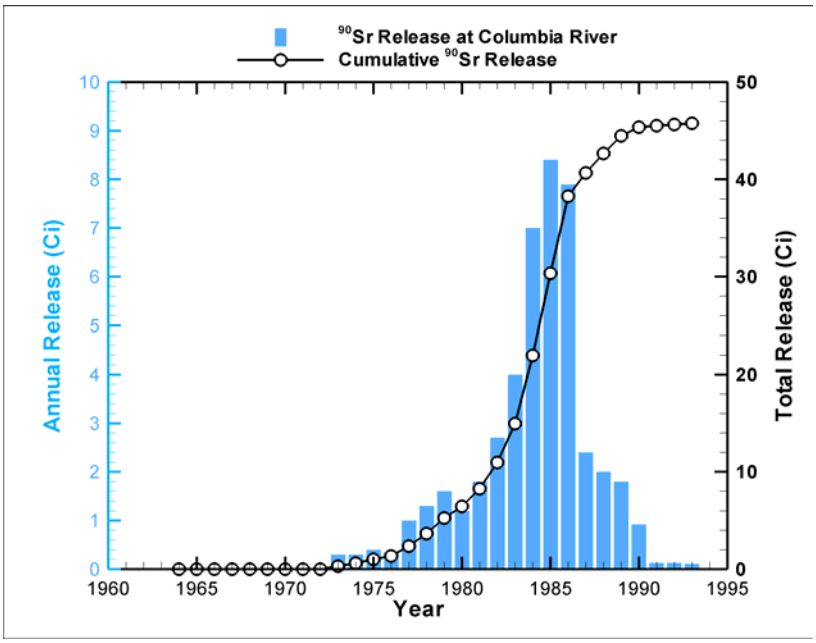


**Figure 4**. Reported Annual and Cumulative Releases of Strontium-90 to the Columbia River from the 100-N Area

Monitoring Project. The sample results from these two projects and reports from special scientific studies are the major sources of current environmental data for the 100-N Area riparian and aquatic habitats.

At the 100-N Area, the Surface Environmental Surveillance Project typically collects Columbia River water from near shore and cross-river transect stations (10 locations, collected annually), and riverbank spring water (2 locations, collected annually). External radiation dose is measured with thermoluminescent dosimeters at three shoreline locations (collected quarterly). Biota samples for whitefish, carp, geese, cottontail rabbit, and mule deer are sampled at or near the 100-N Area on a biannual basis. Soil samples are collected at or near the 100-N Area at four locations on a 3 to 5 year frequency. Vegetation samples are collected at or near the 100-N Area at three locations on a 3 to 5 year frequency. The data from these monitoring activities are published in the Hanford Site environmental report and an annual data report (e.g., Poston et al. 2002; Bisping 2002).

The Hanford Site Near-Facility Environmental Monitoring Program collects soil and vegetation samples, water samples from riverbank springs or shoreline seepage wells, conducts radiological surveys, and measures external radiation measurements using thermoluminescent dosimeters at the 100-N Area (Perkins et al. 2002). The data from these monitoring activities is published in the Hanford Site environmental report and an annual data report (e.g., Poston et al. 2002; Perkins et al. 2002).

# Literature Review Process

The literature review process was designed to target documents and articles specific to the 100-N Area. A list of the literature was produced and, to the extent possible, a brief summary of the document was written with more detailed summary information provided for the reports deemed most likely to be useful for future 100-N Area evaluations.

A query of the available Hanford Site literature discovered over 220 technical reports/documents with potential information concerning aquatic and biological receptors or their environs at the 100-N Area. The documents were grouped into the following categories: technical reports, annual DOE status reports on remedial action at 100-N Area, annual Hanford Site environmental reports, annual Hanford Site groundwater monitoring reports, and annual Hanford Site near-field monitoring reports.

To select the reports and other documents to be summarized, the primary criteria included the following items:

1. Were the data reported directly related to receptors or contaminant sources in the riparian and aquatic zones near the 100-N Area?

2. Were the data related to species that reside or frequent the riparian or aquatic zones at the 100-N Area?

3. Were the data related to uptake or accumulation of constituents that may be of concern at the 100-N Area?

An Excel spreadsheet containing the results of the literature search is provided in Appendix A. Each document was sorted by the criteria shown in Table 1.

**Table 1**. Sorting Criteria for the 100-N Area Riparian and Aquatic Receptor Literature Search

| Category | Comment |
|---|---|
| Author | Author |
| Year | Year the report was issued |
| Report Number | Hanford Site contractor report number |
| Institution | Institution issuing the report |
| City | Location of institution |
| Pertinence | Pertinence to 100-N receptor topic (pertinent, moderate, low) |
| Rad | Contains radiological data |
| Organics | Contains data on organic compounds |
| Inorganic | Contains data on inorganic compounds |
| Media Sampled | Type of environmental media sampled |
| Human Dose | Contains data on human dose |
| Environment | Environment type (e.g., terrestrial, riparian, aquatic) |
| 100-N Data | Contains data specific to 100-N (yes or no) |
| Comments | Short description of report |

This report summarizes selected documents listed in Appendix A by major habitat type and biological media sampled. The data contained in some of the reports are available in environmental databases (e.g., Hanford Environmental Information System [HEIS]) and when possible these databases have been identified in the review.

# Biological Resources and Environments Found at the 100-N Area

Several reports are available that provide general categories and descriptions of Hanford habitats and biota. These studies are useful for this review because they document the habitat and biota found at the 100-N Area and describe environments similar to 100-N Area and background environments that can be used for comparisons.

## Riparian Environment

The riparian zone along the Hanford Reach refers to the band along the river shoreline that is influenced by the flow of the river and the increased availability of water along the riverbank and at the river edge. The annual Hanford Site National Environmental Policy Act (NEPA) Characterization report (Neitzel 2002) provides a detailed summary of the climate, meteorology, ecology, geology, hydrology, cultural resources, and socioeconomics for the entire Hanford Site, with selected information grouped by

major operational areas (e.g., 200 Areas, 100 Areas) and some specific summaries for the 100-N Area. Hanford Site climate data summaries can be found in the annual climatology reports (e.g., Hoitink et al. 2003).

A prominent feature of the 100-N Area shoreline is the steep sloping bank separating the uplands and the river shoreline. Because the bank is so steep, the width of the riparian vegetation band between the 100-N Area and the river shore is less than 100 meters. The steep bank primarily has a northwest-facing aspect. During 2002, a vector layer describing the substrate types and macrophyte communities along the low water line at the 100-N Area shoreline of the Hanford Reach was developed as under the Ecological Monitoring and Compliance Project at PNNL under the Public Safety and Resource Protection Program (Task Manager – Brett Tiller, PNNL). The GIS map layers for the riparian vegetation communities and shoreline substrate are shown in Figure 5. This figure indicates that along a portion of the shoreline adjacent to the 100-N Area, boulders and large rocks (substrate class 4) fill the shoreline area and no riparian vegetation is present.

## Riparian Biota

Fitzner et al. (1994) lists special-status wildlife species and their habitats, while Fitzner and Gray (1990) list non-special-status species, some of which use the 100-N Area. Sackschewsky and Downs (2001) describe the various plant communities on Hanford and list special status plant species and their general locations, and provide a list of the plants known to occur on Hanford.

The annual Hanford Site National Environmental Policy Act (NEPA) Characterization report (Neitzel 2002) provides a detailed summary of the ecology for the entire Hanford Site, with selected information grouped by major operational areas (e.g., 200 Areas, 100 Areas) and some specific summaries for the 100-N Area.

Downs et al. (1993) identified primary habitat types and vegetation associations in Hanford Site riparian areas. This report also provides a description of the riparian and aquatic biota found on site including common plants, mammals, birds, invertebrates, and fish as well as identifying habitat issues for threatened, endangered, or sensitive species. Landeen et al. (1993) provides a list of birds (including water birds), small and large mammals, insects, and plants found at the 100-N Area (and other 100 Area locations). The report briefly discusses food chains. Other reports (e.g., Sackschewsky 1992; Sackschewsky and Landeen 1992) provide information on riparian vegetation, especially rare or endangered species found along the Hanford Reach, but do not specifically discuss the 100-N Area. Surveys of the Hanford Reach for plant species of concern have not documented any rare species in the riparian vegetation at the 100-N Area (Hall 1998; Cadwell 1995).

The Hanford Site's Ecological Monitoring and Compliance Project maintains compliance, monitoring, and inventory data for biotic organisms, populations, and communities found across the Hanford Site (Database Task Manager: Mary Ann Simmons, PNNL). One compliance-related inventory documented the plant species for terrestrial vegetation at the 100-N Area cribs in 1994 (Table 2). Additional data on the bird species present and vegetation communities within the 100-N Area perimeter fence have been collected annually since 1994 as part of the Compliance/Protection/Mitigation Task under the Ecological

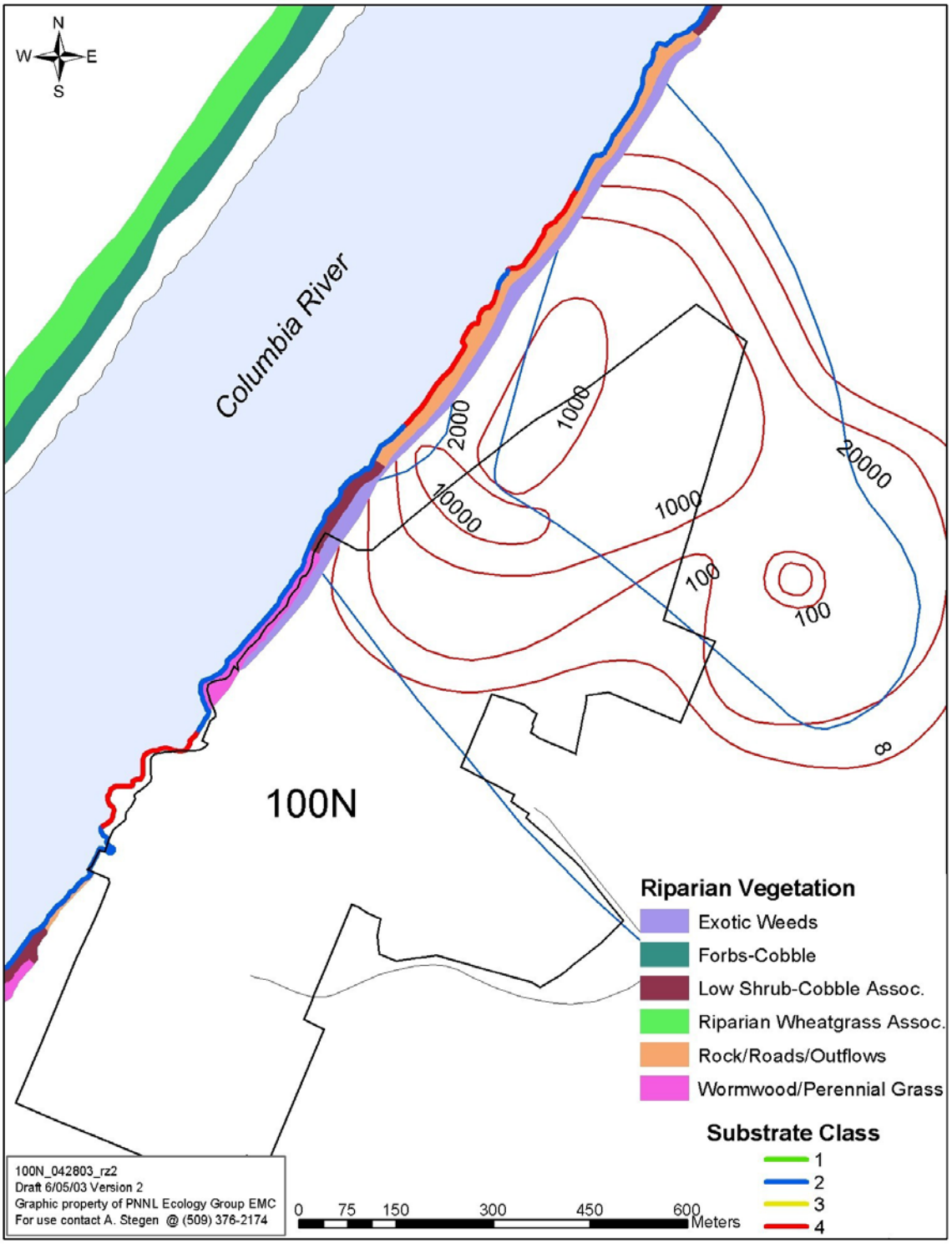


**Figure 5**. Vegetation Communities and Shoreline Substrate Near the 100-N Area. Groundwater plumes (pCi/L) for strontium-90 and tritium pCi/L are shown with red and blue contor lines, respectively.

**Table 2**. Plant Species Found in the 100-N Area Cribs, 1994

| Genus and Species | Common Name |
|---|---|
| *Achillea millefolium* | Yarrow |
| *Artemisia campestris* | Pacific Sagebrush |
| *Asclepias speciosa* | Showy milkweed |
| *Balsamorhiza spp.* | Balsam root |
| *Bromus tectorum* | Cheatgrass |
| *Centaurea diffusa* | Tumble knapweed |
| *Chrysothamnus nauseosus* | Gray rabbitbrush |
| *Melilotus alba* | White sweetclover |
| *Poa sandbergii* | Sandberg's bluegrass |
| *Salsola kali* | Russian thistle |
| *Sisymbrium altissimum* | Jim Hill's tumblemustard |
| *Sporobolus cryptandrus* | Sand dropseed |
| *Tragopogon dubius* | Yellow salsify |

Monitoring and Compliance Program (Task Manager – Mike Sackschewsky, PNNL). These data are available but have not been summarized in this report.

Plant community map layers in GIS format have been produced and maintained for the 100-N Area's terrestrial environment and more recently for the riparian environment, as part of the Hanford Site's Ecological Monitoring and Compliance Program (Project Manager – Janelle Downs, PNNL). Shoreline surveys for rare plants were conducted during 1993 to 1995 as part of this project. The surveys did not identify any rare plants along the 100-N Area shoreline. In addition, plant lists were generated for the 100-N Area riverbank springs in 1994 (Table 3).

Avian surveys at the 100-N Area were initiated in 1994 and continued through 1997 to document winter bird use of the Columbia River shoreline and riparian habitat. A 1-kilometer transect was surveyed at the 100-N Area during December, January, and February and birds within 100 meters on both sides of each transect were counted. Table 4 lists the bird species observed during these surveys and data are archived in the Ecological Monitoring and Compliance Program's databases.

Weekly surveys were conducted from late November through mid-February during four consecutive winters (1997-1998 through 2000-2001) near the 100-N Area. Bird observations were summarized by three general habitats: shoreline, near shore (in water no more than 15 meters from waters' edge) and open water habitats. The total number of each species observed over the 3-year period is shown in Table 5. Data are archived in the Ecological Monitoring and Compliance Program databases.

The list of reptiles and amphibians reported in the annual Hanford Site National Environmental Policy Act (NEPA) Characterization report (Neitzel et al. 2002) is provided in Table 6. Small mammals, breeding birds, and amphibians have not been inventoried in the 100-N Area riparian zone. Small mammals have however been inventoried in other areas with similar vegetation communities as part of the ongoing Riparian Characterization Task under the Ecological Monitoring and Compliance Program (Task Manager – Brett Tiller, PNNL).

**Table 3**. Plant Species Found Near 100-N Area Riverbank Springs, 1994

| Genus and Species | Common Name |
|---|---|
| *Achillea millefolium* | Yarrow |
| *Agropyron dasytachyum* | Thickspike wheatgrass |
| *Agropyron repens* | Quackgrass |
| *Agropyron spicatum* | Bluebunch wheatgrass |
| *Agrostis spp.* | Bentgrass |
| *Amsinckia lycopsoides* | Fiddleneck |
| *Apocynum cannabinum* | Indian hemp |
| *Artemisia campestris* | Pacific Sagebrush |
| *Artemisia dracunculus* | Tarragon |
| *Artemisia lindleyana* | Columbia River mugwort |
| *Artemisia ludoviciana* | Prairie sagebrush |
| *Artemisia tridentate* | Big sagebrush |
| *Asclepias speciosa* | Showy milkweed |
| *Bromus japonicus* | Japanese brome |
| *Bromus tectorum* | Cheatgrass |
| *Centaurea diffusa* | Tumble knapweed |
| *Chrysothamnus nauseosus* | Gray rabbitbrush |
| *Cirsium arvense* | Canada thistle |
| *Convolvulus arvensis* | Field bindweed |
| *Conyza canadensis* | Horseweed |
| *Coreopsis atkinsoniana* | Columbia tickseed |
| *Dianthus armeria* | Grass pink |
| *Equisetum spp.* | Horsetail |
| *Erodium cicutarium* | Storksbill |
| *Festuca arundinacea* | Tall fescue |
| *Festuca spp.* | Fescue |
| *Gaillardia aristata* | Blanket flower |
| *Helenium autumnale* | Sneezeweed |
| *Hypericum perforatum* | Klamath weed |
| *Lactuca serriola* | Prickly lettuce |
| *Medicago lupulina* | Black medick |
| *Melilotus alba* | White sweetclover |
| *Morus alba* | White mulberry |
| *Oryzopsis hymenoides* | Indian ricegrass |
| *Phalaris arundinacea* | Reed canarygrass |
| *Plantago lanceolata* | English plantain |
| *Poa nevadensis* | Nevada bluegrass |
| *Poa pratensis* | Kentucky bluegrass |
| *Poa sandbergii* | Sandberg's bluegrass |
| *Polygonum persicaria* | Heartweed |
| *Potentilla norvegica* | Norwegian cinquefoil |
| *Rorippa islandica* | Marsh yellowcress |
| *Rumex salicifolius* | Willow dock |
| *Salsola kali* | Russian thistle |

**Table 3**. (contd)

| Genus and Species | Common Name |
|---|---|
| *Sisymbrium altissimum* | Jim Hill's tumblemustard |
| *Sitanion hystrix* | Bottlebrush grass |
| *Sporobolus cryptandrus* | Sand dropseed |
| *Stipa comata* | Needle-and-thread grass |
| *Tragopogon dubius* | Yellow salsify |
| *Verbascum thapsus* | Common mullein |

**Table 4**. Bird Species Observed During Winter Shoreline and Riparian Surveys, 1994-1997

| Genus and Species | Common Name |
|---|---|
| | Gull spp. |
| *Aechmophorus occidentalis* | Western grebe |
| *Agelaius phoeniceus (Linnaeus)* | Red-winged blackbird |
| *Anas platyrhynchos* | Mallard duck |
| *Ardea herodias* | Great blue heron |
| *Branta canadensis moffitti* | Western Canada goose |
| *Bucephala albeola* | Bufflehead duck |
| *Bucephala clangula* | Common goldeneye duck |
| *Bucephala islandica* | Barrow's goldeneye duck |
| *Buteo jamaicensis* | Red-tailed hawk |
| *Carpodacus mexicanus* | House finch |
| *Charadrius vociferus* | Killdeer |
| *Colaptes auratus* | Northern flicker (common flicker) |
| *Columba livia* | Rock dove |
| *Corvus corax* | Common raven |
| *Dendroica coronata* | Yellow-rumped warbler |
| *Eremophila alpestris* | Horned lark |
| *Fulica americana* | American coot |
| *Grus canadensis* | Sandhill crane |
| *Junco hyemalis* | Dark-eyed junco |
| *Lanius ludovicianus* | Loggerhead shrike |
| *Larus delawarensis* | Ring-billed gull |
| *Lophodytes cucullatus* | Hooded merganser |
| *Mergus merganser* | Common merganser |
| *Mergus serrator* | Red-breasted Merganser |
| *Pelecanus erythrorhynchos* | American white pelican |
| *Phalacrocorax auritus* | Double-crested Cormorant |
| *Phasianus colchicus* | Ring-necked pheasant |
| *Pica pica* | Black-billed magpie |
| *Podiceps auritus* | Horned grebe |
| *Podilymbus podiceps* | Pied-billed grebe |
| *Sturnella neglecta* | Western meadowlark |
| *Sturnus vulgaris* | European starling |
| *Turdus migratorius* | American robin |
| *Zonotrichia leucophrys* | White-crowned sparrow |

**Table 5**. Total Bird Abundance Recorded During Winter Bird Surveys Near 100-N Area, 1997-2001

| Genus and Species | Common Name | Shoreline | Near Shore | Open Water | Habitat Type Not Recorded |
|---|---|---|---|---|---|
| | Goldeneye spp. | | 8 | 58 | |
| | Unidentified grebe spp. | | 5 | 8 | |
| | Unidentified gull spp. | | | 1 | |
| *Accipiter striatus* | Sharp-shinned hawk | | | | 1 |
| *Aechmophorus occidentalis* | Western grebe | | | 1 | |
| *Agelaius phoeniceus* | Red-winged blackbird | | 14 | | |
| *Anas americana* | American wigeon | | 2 | | |
| *Anas crecca* | American green-winged teal | | 2 | | |
| *Anas platyrhynchos* | Mallard | | 225 | 25 | 11 |
| *Anas strepera* | Gadwall | | 3 | | |
| *Ardea herodias* | Great blue heron | 10 | | | |
| *Branta canadensis* | Canada goose | 169 | 522 | 248 | |
| *Bucephala albeola* | Bufflehead | | 23 | 41 | |
| *Circus cyaneus* | Northern harrier | 1 | | | |
| *Eremophila alpestris* | Horned lark | | | | 2 |
| *Falco sparverius* | American kestrel | | | | 1 |
| *Gavia immer* | Common loon | | | 6 | |
| *Haliaeetus leucocephalus* | Bald eagle | 12 | | 1 | |
| *Lanius ludovicianus* | Loggerhead shrike | | | | 1 |
| *Mergus merganser* | Common merganser | 8 | 50 | 9 | |
| *Pelecanus erythrorhynchos* | American white pelican | 1 | 5 | 3 | |
| *Phalacrocorax auritus* | Double-crested cormorant | 2 | 2 | 10 | |
| *Pica pica* | Black-billed magpie | 1 | 2 | | 3 |
| *Podiceps auritus* | Horned grebe | | 1 | 4 | |
| *Podiceps nigricollis* | Eared grebe | | | 11 | |
| *Podilymbus podiceps* | Pied-billed grebe | 3 | 72 | 23 | |
| *Sayornis saya* | Say's phoebe | | | | 1 |
| *Sturnella neglecta* | Western meadowlark | | | | 1 |
| *Sturnus vulgaris* | European starling | | 20 | | |

## Historical Review of 100-N-Springs Shoreline (Operational Impacts, Rip-Rap Installation, and Development of Seep Water Groundwater Wells)

The segment of river shoreline to the northwest of the 1301-N LWDF (waste site 116-N-1) has been referred to over the years as N-Springs. During operation of this LWDF, which consisted of an inlet line, crib, and infiltration trench, effluent disposal to the LWDF was sufficient to saturate the underlying vadose zone down to the water table, and to create a mound on the water table (Figure 6). This, in turn, caused increase flow of groundwater across the interface with the Columbia River.

One of the first complete analyses of reactor effluent disposal to this facility is presented in Eliason (1967). The field investigation included extensive sampling of wells and riverbank springs during the

**Table 6**. Reptiles and Amphibians Found on the Hanford Site (Neitzel et al. 2002)

| Scientific Name | Common Name |
|---|---|
| **Reptiles** | |
| *Charina bottae* | Rocky Mountain rubber boa |
| *Chrysemys picta* | painted turtle |
| *Coluber constrictor* | Western yellow-bellied racer |
| *Crotalus viridis* | Western rattlesnake |
| *Hupsiglena torquata* | night snake |
| *Masticophis taeniatus* | striped whipsnake |
| *Phrynosoma douglassii* | short-horned lizard |
| *Pituiphis melanoleucus* | Great Basin gopher snake |
| *Sceloporus graciosus* | northern sagebrush lizard |
| *Thamnophis sirtalis* | common garter snake |
| *Uta stansburiana* | side-blotched lizard |
| **Amphibians** | |
| *Ambystoma tigrinum* | tiger salamander |
| *Bufo woodhousei* | woodhouse toad |
| *Hyla regilla* | Pacific treefrog |
| *Rana catesbeiana* | bullfrog |
| *Scaphiopus intermontanus* | Great Basin spadefoot |

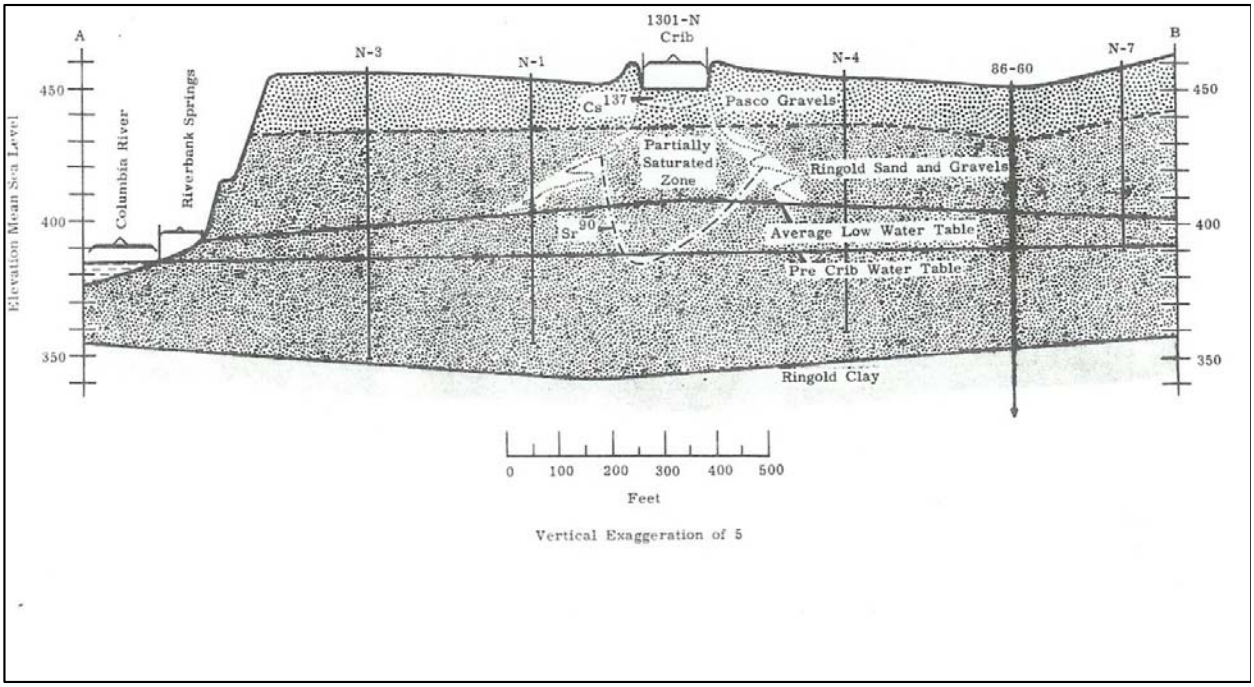


**Figure 6**. Geological Cross Section Through 1301-N Liquid Waste Disposal Facility and the Adjacent River Channel

preceding two years. The report describes sampling points being established at 30.5-meter intervals along the 305 meters of spring front. The sampling points were named following the convention 500-S, 400-S, 300-S, and so on. Photographs in the report show these sampling points to be pipes inserted horizontally into the riverbank, through which water freely flowed. Six wells, each equipped with a 0.61-meter screened interval emplaced at different depths in the aquifer, were also installed as part of this project. These wells were subsequently named the 199-N-8 (T, P, S, Q, R, and U) wells and placed in routine monitoring service in 1973 as part of the 1323-N LWDF (Probasco 1986). The 1967 field evaluation and analysis included estimates for travel time from the facility to the riverbank springs, which was 79 days for tritium—a radionuclide that moves at the same rate as groundwater. Other radionuclides moved more slowly because of their interaction with soil.

By the late 1970s, interest in the environmental conditions created by disposal to the 1301-N LWDF increased. A site characterization and operational monitoring program was established to (1) initiate studies to characterize ecosystems; (2) measure effluent levels and identify ecosystem changes; and (3) conduct data management such that trends over time can be identified (Poppe 1979). The facilities available to conduct the characterization and monitoring included some groundwater monitoring wells, the 199-N-8 series of wells installed earlier, and riverbank springs, which were still extensive. For the latter, the riverbank was divided into eight spring zones, each of which was 61-meters long, with the first being located adjacent to well 199-N-8T, and the remainder extending downstream along the shoreline (Figure 7). The zones were named SP-1, SP-2, SP-3, and so on. Monitoring within these zones included riverbank springs, vegetation, and direct radiation (thermoluminescent dosimeter) measurements. Two formats for annual reports were established: (1) an environmental release report, which covered atmospheric releases and liquid effluent releases, and disposal of solid radioactive and non-radioactive wastes; and (2) a radiological surveillance report for the 100-N Area environment, which included data summaries for all measurements, sampling schedules/locations, and procedures. During the late 1970s and up to 1986, UNC Nuclear Industries prepared these reports.

The next significant evolution of monitoring the shoreline began in the late 1980s, partially as a consequence of installing basalt riprap along the N-Springs shoreline (Figure 8). Engineering drawings for riprap had been prepared in 1977 (Hanford Drawing 1977) but the actual installation did not occur until fall 1984 (Probasco 1986). The project included installing thirteen seepage sampling wells within the riprap, such that riverbank seepage could continue to be monitored in a more efficient manner. The seep wells consist of a carbon steel casing 30.48 centimeters in diameter set vertically in the riprap (Figure 9). The lower end of the casing was perforated with a series of 8 holes, 0.95-centimeter in diameter at 15.24-centimeter vertical intervals. The casing was set such that the perforated interval spanned the pre-riprap grade. These seep wells were subsequently sampled on an annual basis for analysis of radionuclides. Samples were also collected annually from several riverbank springs outside of the riprap area and from the composite sampling well 199-N-8T. Starting in 1985, use of the 1325-N LWDF (116-N-3 waste site) began and disposal to the 1301-N LWDF was significantly reduced, thus changing the supply rate and some of the characteristics of the groundwater that fed N-Springs. The 1325-N LWDF is located farther inland than 1301-N, and offered a longer groundwater pathway for radionuclide transport, which increased radionuclide “storage” capacity on aquifer solids and time for radioactive decay to occur.

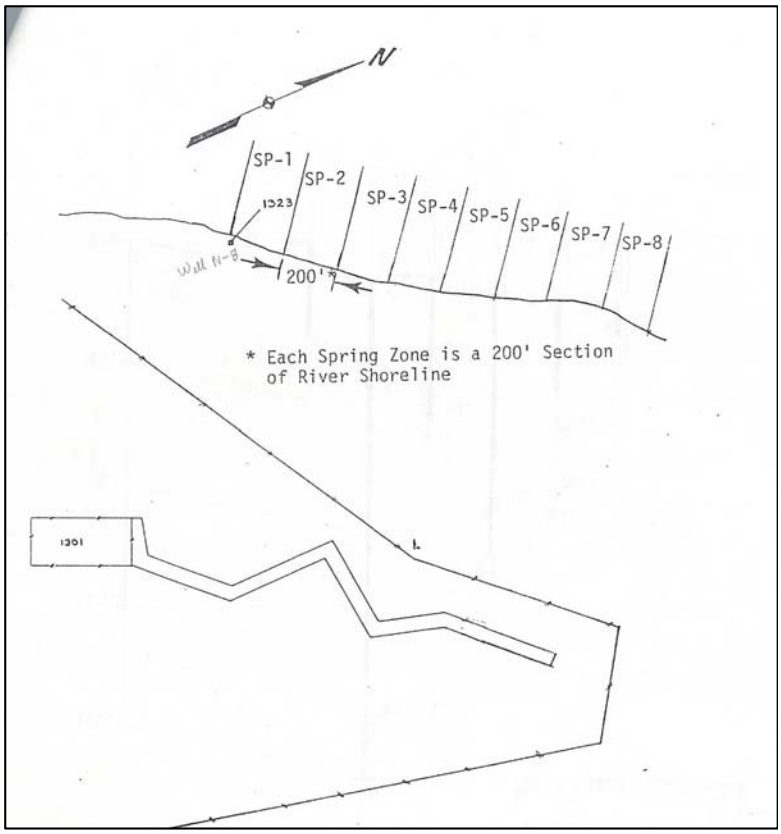


**Figure 7**. 100-N Area Spring Zones Sampled During the Early Years of the Environmental Monitoring Program

**Figure 8**. Riprap Boulders Along the 100-N Area Shoreline, 1997

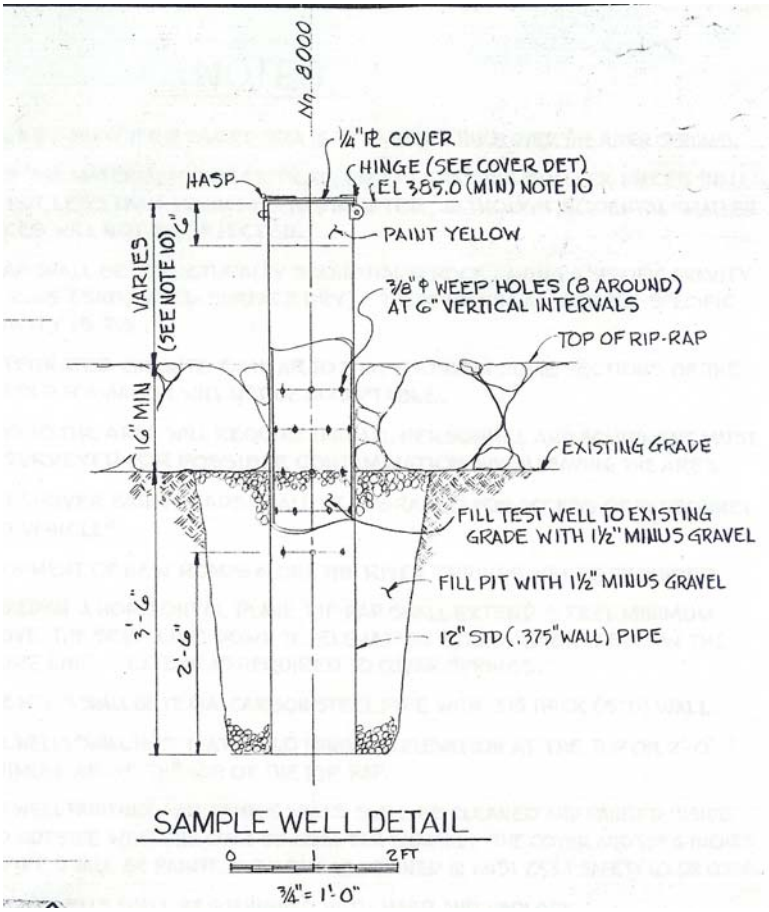


**Figure 9**. Diagram of Seep Well Installed in 100-N Springs Riprap

Through 1987, UNC Nuclear Industries prepared the reports describing the results of N-Springs monitoring. Starting in 1988, they were published by Westinghouse Hanford Company, and after 1995 by Fluor Hanford, Inc.

Throughout the early and mid-1990s, environmental sampling along the N-Springs shoreline was conducted by the Near-Field Environmental Monitoring Project, with additional monitoring of natural riverbank springs and biota being conducted under the PNNL Surface Environmental Surveillance Project. For most years, the analytical results for samples collected from the seep wells, and from the composite sample well 199-N-8T (or replacement composite sample well 199-N-46 after 1993), were included in the Near-Field Environmental Monitoring Project's reports. Up until approximately 1989, the report titles included the words "Characterization of Radionuclide Concentrations Along the N-Springs Shoreline for (year);" following that series, the report titles contained the words "Westinghouse Hanford Company Environmental Surveillance Annual Report: Calendar Year (year)." This title format continued until Fluor Hanford, Inc. became the primary contractor at the Hanford Site; starting in 1997, the report titles contained "Hanford Site Near-Facility Environmental Monitoring Annual Report, Calendar Year (year)," which continues as of 2003. The latter series of reports were also included in the Hanford Site annual environmental report, starting with the 1999 report (Poston et al. 2000).

## Aquatic Environment

For the purposes of this report, the aquatic environment includes aquatic habitat within the Columbia River and the persistent riverbank springs along the rivers edge.

The annual Hanford Site National Environmental Policy Act (NEPA) Characterization report (Neitzel 2002) provides a detailed summary of the ecology, biological resources, and hydrology for the entire Hanford Site, with selected information grouped by major operational areas (e.g., 200 Areas, 100 Areas) and some specific summaries for the 100-N Area. The Comprehensive River Conservation Study and Environmental Impact Statement for the Hanford Reach of the Columbia River (U.S. Department of Interior 1996) also provides general and specific information on the riparian and aquatic environments found within the Reach.

Two aquatic and riparian resource reports were issued evaluating the impact of the proposed Ben Franklin dam (e.g., Fickeisen et al. 1980a and 1980b). These studies discuss the various species found in the Hanford Reach and its shoreline.

Gray and Dauble (1977) provide a species list of fish found in the Hanford Reach over a 30-year period. Major and indicator species lists are provided for both terrestrial and aquatic flora and fauna in Weiss and Mitchell (1992). Neitzel and Frest (1993) evaluated the Hanford Reach for two potentially threatened invertebrate species (great Columbia River limpet [previously called the short face lanx] and the giant Columbia River spire snail [previously called the Columbia pebblesnail]) and identified potential habitat at 100-N Area. Another survey (Neitzel and Frest 1989) for these species found the giant Columbia River spire snail and great Columbia River limpet near the 100-F Area, but the survey did not extend to the 100-N Area. The fish species in the Hanford Reach of the Columbia River reported in the annual Hanford Site National Environmental Policy Act (NEPA) Characterization report (Neitzel et al. 2002) is provided in Table 7.

Fall chinook salmon, an important resource in the Pacific Northwest, are not known to have spawning nests (redds) in the Columbia River near the 100-N Area. Surveys of redds and the river indicate the closest areas to the 100-N Area with substantial salmon redds are at Coyote Rapids, upstream, and the 100-D Area, downstream.

During 2002, a vector layer describing the substrate types and macrophyte communities along the low water line at the 100-N Area shoreline of the Hanford Reach was developed as under the Ecological Monitoring and Compliance Project at PNNL under the Public Safety and Resource Protection Program (Task Manager – Brett Tiller, PNNL). The substrate classifications used for the geographic information system (GIS) map layer are listed in Table 8. The GIS map layer for the shoreline substrate is shown in Figure 5. This figure indicates that along a portion of the shoreline adjacent to the 100-N Area, boulders and large rocks (substrate class 4) fill the shoreline.

**Table 7**. Fish Species in the Hanford Reach of the Columbia River

| Scientific Name | Common Name |
|---|---|
| *Alosa sapidissima* | American shad |
| *Acipenser transmontanus* | white sturgeon |
| *Acrocheilus alutaceus* | chiselmouth |
| *Ameiurus melas* | black bullhead |
| *Ameiuruss natalis* | yellow bullhead |
| *Catostomus columbianus* | bridgelip sucker |
| *Catostomus macrocheilus* | largescale sucker |
| *Catostomus platyrhynchus* | mountain sucker |
| *Coregonus clupeaformis* | lake whitefish |
| *Cottus asper* | prickley sculpin |
| *Cottus bairdi* | mottled sculpin |
| *Cottus beldingi* | Paiute sculpin |
| *Cottus perplexus* | reticulate sculpin |
| *Cottus rotheus* | torrent sculpin |
| *Cyprinus carpio* | carp |
| *Entosphenus tridentatus* | Pacific lamprey |
| *Gasterosteus aculeatus* | threespine stickleback |
| *Ictalurus nebulosus* | brown bullhead |
| *Ictalurus punctatus* | channel catfish |
| *Lampetra ayresi* | river lamprey |
| *Lepomis gibbosus* | pumpkinseed |
| *Lepomis macrochirus* | bluegill |
| *Lota lota* | burbot |
| *Micropterus dolomieui* | smallmouth bass |
| *Micropterus salmoides* | largemouth bass |
| *Mylocheilus caurinus* | peamouth |
| *Oncorhynchus clarki* | cutthroat trout |
| *Oncorhynchus kisutch* | coho salmon |
| *Oncorhynchus mykiss* | rainbow trout (steelhead) |
| *Oncorhynchus nerka* | sockeye salmon |
| *Oncorhynchus tshawytscha* | chinook salmon |
| *Perca flavescens* | yellow perch |
| *Percopsis transmontana* | sandroller |
| *Pomoxis annularis* | white crappie |
| *Pomoxis nigromaculatus* | black crappie |
| *Prosopium williamsoni* | mountain whitefish |
| *Ptychocheilus oregonensis* | Northern pikeminnow (aka squawfish) |
| *Rhinichthys cataractae* | longnose dace |
| *Rhinichthys falcatus* | leopard dace |
| *Rhinichthys osculus* | speckled dace |
| *Richardsonius balteatus* | redside shiner |
| *Salvelinus malma* | Dolly Varden |
| *Stizostedion vitreum* | walleye |
| *Tinca tinca* | tench |

**Table 8**. Sediment Classifications Used for the 2002 Field Mapping of 100-N Area Substrate

| Category | Sediment Classification | Average Particle Diameter Size (cm) |
|---|---|---|
| 1 | Fines, sand, silt, and mud | <0.6 |
| 2 | Gravel-med cobble | 0.6–15.2 |
| 3 | Large cobble | 15.2–30.5 |
| 4 | Boulder/bedrock | >30.5 |

## 100-N Area Threatened or Endangered Species Issues

Threatened or endangered animal species that may be found in the vicinity of the 100-N Area shoreline include the bald eagle (*Haliaeetus leucocephalus*) (federal and state threatened), the American white pelican (*Pelecanus erythrorhychos*) (state endangered), the upper Columbia river steelhead (*Oncorhynchus mykiss*) (federal endangered, state candidate) and the upper Columbia river spring chinook salmon (*Oncorhynchus tshawytscha*) (federal endangered, state candidate). Eagles may forage in the area, and could perch on any trees in the area, but they are not residents in the vicinity of the 100-N Area. The nearest roost trees are on the west side of the 100-K Area (DOE 1994). White pelicans have been observed near the shoreline both immediately upstream and downstream of the 100-N Area (Ecological Compliance Assessment Project database – Corey Duberstein, Data Manager). Upper Columbia River chinook salmon do not spawn in the Hanford Reach. However, the adults could pass near the 100-N Area shoreline on their way upstream and the juvenile salmon may pass near the 100-N Area shoreline on their way downstream. Upper Columbia River steelhead do spawn in the Hanford Reach, but the water velocity in the areas immediately adjacent to the 100-N Area are too low and the river bottom cobbles are too large to support steelhead spawning. Eldred (1970) examined the Columbia River between Ringold and Priest Rapids Dam for steelhead spawning areas and did not find any between the 100-D Area and Coyote Rapids (upriver from the 100-K Area). Juvenile steelhead could be resident in the 100-N Area for short periods.

Other animal species of concern that could be present in the area include the giant Columbia River spire snail (*Fluminicola columbiana*) and the great Columbia River limpet (*Fisherola nuttalli*), both of which were found by Neitzel and Frest (1989) at the 100-F Area. These snails are both state candidate species, and may be found on rocks below the low water level. Other state candidate species observed in the 100-N Area riparian or near-shore areas are the common loon (*Gavia immer*), which is regularly seen near the shore both immediately upstream and downstream of the 100-N Area, and the western grebe (*Aechmorus occidentalis*), which was observed once near the shoreline just upstream of the 100-N Area (Ecological Compliance Assessment Project database).

There are no plant species that are federally listed as endangered or threatened that could occur at the 100-N Area, but there are several species listed by Washington State as threatened or sensitive that could be in the area. These species include four state threatened species – awned halfchaff sedge (*Lipocarpha aristulata*), grand redstem (*Ammannia robusta*), lowland toothcup (*Rotala ramosior*), and the persistent sepal yellowcress (*Rorippa columbiae*), and two state sensitive species – the Canadian St. John's wort (*Hypericum majus*) and the shining flatsedge (*Cyperus bipartitus*). All of these species are found near the Columbia River shoreline in wetland areas; the yellowcress is often found in rockier areas than the other

species. None of these species have been reported at the 100-N Area, but relatively little of that shoreline has been extensively studied. Caplow and Beck (1996) identified wetland areas throughout the Hanford Reach via aerial survey followed by foot and boat surveys. They identified over 30 wetland areas, but apparently did not identify any in the vicinity of the 100-N Area; however, they surveyed very little of the shoreline in proximity to the reactor areas along the Columbia River.

# Contaminant Data Literature Summary

This section summarizes contaminant data for the 100-N Area found during the literature search. The data is presented for riparian (abiotic and biotic) and the aquatic (abiotic and biotic) environments. Tables 9 through 18 show the maximum concentrations of contaminants found during wildlife,

**Table 9**. Maximum Concentration (pCi/g dry wt.) Radionuclides in Soil and River Sediment Near the 100-N Area, 1993 to Present (SESP Sampling)

| Contaminant | Max value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|
| Be-7 | 0.479 | 15 | 0.195 | | 100-N Spring-5 |
| Ce/Pr-144 | 0.0111 | 6 | 0.238 | U[(a)] | 100-N Spring Shoreline |
| Co-60 | 1.05 | 15 | 0.117 | | 100-N Spring-1 |
| Cs-134 | 0.057 | 15 | 0.021 | U | 100-N Shore above HGP[(b)] |
| Cs-137 | 0.649 | 15 | 0.0948 | | 100-N Spring Shoreline |
| Eu-152 | 0.899 | 1 | 0.117 | | 100-N Shore above HGP |
| Eu-154 | 0.157 | 15 | 0.106 | | E of 100-N Area |
| Eu-155 | 0.103 | 15 | 0.109 | U | E of 100-N Area |
| K-40 | 16.9 | 15 | 1.73 | | 100-N Shore above HGP |
| Pu-238 | 0.000553 | 12 | 0.000349 | | 100-N Spring Shoreline |
| Pu-239/240 | 0.0155 | 12 | 0.00253 | | 100-N Spring Shoreline N |
| Ra-226 | 0.9 | 5 | 0.106 | | 100-N Spring-1 |
| Ra-228 | 1 | 5 | 0.163 | | 100-N Spring-1 |
| Ru-106 | 0.155 | 15 | 0.187 | U | NE of 100-N Area |
| Sb-125 | 0.0597 | 15 | 0.0825 | U | E of 100-N Area |
| Sr-90 | 46.7 | 15 | 8.53 | | 100-N Spring-3 |
| U-234 | 0.146 | 6 | 0.035 | | 100-N Shore above HGP |
| U-235 | 0.154 | 12 | 0.0904 | | NE of 100-N Area |
| U-238 | 1.45 | 12 | 0.287 | | E of 100-N Area |
| Zn-65 | -0.0138 | 6 | 0.0695 | U | 100-N Spring Shoreline |
| Zr/Nb-95 | 0.00429 | 6 | 0.0659 | U | 100-N Spring Shoreline |

(a) U = Undetected.
(b) HGP = Hanford Generating Plant, Washington State Public Power Supply System.

**Table 10**. Maximum Concentrations (pCi/g, wet wt.) of Radionuclides in Wildlife Samples Collected Near the 100-N Area, 1993 to Present (SESP Sampling)

| Species | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Canada goose | Be-7 | 0.087 | 16 | 0.229 | U[(a)] | 100-N - 100-D |
| | Ce/Pr-144 | -0.127 | 1 | 0.149 | U | 100-N - 100-D |
| | Co-60 | 0.0348 | 16 | 0.0338 | U | 100-N - 100-D |
| | Cs-134 | 0.0293 | 16 | 0.034 | U | 100-N - 100-D |
| | Cs-137 | 0.044 | 16 | 0.0229 | U | 100-N - 100-D |
| | Eu-154 | 0.11 | 16 | 0.0717 | U | 100-N - 100-D |
| | Eu-155 | 0.0391 | 16 | 0.0482 | U | 100-N - 100-D |
| | K-40 | 3.7 | 16 | 1.04 | | 100-N - 100-D |
| | Ru-106 | 0.134 | 11 | 0.19 | U | 100-N - 100-D |
| | Sb-125 | 0.0473 | 11 | 0.018 | U | 100-N - 100-D |
| | Sr-90 | 0.717 | 27 | 0.164 | | 100-N - 100-D |
| | Zn-65 | 0.0371 | 1 | 0.0441 | U | 100-N - 100-D |
| | Zr/Nb-95 | 0.00808 | 1 | 0.0526 | U | 100-N - 100-D |
| Mule deer | Be-7 | 0.54 | 3 | 0.567 | U | Across river 100-N |
| | Co-60 | 0.00593 | 3 | 0.0176 | U | Across river 100-N |
| | Cs-134 | 0.00569 | 3 | 0.0091 | U | Across river 100-N |
| | Cs-137 | 0.0076 | 3 | 0.00974 | U | Across river 100-N |
| | Eu-154 | 0.0386 | 3 | 0.0403 | U | Across river 100-N |
| | Eu-155 | 0.0158 | 3 | 0.0201 | U | Across river 100-N |
| | K-40 | 3.27 | 3 | 0.59 | | Across river 100-N |
| | Ru-106 | 0.0189 | 3 | 0.11 | U | Across river 100-N |
| | Sb-125 | 0.0252 | 3 | 0.0217 | U | Across river 100-N |
| | Sr-90 | 0.588 | 3 | 0.127 | | Across river 100-N |
| Pheasant | Be-7 | 0.0344 | 2 | 0.235 | U | Near 100-N |
| | Ce/Pr-144 | -0.00974 | 2 | 0.176 | U | Near 100-N |
| | Co-60 | 0.0207 | 3 | 0.0204 | | Near 100-N |
| | Cs-134 | 0.0622 | 3 | 0.0164 | | Near 100-N |
| | Cs-137 | 1.99 | 3 | 0.204 | | Near 100-N |
| | Eu-154 | 0.0136 | 2 | 0.0548 | U | Near 100-N |
| | Eu-155 | 0.00797 | 2 | 0.0485 | U | Near 100-N |
| | K-40 | 3.56 | 3 | 0.809 | | Near 100-N |
| | Ru-106 | 0.142 | 2 | 0.168 | U | Near 100-N |
| | Sb-125 | 0.0275 | 2 | 0.0593 | U | Near 100-N |
| | Sr-90 | 0.0799 | 4 | 0.0475 | | Near 100-N |
| | Zn-65 | 0.0617 | 3 | 0.0409 | | Near 100-N |
| | Zr/Nb-95 | 0.0191 | 2 | 0.0615 | U | Near 100-N |

(a) U = Undetected.

**Table 11**. Maximum Concentration (pCi/g, dry wt.) of Radionuclides in Vegetation Samples Collected Near the 100-N Area, 1993 to Present (SESP Sampling)

| Species | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Balsamroot | Be-7 | 3.67 | 10 | 0.788 | | 100-N - 100-D |
| | Ce/Pr-144 | 0.125 | 10 | 0.275 | U[(a)] | 100 KE - 100-N |
| | Co-60 | 0.0441 | 10 | 0.0116 | | 100 KE - 100-N |
| | Cs-134 | 0.0209 | 10 | 0.0266 | U | 100 KE - 100-N |
| | Cs-137 | 0.087 | 10 | 0.0184 | | 100 KE - 100-N |
| | Eu-154 | 0.0607 | 10 | 0.112 | U | 100-N - 100-D |
| | Eu-155 | 0.0216 | 10 | 0.102 | U | 100 KE - 100-N |
| | K-40 | 39.9 | 10 | 4.51 | | 100-N - 100-D |
| | Ru-106 | 0.221 | 10 | 0.444 | U | 100-N - 100-D |
| | Sb-125 | 0.0376 | 10 | 0.125 | U | 100-N - 100-D |
| | Sr-90 | 0.0578 | 10 | 0.0137 | | 100-N - 100-D |
| | Zn-65 | 0.137 | 10 | 0.0777 | | 100 KE - 100-N |
| | Zr/Nb-95 | 0.0419 | 10 | 0.128 | U | 100-N - 100-D |
| Cymopteris | Be-7 | 4.04 | 1 | 0.639 | | 100 KE - 100-N |
| | Ce/Pr-144 | 0.0579 | 1 | 0.29 | U | 100 KE - 100-N |
| | Co-60 | 0.012 | 1 | 0.0368 | U | 100 KE - 100-N |
| | Cs-134 | 0.0034 | 1 | 0.0321 | U | 100 KE - 100-N |
| | Cs-137 | -0.00372 | 1 | 0.0352 | U | 100 KE - 100-N |
| | Eu-154 | 0.114 | 1 | 0.132 | U | 100 KE - 100-N |
| | Eu-155 | 0.0441 | 1 | 0.0904 | U | 100 KE - 100-N |
| | K-40 | 32.8 | 1 | 3.62 | | 100 KE - 100-N |
| | Ru-106 | -0.062 | 1 | 0.284 | U | 100 KE - 100-N |
| | Sb-125 | 0.0158 | 1 | 0.0801 | U | 100 KE - 100-N |
| | Sr-90 | 0.00737 | 3 | 0.00619 | | 100 KE - 100-N |
| | Zn-65 | 0.126 | 1 | 0.0974 | | 100 KE - 100-N |
| | Zr/Nb-95 | 0.0129 | 5 | 0.0874 | U | 100 KE - 100-N |
| Milfoil | Be-7 | 4.16 | 5 | 1.08 | | 100-N - 100-D |
| | Ce/Pr-144 | -0.0834 | 5 | 0.398 | | 100-N - 100-D |
| | Co-60 | 0.12 | 5 | 0.0557 | U | 100-N - 100-D |
| | Cs-134 | 0.0129 | 5 | 0.0364 | U | 100-N - 100-D |
| | Cs-137 | 0.147 | 5 | 0.0581 | | 100-N - 100-D |
| | Eu-154 | 0.246 | 5 | 0.142 | | 100-N - 100-D |
| | Eu-155 | 0.1 | 5 | 0.0974 | U | 100-N - 100-D |
| | K-40 | 21.7 | 5 | 2.95 | | 100-N - 100-D |
| | Ra-226 | 0.441 | 1 | 0.182 | | 100-N - 100-D |
| | Ra-228 | 0.447 | 1 | 0.326 | | 100-N - 100-D |
| | Ru-106 | 0.341 | 5 | 0.408 | U | 100-N - 100-D |
| | Sb-125 | 0.0972 | 5 | 0.124 | U | 100-N - 100-D |
| | Sr-90 | 0.161 | 5 | 0.0339 | | 100-N - 100-D |
| | U-234 | 0.819 | 3 | 0.0894 | | 100-N - 100-D |
| | U-235 | 0.0253 | 3 | 0.00685 | | 100-N - 100-D |
| | U-238 | 0.669 | 3 | 0.0964 | | 100-N - 100-D |
| | Zn-65 | 0.121 | 3 | 0.0938 | | 100-N - 100-D |
| | Zr/Nb-95 | 0.109 | 3 | 0.118 | U | 100-N - 100-D |

**Table 11**. (contd)

| Species | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Mulberry | Be-7 | 2.69 | 4 | 0.32 | | 1 mi. DS[b] E. Edge RCA,[c] 100-N Spring |
| | Co-60 | 0.00682 | 4 | 0.0096 | U | 100 yds DS 100-N TLD[d] (in RCA) |
| | Cs-134 | 0.000541 | 4 | 0.0079 | U | 100 yds DS 100-N TLD (in RCA) |
| | Cs-137 | 0.0175 | 4 | 0.0076 | U | Tree by 100-N TLD upstream RCA |
| | Eu-154 | 0.0206 | 4 | 0.069 | U | 100 N Area |
| | Eu-155 | 0.00584 | 4 | 0.018 | U | Tree by 100-N TLD upstream RCA |
| | K-40 | 11.2 | 4 | 1.5 | | 100 N Area |
| | Pu-238 | 7.34E-06 | 3 | 0.00019 | U | 1 mi. DS E. edge RCA, 100-N Spring |
| | Pu-239/240 | 0.000168 | 3 | 0.0003 | U | 1 mi. DS E. edge RCA, 100-N Spring |
| | Ru-106 | -0.00745 | 4 | 0.058 | U | Tree by 100-N TLD upstream RCA |
| | Sb-125 | 0.0121 | 4 | 0.061 | U | 100-N Area |
| | Sr-90 | 28.2 | 4 | 4.9 | | 100 yds DS 100-N TLD (in RCA) |
| Perennial Vegetation | Be-7 | 4.52 | 9 | 0.635 | | E of 100-N Area |
| | Ce/Pr-144 | 0.0363 | 4 | 0.391 | U | 100-N Spring Shoreline |
| | Co-60 | 0.0348 | 9 | 0.027 | | E of 100-N Area |
| | Cs-134 | 0.00664 | 9 | 0.02 | U | 100-N Spring Shoreline |
| | Cs-137 | 0.0487 | 9 | 0.0472 | | 100-N Spring Shoreline |
| | Eu-154 | 0.27 | 9 | 0.127 | | NE of 100-N Area |
| | Eu-155 | 0.0162 | 9 | 0.0458 | U | NE of 100-N Area |
| | K-40 | 19.8 | 9 | 2.15 | | 100-N Spring Shoreline |
| | Pu-238 | 9.39E-05 | 9 | 0.0002 | | E of 100-N Area |
| | Pu-239/240 | 0.00047 | 9 | 0.0002 | | 100-N Spring Shoreline |
| | Ru-106 | 0.0358 | 9 | 0.13 | U | NE of 100-N Area |
| | Sb-125 | 0.102 | 9 | 0.111 | U | 100-N Spring Shoreline |
| | Sr-90 | 0.408 | 9 | 0.0757 | | 100-N Spring Shoreline |
| | U-234 | 0.0103 | 9 | 0.0084 | | NE of 100-N Area |
| | U-235 | 0.00223 | 9 | 0.008 | U | 100-N Spring Shoreline |
| | U-238 | 0.00574 | 9 | 0.0068 | U | NE of 100-N Area |
| | Zn-65 | 0.00462 | 4 | 0.0445 | U | NE of 100-N Area |
| | Zr/Nb-95 | -0.00239 | 4 | 0.0335 | U | E of 100-N Area |
| Reed Canarygrass | Be-7 | 0.661 | 1 | 0.25 | | 100-N Area |
| | Co-60 | 0.00354 | 1 | 0.019 | U | 100-N Area |
| | Cs-134 | -0.0147 | 1 | 0.014 | U | 100-N Area |
| | Cs-137 | 0.0151 | 1 | 0.015 | U | 100-N Area |

**Table 11**. (contd)

| Species | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Reed Canarygrass (contd) | Eu-154 | -0.0325 | 1 | 0.057 | U | 100-N Area |
| | Eu-155 | 0.0121 | 1 | 0.04 | U | 100-N Area |
| | K-40 | 12.8 | 1 | 1.5 | | 100-N Area |
| | Ru-106 | -0.0422 | 1 | 0.13 | U | 100-N Area |
| | Sb-125 | -0.00412 | 1 | 0.038 | U | 100-N Area |
| | Sr-90 | 11.1 | 1 | 2.5 | | 100-N Area |

(a) U = Undetected
(b) DS = Downstream.
(c) RCA = Radiological control area.
(d) TLD = Thermoluminescent dosimeter.

vegetation, soil, and water sampling by the Surface Environmental Surveillance Project (SESP) staff from 1993 to present. Maximum concentrations are presented because they provide a worst case highly conservative screen of the data and help to focus attention on contaminants, media, species, and areas of concern within the 100-N Area. However, using maximum concentrations may bias the interpretation because outlying data points (e.g., anomalous data) may not accurately represent the environmental conditions. For some media, the average concentrations reported for SESP data from 1993 to present are also provided. These results provide an indication of central tendency and may provide a better indication of environmental conditions. The maximum concentrations of radionuclides and metals found in wildlife, vegetation, soil, and water samples from the early 1970s to present are shown in Appendix A. In addition, external radiation has been measured with thermoluminescent dosimeters in several locations near 100-N Area. Maximum external doses measured in the area from 1970 to 2003 are shown in Appendix Table B.9. Ambient air sample data for radionuclides at the 100-N Area is available but not included in this report. A synopsis for the contaminants of concern is present in the Overall Summary section of this report.

## Contaminant Data for Riparian Environment

Sula (1980) conducted a radiological survey of exposed shoreline and islands of the Columbia River between the Vernita Bridge and the Snake River confluence. External exposure rates were measured along the exposed shorelines. From the 100-K to 100-N Areas, the average exposure rate was 11 ± 2 μR/h, and from the 100-N to 100-D Areas, the average was 8 ± 2 μR/h. The maximum rate was 880 μR/h from skyshine near the 100-N Area. The study also sampled vegetation and soil for gamma-emitting radionuclides. No discrete particles of cobalt-60 contaminated metal, associated with releases from the single-pass reactors, were found near the 100-N Area.

Reiman and Dahlstrom (1990) conducted an aerial survey of gamma exposure rates at the Hanford Site. The report provides isoradiation contour maps of the 100-N Area and other Hanford operational areas. For the 100-N Area, the highest rates were measured at the liquid waste disposal facilities (7,000,000 to 22,000,000 counts per second). Along the Columbia River shoreline the rates were 22,000

**Table 12**. Maximum Concentration Radionuclides in Water Samples Near the 100-N Area, 1993 to Present (SESP Sampling)

| Sample Source | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Drinking | Alpha | 1.06 | 5 | 0.96 | U[(a)] | 100-N Area |
| | Beta | 4.21 | 5 | 1.8 | | 100-N Area |
| | I-131 | 0.215 | 2 | 0.38 | U | 100-N Area |
| | Ra-226 | 0.0302 | 2 | 0.011 | | 100-N Area |
| | Ra-228 | 0.668 | 2 | 0.29 | | 100-N Area |
| | Sr-90 | 0.0894 | 3 | 0.038 | | 100-N Area |
| | Tritium | 136 | 3 | 77 | U | 100-N Area |
| Groundwater | Be-7 | 8.47 | 1 | 11 | U | 100-N Area-Plant rooting zone |
| | Co-60 | 0.993 | 1 | 1.1 | U | 100-N Area-Plant rooting zone |
| | Cs-134 | -1.56 | 1 | 1.2 | U | 100-N Area-Plant rooting zone |
| | Cs-137 | 0.211 | 1 | 1.1 | U | 100-N Area-Plant rooting zone |
| | Eu-154 | 2.74 | 1 | 3.3 | U | 100-N Area-Plant rooting zone |
| | Eu-155 | -0.889 | 1 | 2.1 | U | 100-N Area-Plant rooting zone |
| | K-40 | 3.82 | 1 | 28 | U | 100-N Area-Plant rooting zone |
| | Ru-106 | 1.51 | 1 | 9.5 | U | 100-N Area-Plant rooting zone |
| | Sb-125 | -1.08 | 1 | 2.4 | U | 100-N Area-Plant rooting zone |
| | Sr-90 | 109 | 1 | 25 | | 100-N Area-Plant rooting zone |
| | Tritium | -20.8 | 1 | 110 | U | 100-N Area-Plant rooting zone |
| River | Alpha | 1.12 | 22 | 0.767 | | 100-N Area |
| | Be-7 | 11.2 | 33 | 11.7 | U | 100-N Area |
| | Beta | 3.63 | 22 | 1.69 | | 100-N Area |
| | Ce/Pr-144 | 10.3 | 12 | 8.56 | | 100-N Area |
| | Co-60 | 1.23 | 33 | 1.48 | U | 100-N Area |
| | Cs-134 | 1.29 | 33 | 0.934 | | 100-N Area |
| | Cs-137 | 1.93 | 33 | 1.32 | | 100-N Area |
| | Eu-154 | 3.43 | 33 | 5.06 | U | 100-N Area |
| | Eu-155 | 2.21 | 33 | 2.92 | U | 100-N Area |
| | K-40 | 141 | 33 | 32.2 | U | 100-N Area |
| | Ru-106 | 14.3 | 23 | 9.12 | U | 100-N Area |
| | Sb-125 | 3.24 | 23 | 2.5 | U | 100-N Area |
| | Sr-90 | 4.55 | 110 | 0.869 | | 100-N Area |
| | Tc-99 | 0.512 | 21 | 1.36 | U | 100-N Area |
| | Tritium | 998 | 119 | 90.2 | | 100-N Area |

**Table 12**. (contd)

| Sample Source | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| River (contd) | U-234 | 0.411 | 102 | 0.0757 | | 100-N Area |
| | U-235 | 0.0327 | 102 | 0.034 | U | 100-N Area |
| | U-238 | 0.275 | 102 | 0.1 | | 100-N Area |
| | Zn-65 | 5.16 | 12 | 4.44 | | 100-N Area |
| | Zr/Nb-95 | 2.72 | 12 | 2.18 | | 100-N Area |
| Seep | Alpha | 8.07 | 13 | 3.33 | | 100-N Spring 8-13 |
| | Be-7 | 22.3 | 13 | 35 | U | 100-N Spring 8-13 |
| | Beta | 15600 | 13 | 1450 | | 100-N Spring 8-13 |
| | Ce/Pr-144 | 4.77 | 3 | 15.5 | U | 100-N Spring 8-13 |
| | Co-60 | 2.15 | 13 | 1.65 | U | 100-N Spring 8-13 |
| | Cs-134 | 2.42 | 13 | 3.73 | U | 100-N Spring 8-13 |
| | Cs-137 | 1.3 | 13 | 2.2 | U | 100-N Spring 8-13 |
| | Eu-154 | 7.95 | 13 | 11.1 | U | 100-N Spring 8-13 |
| | Eu-155 | 2.49 | 13 | 4.9 | U | 100-N Spring 8-13 |
| | K-40 | 324 | 13 | 91.9 | | 100-N Spring 8-13 |
| | Ru-106 | 40.5 | 12 | 38.3 | | 100-N Spring 8-13 |
| | Sb-125 | 6.6 | 12 | 6.9 | U | 100-N Spring 8-13 |
| | Sr-90 | 9870 | 12 | 1850 | | 100-N Spring 8-13 |
| | Tc-99 | 2.42 | 4 | 0.72 | | 100-N Spring 8-13 |
| | Tritium | 30900 | 13 | 2380 | | 100-N Spring 8-13 |
| | U-234 | 1.35 | 4 | 0.189 | | 100-N Spring 8-13 |
| | U-235 | 0.0405 | 4 | 0.022 | | 100-N Spring 8-13 |
| | U-238 | 1.08 | 4 | 0.158 | | 100-N Spring 8-13 |
| | Zn-65 | 10 | 3 | 6.41 | | 100-N Spring 8-13 |
| | Zr/Nb-95 | 1.09 | 3 | 8.47 | U | 100-N Spring 8-13 |

(a) U = Undetected.

to 222,000 counts per second, with elevated rates (compared to a background <700 counts per second) extending across the river to the Grant County shoreline with rates of 700 to 7,000 counts per second.

Poston et al. (1995) reviewed soil and vegetation sampling efforts at or near the 100-N Area and compared the combined results with the other Hanford areas and offsite. Strontium-90 and tritium were the only radionuclides that accumulated significantly above background in shoreline vegetation up or downstream of the 100-N Area.

Price (1998) reviewed historical data on the radionuclide levels in soil samples collected routinely for environmental sampling programs both on and near the Hanford Site. Although the 100-N Area data was not comprehensive, the report provides offsite and other control results for strontium-90, cesium-137, plutonium-238, plutonium-239/240, americium-241, and uranium.

For Surface Environmental Surveillance Project samples, the average concentration of strontium-90 in soil samples collected around the 100-N Area during 1993 to 2003 was 3.20 ± 12.0 pCi/g. Soil samples collected near the 100-N Area riverbank springs in 1997 had the highest levels of strontium-90.

**Table 13**. Maximum Concentration of Metals, Anions, and Volatile Organic Compounds in Riverbank Springs Near the 100-N Area,[a] 1994 to Present (SESP Sampling)

| Contaminant | Max Value (µg/L) | Number of Samples | Total Analytical Error (±) | Lab Qualifier |
|---|---|---|---|---|
| **Volatile Organics** | | | | |
| 1,1,1-Trichloroethane | 0.36 | 1 | -- | U[b] |
| 1,1,2-Trichloroethane | 0.53 | 1 | -- | U |
| 1,1-Dichloroethane | 0.37 | 1 | -- | U |
| 1,2-Dichloroethane | 0.43 | 1 | -- | U |
| 1,4-Dichlorobenzene | 0.5 | 1 | -- | U |
| 1-Butanol | 25 | 1 | -- | U |
| Acetone | 1.4 | 1 | -- | U |
| Benzene | 0.38 | 1 | -- | U |
| Carbon Disulfide | 0.33 | 1 | -- | U |
| Carbon Tetrachloride | 0.35 | 1 | -- | U |
| Chloroform | 1.5 | 3 | -- | L[c] |
| Cis-Dichloroethylene | 0.47 | 1 | -- | U |
| Ethylcyanide | 2.1 | 1 | -- | U |
| Hexone | 1.1 | 1 | -- | U |
| Methone | 3.4 | 1 | -- | U |
| Methylene Chloride | 1.3 | 2 | -- | U |
| Perchloroethylene | 1.4 | 2 | -- | U |
| Tetrahydrofuran | 2.5 | 1 | -- | U |
| Toluene | 0.44 | 1 | -- | U |
| Trans-Dichloroethylene | 0.48 | 1 | -- | U |
| Trichloroethylene | 0.39 | 1 | -- | U |
| Vinyl Chloride | 1.3 | 1 | -- | U |
| Xylenes | 1.3 | 1 | -- | U |
| Metals | | | | |
| Ag | 4.5 | 1 | -- | U |
| Al | 9400 | 2 | -- | -- |
| As | 3.6 | 1 | -- | L |
| Ba | 140 | 3 | 67.2 | -- |
| Be | 0.2 | 1 | -- | U |
| Ca | 32000 | 3 | 5760 | -- |
| Cd | 0.31 | 1 | -- | U |
| Co | 5 | 1 | -- | U |
| Cr | 45 | 2 | 18.9 | B[d] |
| Cr+6 | 5.3 | 2 | -- | -- |
| Cu | 30 | 2 | -- | U |
| Fe | 12000 | 3 | 1080 | -- |
| K | 3000 | 3 | 630 | -- |
| Mg | 10000 | 3 | 2100 | -- |
| Mn | 680 | 3 | 102 | -- |
| Na | 8500 | 3 | 2300 | -- |
| Ni | 25 | 2 | -- | U |

**Table 13**. (contd)

| Contaminant | Max Value (µg/L) | Number of Samples | Total Analytical Error (±) | Lab Qualifier |
|---|---|---|---|---|
| Pb | 4.9 | 1 | 1.47 | -- |
| Sb | 43 | 2 | -- | U |
| Se | 3.8 | 1 | -- | U |
| Sn | 85 | 2 | 76.5 | L |
| Sr | 150 | 2 | | -- |
| Tl | 3.7 | 1 | -- | U |
| V | 42 | 3 | 25.2 | -- |
| Zn | 460 | 3 | 152 | -- |
| **Anions** | | | | |
| Bromide | 21 | 1 | 2.52 | L |
| Chloride | 10000 | 3 | 1800 | D[e] |
| Fluoride | 600 | 3 | 234 | -- |
| Nitrate | 15000 | 3 | 3150 | D |
| Nitrite | 11 | 1 | -- | U |
| Phosphate | 83 | 1 | -- | U |
| Sulfate | 26000 | 3 | 9360 | D |

(a) Sample collection location: 100-N Spring 8-13.
(b) U = Undetected.
(c) L = Detected value but below the contract required quantitation limit.
(d) B = Detected in analytical blank.
(e) D = Dilution required prior to final analysis.

## 100-N Area Springs Monitoring Prior to Installation of Riprap (pre-1984)

The contaminant data literature review conducted for this report focused on data reports prepared after initiation of a formal environmental surveillance program for 100-N Area in 1979, and particularly on data collected following the installation of riprap and seep wells in 1984. However, some data for the earlier period are contained in published special investigation reports (e.g., Eliason 1967). Further effort is required to incorporate those earlier data into meaningful trend information.

## 100-N Area Springs Monitoring Subsequent to Installation of Riprap (post-1984)

The 100-N Reactor was shut down in 1987, so liquid effluent release to the 1325-N LWDF essentially stopped, and the supply of contaminants to N-Springs started to decrease significantly. The decrease in level of contamination at N-Springs since shutdown of the reactor and waste disposal facilities, along with any potential change in trend that correlates with operation of the pump-and-treat system (startup in September 1995), are key topics that pertain to decisions regarding remedial actions for strontium-90 contamination.

For this literature review, an attempt was made to identify and obtain copies of all reports containing analytical results for samples from riverbank springs and rip-rap seep wells that are associated with

**Table 14**. Maximum Concentration of Metals, Anions and Volatile Organic Compounds Measured in the Columbia River Near the 100-N Area, 1994 to Present (SESP Sampling)

| Contaminant | Max Value (µg/L) | Number of Samples | Total Analytical Error (±) | Lab Qualifier |
|---|---|---|---|---|
| **Volatile Organics** | | | | |
| 1,1,1-Trichloroethane | 0.36 | 10 | -- | U[a] |
| 1,1,2-Trichloroethane | 0.53 | 10 | -- | U |
| 1,1-Dichloroethane | 0.37 | 10 | -- | U |
| 1,2-Dichloroethane | 0.43 | 10 | -- | U |
| 1,4- Dichlorobenzene | 0.5 | 10 | -- | U |
| 1-Butanol | 25 | 10 | -- | U |
| Acetone | 7.9 | 10 | -- | B,[b] L[c] |
| Benzene | 0.38 | 10 | -- | U |
| Carbon Disulfide | 0.33 | 10 | -- | U |
| Carbon Tetrachloride | 0.35 | 10 | -- | U |
| Chloroform | 0.41 | 10 | -- | U |
| Cis-Dichloroethylene | 0.47 | 10 | -- | U |
| Ethylcyanide | 2.1 | 10 | -- | U |
| Hexone | 1.1 | 10 | -- | U |
| Methone | 3.4 | 10 | -- | U |
| Methylene chloride | 0.51 | 18 | -- | B, L |
| Perchloroethylene | 0.35 | 10 | -- | U |
| Tetrahydrofuran | 2.5 | 10 | -- | U |
| Toluene | 0.44 | 10 | -- | U |
| Tran-Dichloroethylene | 0.48 | 10 | -- | U |
| Trichloroethylene | 0.39 | 10 | -- | U |
| Vinyl Chloride | 1.3 | 10 | -- | U |
| Xylenes | 1.3 | 10 | -- | U |
| **Metals** | | | | |
| Ag | 4.5 | 10 | -- | U |
| Al | 91 | 22 | 19.1 | L, B |
| As | 2.6 | 10 | -- | U |
| Ba | 33 | 30 | 15.8 | -- |
| Be | 0.2 | 10 | -- | U |
| Ca | 18000 | 30 | 3240 | -- |
| Cd | 2.1 | 17 | 0.693 | B, L |
| Co | 7.6 | 11 | 2.28 | L |
| Cr | 19 | 15 | 9.12 | B, L |
| Cu | 8.7 | 21 | -- | U |
| Fe | 130 | 30 | 42.9 | -- |
| K | 1500 | 20 | 315 | B |
| Mg | 4600 | 30 | 966 | -- |
| Mn | 8.5 | 30 | 1.53 | L |
| Na | 3100 | 30 | 837 | -- |
| Ni | 16 | 11 | 4.32 | L |
| Pb | 1.7 | 11 | -- | U |

**Table 14**. (contd)

| Contaminant | Max Value (µg/L) | Number of Samples | Total Analytical Error (±) | Lab Qualifier |
|---|---|---|---|---|
| Sb | 43 | 10 | -- | U |
| Se | 3.8 | 10 | -- | U |
| Sn | 49 | 12 | 44.1 | L |
| Sr | 99 | 20 | -- | -- |
| Tl | 3.7 | 10 | -- | U |
| V | 3.1 | 13 | 1.86 | L |
| Zn | 25 | 25 | 8.25 | -- |
| **Anions** | | | | |
| Bromide | 15 | 10 | -- | U |
| Chloride | 1300 | 30 | 234 | -- |
| Fluoride | 400 | 30 | 228 | -- |
| Nitrate | 1600 | 22 | 336 | -- |
| Nitrite | 18 | 10 | 9.72 | L |
| Phosphate | 83 | 10 | -- | U |
| Sulfate | 10000 | 30 | 3600 | D[(d)] |

(a) U = Undetected
(b) B = Detected in analytical blank
(c) L= Detected value but below the contract required quantitation limit.
(d) D = Dilution required prior to final analysis.

N-Springs, and also the wells used to obtain composite samples of near-river groundwater (wells 199-N-8T and 199-N-46) (Figure 10). Because no electronic database for non-PNNL results could be identified (the results collected outside of the PNNL projects are not entered into HEIS), it was decided to copy data from published reports and enter them into an electronic spreadsheet, such that trend charts could be prepared. As of July 2003, efforts are still underway to obtain copies of all data reports identified. For water samples from riverbank springs and the Columbia River collected under PNNL SESP and its predecessors, the data are contained in HEIS under the surface water (SW) media category, or in project-specific databases maintained by PNNL.

The water quality data from seep wells at the 100-N Area springs that are available to investigate contaminant trends since approximately 1985 include the radionuclides strontium-90 and tritium. No chemical (e.g., anions, cations) or physical parameters (e.g., pH, specific conductance) are available for these samples. Analysis of trends in all available historical analytical results is beyond the scope of this literature review, but some trend analysis is possible with the most accessible data. The strontium-90 trend in seep well NS-3 is shown in Figure 11. Following shutdown of the 100-N Reactor in 1988, there is a noticeable decline in concentrations, which correlates with a decline in water-table elevation as the mound beneath 1301-N and 1325-N LWDF dissipates (see water level trend for well 199-N-2, Figure 11). Declining strontium-90 concentrations in seep well NS-4 lag the decline in NS-3, perhaps because some strontium-90 is displaced in a downstream direction from the central portion of the plume.

There is a noticeable increase in strontium-90 concentrations at seep well NS-3 following the startup of the pump-and-treat system in September 1995 (Figure 11). Also, during 1996 and 1997, there was an

**Table 15**. Maximum Concentration (pCi/g, dry wt.) of Radionuclides in Soil and River Sediments Near the 100-N Area, 1993 to Present (SESP Sampling)

| Contaminant | Max value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|
| Be-7 | 0.479 | 15 | 0.195 | | 100-N Spring-5 |
| Ce/Pr-144 | 0.0111 | 6 | 0.238 | U[(a)] | 100-N Spring Shoreline |
| Co-60 | 1.05 | 15 | 0.117 | | 100-N Spring-1 |
| Cs-134 | 0.057 | 15 | 0.021 | U | 100-N Shore above HGP[(b)] |
| Cs-137 | 0.649 | 15 | 0.0948 | | 100-N Spring Shoreline |
| Eu-152 | 0.899 | 1 | 0.117 | | 100-N Shore above HGP |
| Eu-154 | 0.157 | 15 | 0.106 | | E of 100-N Area |
| Eu-155 | 0.103 | 15 | 0.109 | U | E of 100-N Area |
| K-40 | 16.9 | 15 | 1.73 | | 100-N Shore above HGP |
| Pu-238 | 0.000553 | 12 | 0.000349 | | 100-N Spring Shoreline |
| Pu-239/240 | 0.0155 | 12 | 0.00253 | | 100-N Spring Shoreline N |
| Ra-226 | 0.9 | 5 | 0.106 | | 100-N Spring-1 |
| Ra-228 | 1 | 5 | 0.163 | | 100-N Spring-1 |
| Ru-106 | 0.155 | 15 | 0.187 | U | NE of 100-N Area |
| Sb-125 | 0.0597 | 15 | 0.0825 | U | E of 100-N Area |
| Sr-90 | 46.7 | 15 | 8.53 | | 100-N Spring-3 |
| U-234 | 0.146 | 6 | 0.035 | | 100-N Shore above HGP |
| U-235 | 0.154 | 12 | 0.0904 | | NE of 100-N Area |
| U-238 | 1.45 | 12 | 0.287 | | E of 100-N Area |
| Zn-65 | -0.0138 | 6 | 0.0695 | U | 100-N Spring Shoreline |
| Zr/Nb-95 | 0.00429 | 6 | 0.0659 | U | 100-N Spring Shoreline |

(a) U= Undetected.
(b) HGP = Hanford Generating Plant, Washington State Public Power Supply System.

unusually high discharge of water through the Columbia River system, which caused the water table beneath 100-N Area to become higher than usual. It is believed that the elevated water table caused the remobilization of strontium-90 held in the normally unsaturated vadose zone beneath the principal waste sites (DOE-RL 1998a). This created a temporary increase in concentrations in the central portion of the plume, which subsequently passed by seep well NS-3. An alternative, but less likely explanation, is that the temporary increase in concentrations seen at the seep well is related to changes in plume movement caused by the groundwater pumping operations.

## Contaminant Data for Riparian Biota

Hedlund et al. (1975) studied mouse populations on knob and kettle topography in south-central Washington that occurs around the 100 Areas. The study reported that the sparse small mammal population adjacent to the 100-N Area might be due to stony soil rather than operations at the 100-N Area facilities. Great basin pocket mice may be more common inland, with deer mice and house mice more likely to occur along the riparian zone. Mouse populations in the riparian zone were not discussed in this report.

**Table 16**. Maximum Concentration (pCi/g, dry wt.) of Radionuclides in Fish Samples Around the 100-N Area, 1993-Present (SESP Sampling)

| Species | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Carp | Be-7 | 0.196 | 24 | 0.193 | | 100-N - 100-D |
| | Ce/Pr-144 | 0.0946 | 8 | 0.155 | U[(a)] | 100-N - 100-D |
| | Co-60 | 0.0225 | 24 | 0.0216 | U | 100-N - 100-D |
| | Cs-134 | 0.0301 | 24 | 0.0165 | | 100-N - 100-D |
| | Cs-137 | 0.0591 | 24 | 0.0247 | | 100-N - 100-D |
| | Eu-154 | 0.0691 | 24 | 0.053 | U | 100-N - 100-D |
| | Eu-155 | 0.0349 | 24 | 0.0583 | U | 100-N - 100-D |
| | K-40 | 4.55 | 24 | 0.956 | | 100-N - 100-D |
| | Ru-106 | 0.105 | 24 | 0.151 | U | 100-N - 100-D |
| | Sb-125 | 0.0913 | 24 | 0.0729 | U | 100-N - 100-D |
| | Sr-90 | 0.765 | 32 | 0.22 | | 100-N - 100-D |
| | U-234 | 0.0143 | 6 | 0.00448 | | 100-N - 100-D |
| | U-235 | 0.00182 | 6 | 0.00577 | U | 100-N - 100-D |
| | U-238 | 0.02 | 6 | 0.0106 | | 100-N - 100-D |
| | Zn-65 | 0.0199 | 8 | 0.0338 | U | 100-N - 100-D |
| | Zr/Nb-95 | 0.0341 | 8 | 0.0492 | U | 100-N - 100-D |
| Sculpin | Be-7 | 0.229 | 1 | 0.229 | U | 100-N Spring Shoreline |
| | Co-60 | 0.0234 | 1 | 0.0234 | U | 100-N Spring Shoreline |
| | Cs-134 | 0.0203 | 1 | 0.0203 | U | 100-N Spring Shoreline |
| | Cs-137 | 0.0128 | 1 | 0.0128 | U | 100-N Spring Shoreline |
| | Eu-154 | -0.0436 | 1 | -0.0436 | U | 100-N Spring Shoreline |
| | Eu-155 | 0.00912 | 1 | 0.00912 | U | 100-N Spring Shoreline |
| | K-40 | 2.6 | 1 | 2.6 | | 100-N Spring Shoreline |
| | Ru-106 | -0.477 | 1 | -0.477 | U | 100-N Spring Shoreline |
| | Sb-125 | -0.0161 | 1 | -0.0161 | U | 100-N Spring Shoreline |
| | Sr-90 | 0.754 | 1 | 0.754 | | 100-N Spring Shoreline |
| Whitefish | Be-7 | 0.33 | 47 | 0.172 | | 100-N - 100-D |
| | Ce/Pr-144 | 0.19 | 20 | 0.284 | U | 100-N - 100-D |
| | Co-60 | 0.0376 | 47 | 0.05 | U | 100-N - 100-D |
| | Cs-134 | 0.0171 | 47 | 0.0162 | | 100-N - 100-D |
| | Cs-137 | 0.133 | 47 | 0.035 | | 100-N - 100-D |
| | Eu-152 | 0.00457 | 5 | 0.033 | U | 100-N - 100-D |
| | Eu-154 | 0.088 | 47 | 0.11 | U | 100-N - 100-D |
| | Eu-155 | 0.0724 | 47 | 0.0874 | U | 100-N - 100-D |
| | K-40 | 5.05 | 47 | 1.2 | | 100-N - 100-D |
| | Ru-106 | 0.286 | 39 | 0.194 | | 100-N - 100-D |
| | Sb-125 | 0.0654 | 39 | 0.059 | U | 100-N - 100-D |
| | Sr-90 | 0.464 | 75 | 0.0883 | | 100-N - 100-D |
| | U-234 | 0.0222 | 8 | 0.00477 | | 100-N - 100-D |
| | U-235 | 0.00178 | 8 | 0.00137 | | 100-N - 100-D |
| | U-238 | 0.0166 | 8 | 0.004 | | 100-N - 100-D |

**Table 16**. (contd)

| Species | Contaminant | Max Value (pCi/g) | Number of Samples | Total Analytical Error (±) | Lab Qualifier | Collection Location |
|---|---|---|---|---|---|---|
| Whitefish (contd) | Zn-65 | 0.059 | 20 | 0.0419 | | 100-N - 100-D |
| | Zr/Nb-95 | 0.0373 | 20 | 0.0486 | U | 100-N - 100-D |

(a) U = Undetected.
Note: All Sr-90 results for fish are for samples of offal (i.e., carcass remaining after fillets and visera are removed).

**Table 17**. Maximum Concentration (μg/g, dry wt.) of Metals in Wildlife Samples Collected Near the 100-N Area Riverbank Springs, 1997 (SESP Sampling)

| Metal (μg/g) | Caddisfly[a] | Clams | Sculpin |
|---|---|---|---|
| Ag | 0.106 | 0.082 | 0.045 (U)[b] |
| As | 3.7 | 15.7 | 0.542 |
| Be | 0.49 | 0.15 (U) | 0.15 (U) |
| Cd | 2.54 | 5.56 | 12.2 |
| Cr | 12.7 | 19.8 | 0.303 |
| Cu | 33.1 | 92.3 | 25.9 |
| Hg | 0.0334 | 0.0497 | 0.378 |
| Ni | 10.9 | 11.6 | 0.357 |
| Pb | 11.6 | 3 | 0.21 |
| Sb | 0.194 | 0.0186 | 0.015 (U) |
| Se | 2.06 | 3.92 | 7.08 |
| Tl | 0.337 | 0.358 | 0.247 |
| Zn | 154 | 107 | 170 |

(a) Three caddisfly, clam, and sculpin samples collected near the 100-N Area Springs in 1997.
(b) Undetected.

Eberhardt et al. (1989) evaluated radionuclide concentrations in wildlife species collected on the Hanford Site from 1971 through 1989; some 100-N Area data was provided (HEIS data). Cadwell (1994, 1995) discusses terrestrial and riparian wildlife and plant species found on the Hanford Site, and reported strontium-90 data for deer antlers collected near the 100 Areas, although the 100-N Area is not specifically mentioned.

Weiss and Mitchell (1992) reviewed ecological data from the 100 Areas of the Hanford Site. This report is primarily a compilation and summary of data, much of which was reported in various annual Hanford Site environmental monitoring reports. The report provides species lists for terrestrial and aquatic organisms and radionuclide contaminant levels, with some data about the concentrations of metal and organic contaminants.

**Table 18**. Maximum Concentration of Metals (µg/g, dry wt.) in Vegetation Samples Collected Near the 100-N Area Riverbank Springs, 1997 (SESP Sampling)

| Metal | Milfoil[(a)] | Periphyton | Reed Canarygrass |
|---|---|---|---|
| Ag | 0.0941 | 0.189 | 0.0694 |
| As | 6.1 | 8.25 | 3.68 |
| Be | 0.491 | 0.809 | 0.399 |
| Cd | 4.18 | 3.52 | 1.06 |
| Cr | 16.1 | 35 | 15.2 |
| Cu | 22.6 | 45 | 18.1 |
| Hg | 0.0379 | 0.0895 | 0.0326 |
| Ni | 15.2 | 28.7 | 11.7 |
| Pb | 17.4 | 49.2 | 14.1 |
| Sb | 0.0473 | 0.0876 | 0.0474 |
| Se | 1.05 | 1.45 | 1 (U)[(b)] |
| Tl | 0.405 | 0.633 | 0.475 |
| Zn | 242 | 260 | 153 |

(a) A total of two milfoil, three periphyton, and three reed canarygrass samples were collected in 1997.
(b) Undetected.

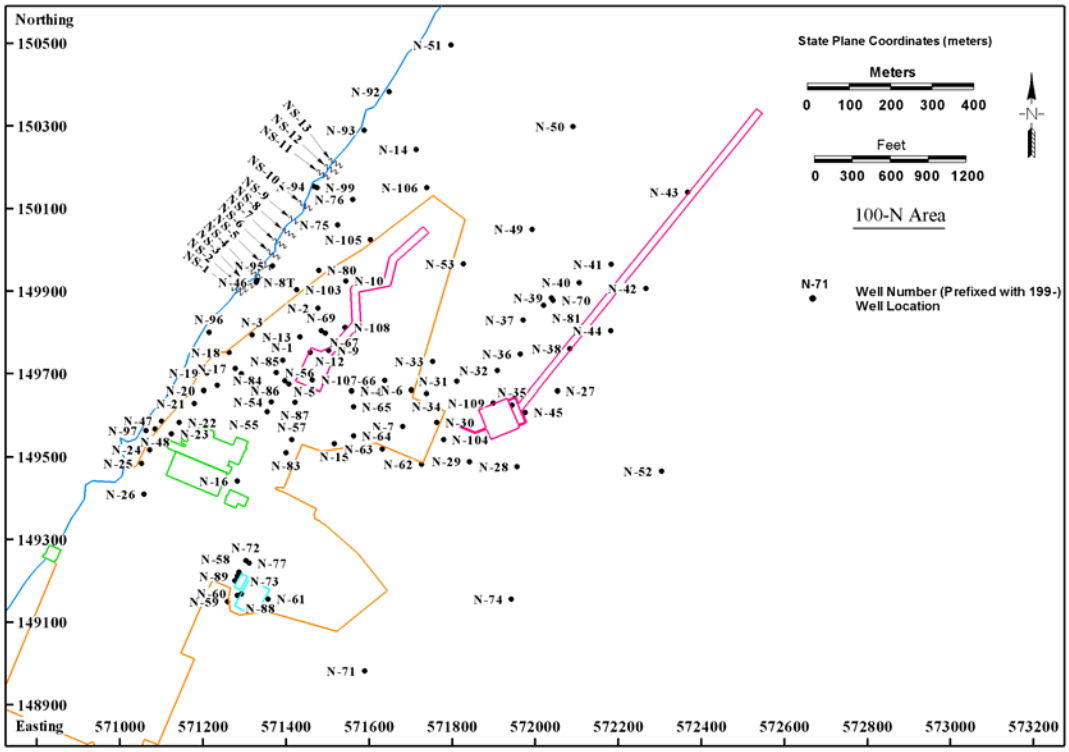


**Figure 10**. Location of Groundwater or Seep Wells in the 100-N Area

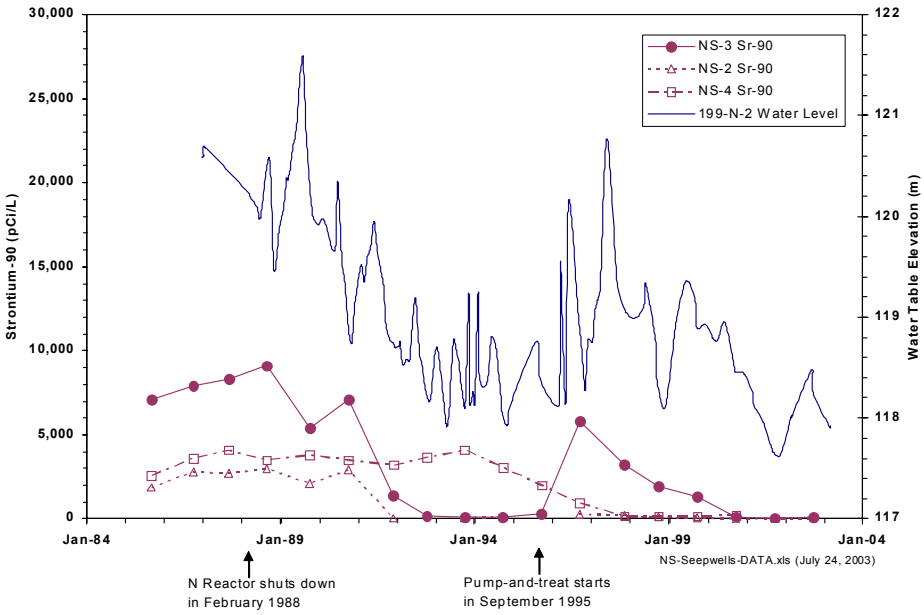


**Figure 11**. Strontium-90 Concentrations in Seep Wells and Water-Table Elevation in Groundwater Well (199-N-2) Nearest the Central Portion of the Groundwater Plume

A Westinghouse Hanford Company letter report (Carpenter 1992) described the levels of activity measured by hand-held instruments and laboratory analyses for strontium-90 and gamma emitters in mulberry trees removed from the surface contamination area at the 100-N Area shoreline.

During 1990 to 1992, Antonio et al. (1993) sampled natural Hanford riparian vegetation that is usable by humans for food or other purposes. They found that the 100-N Area vegetation (chicory, dogbane, willow, yarrow, mulberry foliage, and mulberry fruit) had elevated concentrations compared to background for several radionuclides. Tritium in moisture distilled from plants was detected in mulberry foliage (maximum of 20,000 ± 1,600 pCi/L) and fruit (maximum of 520 ± 210 pCi/L) from the 100-N Area; tritium analysis was not conducted for some species because of limited plant mass. Cobalt-60 was detected for some 100-N Area samples of mulberry foliage (maximum of 0.16 ± 0.055 pCi/g dry wt) and fruit (maximum of 0.025 ± 0.011 pCi/g dry wt.). Strontium-90 was detected in 100-N Area chicory (maximum of 0.28 ± 0.054 pCi/g dry wt.), dogbane (maximum of 2.6 ± 0.50 pCi/g dry wt.), mulberry (maximum of 440 ± 24 pCi/g dry wt.), mulberry fruit (maximum of 0.14 ± 0.028 pCi/g dry wt.), willow (maximum of 0.85 ± 0.16 pCi/g dry wt.), and yarrow (maximum of 2.6 ± 0.46 pCi/g dry wt.). Cesium-137 was detected in some 100-N Area samples of willow (maximum of 0.020 ± 0.016 pCi/g dry wt), yarrow (maximum of 0.060 ± 0.021 pCi/g dry wt.). Plutonium-238 and plutonium-239/240 was detected (both were 0.001 pCi/g dry wt.) in chicory and dogbane from the 100-N Area. These results were higher than for any other shoreline sampling location.

Antonio et al. (1993) reported levels of strontium-90 in reed canarygrass (*Phalaris arundinaceae*) of 0.017 pCi/g (dry wt.) for the 100-N Area. Rickard and Price (1990) reported strontium-90 levels of

50 pCi/g (dry wt.) in reed canarygrass at the 100-N Area and observed that the levels decreased down river from the 100-N Area. They also found elevated strontium-90 in goose eggs on islands downstream of the 100-N Area.

Landeen et al. (1993) provides a list of birds (including water birds), small and large mammals, insects, and plants found at the 100-N Area (and other 100 Area locations). The report briefly discusses food chains. Soil samples from burrows and ant mounds showed very low or undetectable levels of contaminants. Metals and radionuclides in coyote scat and raptor pellets were generally very low, although lead was somewhat elevated in both. Asparagus and reed canarygrass both had generally very low to undetectable values of radionuclides and metals. Milfoil that was sampled near the 100-N Area riverbank spring discharge zone contained lead and zinc at levels above the control levels, and strontium-90 was also detected.

Poston and Cooper (1994) conducted a qualitative evaluation of radionuclide levels in Hanford Site wildlife samples collected from 1983 through 1992. The evaluation included strontium-90 and cesium-137 levels in rabbits, ducks, and deer from the 100-N Area. None of the measured concentrations were high enough to pose any risk to theoretical human consumers who ate 40 kilograms per year of game animals inhabiting the Hanford Site based on the DOE guideline of 100 millirem per year and the National Council on Radiation Protection and Measurements guidelines. Concentrations of strontium-90 in rabbit and deer bones were higher in areas adjacent to industrialized areas.

Poston (1995) measured the concentrations of gamma-emitting radionuclides and strontium-90 in two species of desert parsley and one species of balsamroot on the Hanford Site at the 100 Areas, 200 Areas, and the Fitzner/Eberhardt Arid Land Ecology Reserve (ALE). The 100-N Area was not identified as a specific sampling location; the plants were collected from the 100-K Area to the 100-N Area, and from the 100-N Area to the 100-D Area. Cobalt-60 was only detectable in balsamroot samples at the 100 Areas, but the results were close to the detection limit of 0.02 pCi/g dry wt. Cesium-137 was found only in balsamroot and almost exclusively in the roots, with all 100-Area samples well below 0.15 pCi/g dry wt. The 200 Areas had the highest levels of cesium-137. Interestingly, the concentrations of strontium-90 in terrestrial vegetation were higher for samples collected from ALE, with all 100 Area samples below 0.15 pCi/g dry wt. No attempt was made to evaluate dose from the consumption of these plants by Native Americans because information on specific uses and plant parts used was not available. Sackschewsky et al. (1992) summarized the human uses of these plants.

Tiller et al. (1997) investigated anatomical anomalies (atrophied and infertile testicles and unusually shaped, velvet covered antlers) in Hanford Site mule deer. The report contains information on deer that may have inhabited the 100-N Area, but no data specific to the 100-N Area was provided. The report ruled out radiation, natural aging, infectious agents, and genetic factors as potential causes, but the underlying cause was not found.

Van Verst et al. (1998) surveyed radiological contaminants in the near-shore environment adjacent to the 100-N Area during 1997 to 1998. The near-shore sampling locations bracketed the location where the maximum groundwater contours for strontium-90 were reported (Site 3, Figure 12). Flying insects and

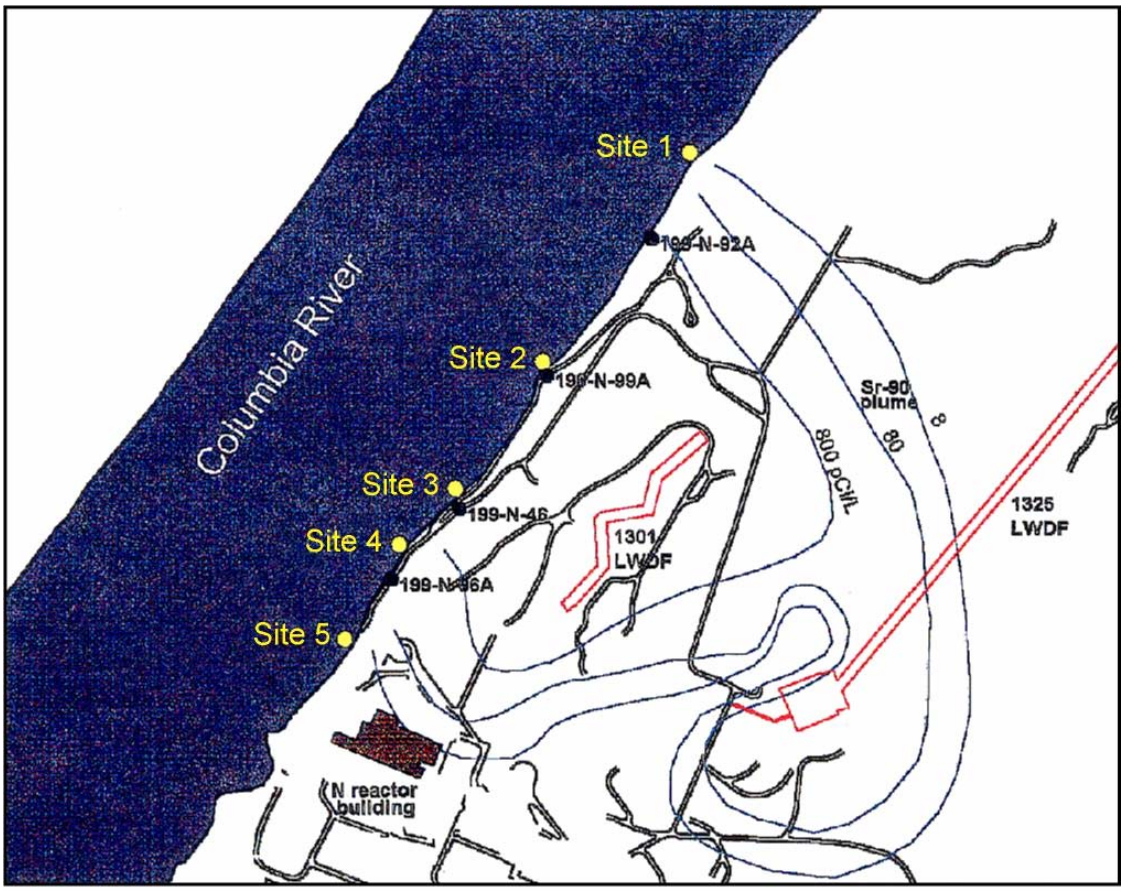


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**Figure 12**. 100-N Area Shoreline Sampling Sites (reported in Van Verst et al. 1998)

reed canarygrass from the 100-N Area near-shore were analyzed for tritium, strontium-90, and gamma emitters. Biota sample results had similar concentration profiles as the water and sediment samples. Adult caddisfly and reed canarygrass had elevated concentrations of strontium-90 compared to background. Generally, the highest biota concentrations for strontium-90 were found at Site 3; however, not all biota was available at each location. The results showed that strontium-90 transferred throughout the local ecosystem, but the spatial extent of the elevated concentrations was limited. Cobalt-60 concentrations at the 100-N Area were elevated compared to background for adult caddisfly and reed canarygrass. Cesium-137 levels at the 100-N Area were elevated compared to background for adult caddisfly, with similar concentrations of cesium-137 for background and 100-N Area reed canarygrass. Selected 100-N Area near-shore biota samples were also analyzed for a suite of metals (including chromium), with no major differences between the 100-N Area and the background locations (for some samples background samples could not be obtained) (HEIS database; Dirkes and Hanf 1998).

Poston et al. (1998) evaluated surveillance data for strontium-90 in alfalfa (*Medicago sativa*) around the Hanford Site. Levels of strontium-90 were slightly higher in fields using irrigation water taken from the Columbia River downstream of the Hanford Site. Monitoring data did not support Hanford air emissions as the source of the increase. In addition, Columbia River water samples failed to show a

statistically significant ($p > 0.05$) contribution for locations downstream of the Hanford Site (i.e., Columbia River water downstream of Hanford was not elevated for strontium-90). Radiological doses modeled for the alfalfa-cow milk, human pathway indicated that the maximum 50-year effective dose equivalent for a standard man consuming 270 liters of milk per year was 0.09 millirem, which is 0.03% of the 300 millirem annual dose resulting from natural and background sources of radiation.

Tiller and Poston (2000) evaluated mule deer antlers on the Hanford Site and at a reference site in central Oregon as indicators of animal uptake of localized strontium-90 contamination. Results showed that the concentration of strontium-90 in deer antlers collected near the Hanford Site 100 Areas (405 pCi/kg dry wt.) were significantly higher that other Hanford locations (190 pCi/kg dry wt.). The report does not provide data specific to the 100-N Area, but it is one of the likely sources of strontium-90 on the Hanford Site. There was a significant negative correlation between age and strontium-90 levels in deer antlers for the 100 Areas' deer. The study did not find any significant correlation between deer antler strontium-90 levels and either soil or vegetation strontium-90 levels. Interestingly, the deer antlers at the reference site samples (2,080 pCi/kg dry wt.) contained roughly five times the levels of strontium-90 compared with Hanford. The elevated concentrations in deer antlers at the reference site are likely related to the deer moving into mountainous regions in the summer where higher precipitation rates may have increased atmospheric fallout from weapons testing.

The Surface Environmental Surveillance Project (SESP) has sampled mule deer, pheasant, and Canada geese around the 100-N Area. The average level of strontium-90 found in these species was $0.13 \pm 0.19$ pCi/g (1 standard deviation). The maximum level (0.72 pCi/g) was found in Canada goose bones collected in 1995 between the 100-N and 100-D Areas. Vegetation was sampled during 1998 and 1999 along the shoreline and near the springs around the 100-N Area. Mulberry and reed canarygrass samples collected along the shoreline had the highest concentrations of strontium-90. The average concentration of strontium-90 in vegetation samples collected during 1993 to 2003 was $2.1 \pm 6.3$ pCi/g.

## Contaminant Data for Aquatic Environment

There have been numerous measurements of radionuclides in 100-N Area riverbank spring water. Many of these results have been reported in topical reports, near-field environmental reports, annual groundwater reports, and annual environmental monitoring reports.

McCormack and Carlile (1984) identified 115 low river stage springs and collected water samples from selected riverbank springs along the Hanford Reach. River stage was held at 36,000 cfs at Priest Rapids Dam from 12:00 AM to 6:00 AM each day from mid-October through November to facilitate this work (long-term average flow at Priest Rapids Dam is 120,000 cfs). The samples were analyzed for tritium, strontium-90, nitrate, and uranium. River water was also sampled 2 to 4 meters from shore to look for groundwater upwelling or underwater seeps. Ten riverbank springs were reported in the 100-N Area with most locations listed as having moderate to heavy flow (qualitative observations). The maximum tritium level in 100-N Area riverbank spring water was 38,000 pCi/L, with near-shore and mid-river water results of 2,700 and 150 pCi/L, respectively. A composite water sample for strontium-90 was collected in the 100-N Area with a result of 28 pCi/L that was roughly 150 times greater than upstream concentrations. The maximum nitrate concentrations in 100-N Area riverbank spring water was 10 mg/L, which was the highest concentration reported for the 100 Areas.

Dirkes (1990) characterized Hanford Reach riverbank springs in 1988 and found radionuclide concentrations were below DOE derived concentration guides, except for strontium-90 at the 100-N Area. In addition, tritium, gross beta and strontium-90 were above U.S. Environmental Protection Agency (EPA) drinking water standards in several springs. Two riverbank spring locations at the 100-N Area were sampled, one near the maximum groundwater plume for strontium-90 (Hanford River Marker [HRM] 8.9) and one farther downstream (HRM 9.5). For riverbank spring water, the maximum strontium-90 levels were measured at HRM 8.9 (7,300 ± 190 pCi/L) and the maximum tritium concentration was measured at HRM 9.5 (76,000 pCi/L). Antimony-125 in riverbank spring water from HRM 8.9 was 43 ± 6.4 pCi/L, which was also elevated compared to background. Only one water sample was analyzed for nitrate (HRM 8.9) and the concentration (29 mg/L) was above background levels but below drinking water standards. One riverbank spring water sample from HRM 8.9 was analyzed for anions, metals, thiourea compounds, pesticides, herbicides, polychlorinated biphenyls (PCBs), volatile organic compounds, and semi-volatile compounds, with most results below the analytical detection limits. However, for this spring detectable levels of sulfate, chloride, total carbon, total organic carbon, magnesium, iron, potassium, manganese, sodium, barium, calcium, zinc, and strontium were reported. River water concentrations of radionuclides and chemicals in samples collected away from the springs were below drinking water standards (HEIS data for radiological, chemical data in report).

DOE (1992) studied riverbank seepage of groundwater along the 100 Areas shoreline and the Hanford town site. During 1991, five riverbank springs were sampled at the 100-N Area along with riverbank spring sediment and adjacent Columbia River water. Temperature, pH, and specific conductivity measurements were monitored for 1 hour prior to sample collection. Gross beta concentrations in the 100-N Area riverbank spring water ranged from 5 to 6,830 pCi/L, tritium levels ranged from 3,400 to 24,300 pCi/L, strontium-90 was detected in two springs at levels of 395 and 3,210 pCi/L, technetium-99 ranged from 2.5 to 6.2 pCi/L, and antimony-125 was detected in one sample at 31 pCi/L. Non-radiological contaminants were detected at low levels for some 100-N Area riverbank spring samples. Chromium was not detected in any of the 100-N Area riverbank springs. The study reported that the farthest upriver spring had the highest strontium-90 levels and that the highest tritium levels were measured at a location downstream of the maximum strontium-90 results. The location of the maximum tritium and strontium-90 concentrations for riverbank spring water was consistent with results from Dirkes (1990) and Van Verst et al. (1998). Contaminant concentrations in Columbia River water samples collected adjacent to the 100-N Area springs were considerably lower that the spring concentrations (e.g., strontium-90 results ranged from 0.9 to 8.1 pCi/L) and reveal the rapid dispersal of contaminants upon entry into the river. Strontium-90 was the only radiological contaminant detected above background levels in sediment samples from the 100-N Area riverbank springs (24.5 to 207 pCi/g). The report observed that radionuclide concentrations at the 100-N Area riverbank springs had generally decreased since 1988 with the decline attributed to changes in liquid discharges to the liquid waste disposal trenches. A detailed appendix of the analytical data is provided. Peterson and Johnson (1992) expanded the initial interpretations of the analytical results from the DOE (1992) study. Their discussion focused on comparing the results from the 1991 sampling effort to previously collected data, comparing results for riverbank spring water concentrations to results for adjacent groundwater, and reviewing the chemical and radiological characteristics of sediments associated with the riverbank springs.

Van Verst et al. (1998) surveyed radiological contaminants in the near-shore environment adjacent to the 100-N Area during 1997 to 1998. The near-shore sampling locations bracketed the location where the maximum groundwater contours for strontium-90 were reported. River water, sediment, and riverbank spring water, and biota samples from the 100-N Area near-shore were analyzed for tritium, strontium and gamma emitters. Background samples were collected upriver from Vernita Bridge. Strontium-90 was detected in all near-shore river water samples collected during September 1997 at the station near the maximum groundwater contour (Figure 12, Site 3), with concentrations ranging from 0.9 to 6.6 pCi/L. The strontium-90 entering the river was rapidly diluted with river water.

At Site 3 (Figure 12), strontium-90 river water levels were diluted by a factor of five for a sample collected approximately 10 meters from shore compared to samples collected closer to shore (Van Verst et al. 1998). The strontium-90 concentration in near-shore river water at the downstream location was 0.3 pCi/L. From September 1997 to July 1998, six near-shore water samples were collected at Site 3, with concentrations ranging from 0.4 to 13 pCi/L. The concentration of strontium-90 for near-shore river water samples collected during high river stage were consistently below the detection limit; however, for samples collected when the daily average flow rate was within 20% of the normal flow, there was no correlation between the detected strontium-90 concentrations and daily average river stage.

Tritium concentrations in near-shore river water samples were elevated compared to background level (25 pCi/L), especially for the farthest downstream location (Site 5, Figure 12) where the maximum concentration of 1,000 pCi/L was roughly 40 times the background (Van Verst et al. 1998). Tritium concentrations for all other 100-N Area near-shore river water samples were below 350 pCi/L. Detection of elevated tritium at Site 5 was consistent with groundwater monitoring data, which reported tritium levels of 19,000 pCi/L in nearby wells.

Concentrations of cobalt-60 and cesium-137 were less than detectable for near-shore river water samples collected at the 100-N Area and at the background location (Van Verst et al. 1998). The 100-N Area near-shore river water samples were also analyzed for a suite of 13 metals (including chromium), with little difference in metals concentrations between locations (HEIS database; Bisping 1998). Water samples collected in August 1997 at cross-river transect stations at the 100-N Area and the Vernita Bridge background location had detectable concentrations of tritium and strontium-90 in all samples. Mean tritium levels in river water at the 100-N Area cross-river transect were (30 pCi/L) that were statistically higher than at Vernita Bridge (25 pCi/L). Mean strontium-90 concentrations at these locations were both approximately 0.1 pCi/L and were not statistically different. For both tritium and strontium-90, concentration gradients were observed from the Hanford shoreline compared to mid-river, with the near shore samples roughly 10% higher for tritium and 40% higher for strontium-90.

In September 1997, riverbank spring water was collected at Site 3 with tritium and strontium-90 concentrations of 14,000 and 6,100 pCi/L, respectively (Van Verst et al. 1998). The September 1997 results at Site 3 were similar to Hanford Site SESP samples collected in November 1997 (14,000 pCi/L for tritium and 9,900 pCi/L for strontium-90) (Dirkes and Hanf 1998). A downstream riverbank spring near Site 5 was also sampled in November 1997, with tritium and strontium-90 levels of 19,000 and 0.59 pCi/L, respectively. No flow has been observed at the Site 3 riverbank spring since 1997, despite multiple visits to that location during the annual SESP riverbank spring sampling events (Poston et al. 2002). For sediment samples collected at the 100-N Area near shore in September 1997, only cobalt-60

(maximum value of 1.0 pCi/g dry wt.) and strontium-90 (maximum value of 47 pCi/g dry wt.) were elevated compared to the Priest Rapids Dam pool background location. Concentrations of strontium-90 in sediment had a similar profile as the near-shore river water samples with the maximum levels observed at Site 3 (at the maximum groundwater contour for strontium-90).

The Surface Environmental Surveillance Project has collected Columbia River water samples, river-bank spring water samples, drinking water samples, and groundwater samples in the rooting zone near the 100-N Area. The average concentration of strontium-90 and tritium for these samples is shown in Table 19.

**Table 19**. Average Concentrations of Strontium-90 and Tritium in Columbia River Water, Riverbank Spring Water, Drinking Water, and Rooting Zone Groundwater Collected Near the 100-N Area, 1993 to Present (average ±1 standard deviation)

| Sample Source | Average $^{90}$Sr (pCi/L) | Average Tritium (pCi/L) |
|---|---|---|
| Drinking Water | 0.07 ± 0.01) | 78 ± 53 |
| Columbia River Water | 0.25 ± 0.67 | 65 ± 100 |
| Riverbank Spring Water | 820 ± 2,800 | 18,000 ± 7900 |
| Groundwater in the Rooting Zone | 110 | -21 |

The maximum concentration of strontium-90 was collected from a riverbank spring below the well building near groundwater monitoring well 199-N-8T during 1997. Changes to the water table resulting from reduced and eliminated discharges of water to the 100-N Area LWDF has decreased the number and discharge of some 100-N Area springs, and flow has been observed at this spring location only once from 1993 through 2002 (Poston et al. 2002) despite the presence of flowing springs at a several downstream locations.

For Surface Environmental Surveillance Project samples from 1993 to 2003, levels of chromium in river water samples averaged 6.4 ± 7.4 µg/L and in riverbank spring water samples averaged 25 ± 29 µg/L, which was above the ambient surface water quality criteria of 10 µg/L for chronic exposure (WAC 173-201A). Two river water samples taken near 100-N spring 8-13 in 1996 were analyzed for hexavalent chromium with a maximum value of 5.3 µg/L. Nitrate and sulfate were also measured in seep and river waster samples from the 100-N Area. The average nitrate concentration in the riverbank spring was 9,600 ± 5,600 µg/L and the average sulfate concentration was 210,000 ± 7,200 µg/L during 1993 to 2002. The average concentration of nitrate and sulfate in river water was 400 ± 33 µg/L and 9,100 ± 260 µg/L. All nitrate concentrations were below the 45,000-µg/L drinking water standard (40 CFR 141). The average sulfate concentrations for riverbank spring water from the 100-N Area approached the secondary (or aesthetic) drinking water standard for sulfate of 250,000 µg/L (40 CFR 141). Manganese concentrations were reported for 30 Columbia River water samples collected near the 100-N Area, with a maximum concentration of 8.5 µg/L. Manganese levels for three samples of riverbank spring water were reported with a maximum concentration of 680 µg/L, which exceeded the EPA secondary (or aesthetic) drinking water standard of 50 µg/L. No data were available for total petroleum hydrocarbons in drinking water, Columbia River water, riverbank spring water, or root zone groundwater.

## Contaminant Data for Aquatic Biota

Weiss and Mitchell (1992) reviewed ecological data from the 100 Areas of the Hanford Site. This report is primarily a compilation and summary of data, much of which was reported in various annual Hanford Site environmental monitoring reports. The report provides species lists for terrestrial and aquatic organisms and radionuclide contaminant levels with some data for metals and organics contaminants concentrations.

Cushing (1993) sampled periphyton and caddis fly larvae for chromium, cobalt-60, strontium-90, and cesium-137 in the 100-N Area and found levels were essentially below detection limits in both species. Some species of insects and plankton are provided in Davis (1962), which analyzed a variety of insect larvae for radionuclides back when the single-pass reactors were operating.

Landeen et al. (1993) found strontium-90, lead, and zinc in milfoil from 100-N Area samples at levels above those found in control samples.

Geist et al. (1994) conducted an assessment of potential impacts of groundwater contaminants to fall chinook salmon in the Hanford Reach. Tritium was not expected to affect salmon because the radiotoxicity levels were higher than the maximum seep water concentrations. Poston (2002) reviewed the risk of strontium-90 to salmon in the Hanford Reach at the 100-N Area and concluded that there was no risk to spawning salmon at this location, because salmon do not spawn in the river adjacent to the 100-N Area shoreline.

Van Verst et al. (1998) surveyed radiological contaminants in the near-shore environment adjacent to the 100-N Area during 1997 to 1998. The near-shore sampling locations bracketed the location where the maximum groundwater contours for strontium-90 were reported (Site 3, Figure 12). River water, sediment, riverbank spring water, periphyton, milfoil, flying insects, clamshells, and reed canarygrass from the 100-N Area near-shore were analyzed for tritium, strontium-90, and gamma emitters. Biota sample results had similar concentration profiles as the water and sediment samples. Periphyton, sculpin, clamshell, and milfoil had elevated concentration of strontium-90 compared to background. Generally, the highest biota concentrations for strontium-90 were found at Site 3; however, not all biota was available at each location and for sculpin it was necessary to collect fish along the entire 100-N Area shore and composite them into one sample to obtain adequate mass for analysis. The results showed that strontium-90 transferred throughout the local ecosystem, but the spatial extent of the elevated concentrations was limited. Cobalt-60 concentrations at the 100-N Area were elevated compared to background for milfoil and periphyton. Cesium-137 levels at the 100-N Area were elevated compared to background for periphyton, with similar concentrations of cesium-137 for background and 100-N Area clamshell and milfoil. Dose estimates for aquatic organisms were below the 1 rad/day limit set by DOE. Selected 100-N Area near-shore biota samples were also analyzed for a suite of metals (including chromium), with no major differences between the 100-N Area and the background locations (for some samples background samples could not be obtained) (HEIS database; Dirkes and Hanf 1998).

EPA (1999) sampled fish (largescale sucker and white sturgeon from 100-F to 100-H Areas; mountain white fish upriver from Vernita Bridge) in the Hanford Reach and analyzed them for a suite of potential contaminants, including organics, inorganics, and radionuclides. This study did not obtain

samples from near the 100-N Area. The U.S. Fish and Wildlife Service (1998) issued a Hanford Site 100 Area assessment plan on Columbia River aquatic resources that evaluated previous reports and suggested future work to fill potential data gaps about the effect of the 100-N Area seeps.

The Surface Environmental Surveillance Project has sampled fish and macrointervebrates near the 100-N Area. Prior to 1993, the maximum concentration of strontium-90 was for clam tissues (1.0 pCi/g) and the maximum level of strontium-90 for clam shell was 260 pCi/g in 1990. Since 1993, the only aquatic species collected near the 100-N Area have been whitefish, sculpin, and carp. The average concentration of strontium-90 found in these species was 0.049 ± 0.14 pCi/g, while the maximum concentration, 0.76 pCi/g, was found in a carp carcass collected in 2002 between the 100-N and 100-D Areas. During 1988, spawned-out fall chinook salmon were collected at the Priest Rapids Dam (upstream of the 100-N Area) and near the White Bluffs (roughly 8 to 12 kilometers downstream of the 100-N Area). Muscles were analyzed for cobalt-60, strontium-90, and cesium-137 with similar concentrations at each location. These results indicate no observed accumulation in fish muscle from radionuclides released to the Columbia River from Hanford operations.

## Contaminant Trends in Non-Biological Samples Near the 100-N Area

Detection and monitoring trends of contaminants in environmental media may indicate changes in exposures through varying source-term emissions or changes in the biological or physical conditions present at the site. Long-term monitoring trends of seep well water collected by the Hanford Site Near-Facility Monitoring Program has been reviewed earlier in the section. DOE's Public Safety and Resource Protection Program has also documented a long-term monitoring effort at the 100-N Area shoreline with near-shore and cross-river transect water samples (1993 to present) and riverbank springs collected since 1988.

### Strontium-90

The maximum concentrations of tritium and strontium-90 in Columbia River water samples collected near the 100-N Area during 1994 to 2002 are shown in Figure 13. The concentrations of tritium and strontium-90 did not reveal any apparent temporal trends and all values were below DOE derived concentration guides and Washington State ambient surface water quality criteria (20,000 and 8 pCi/L, respectively).

Two riverbank springs at the 100-N Area have been monitored since 1988; however, the changing groundwater table at the 100-N Area has reduced the number and volume of riverbank spring discharges. For 1988 through 1992 and 1997, the riverbank spring near well 199-N-8T (at the intersection of the maximum strontium-90 groundwater plume and the river) was sampled. However, this spring has only yielded water once since 1992 and another riverbank spring [spring 8-13] (downriver from the strontium-90 plume) has been sampled from 1993 to present. Figure 14 plots strontium-90 and tritium concentration for the spring near well 199-N-8T for 1988 through 1997. For the riverbank spring water collected near well 199-N-8T, tritium concentrations steadily decreased from 1988 to 1992, with the 1997 level similar to the value for 1992. Tritium concentrations measured at this location exceeded the Washington State ambient water quality criteria of 20,000 pCi/L during 1988 and 1990. Strontium-90 levels in the riverbank spring near well 199-N-8T were similar throughout this time interval, with all

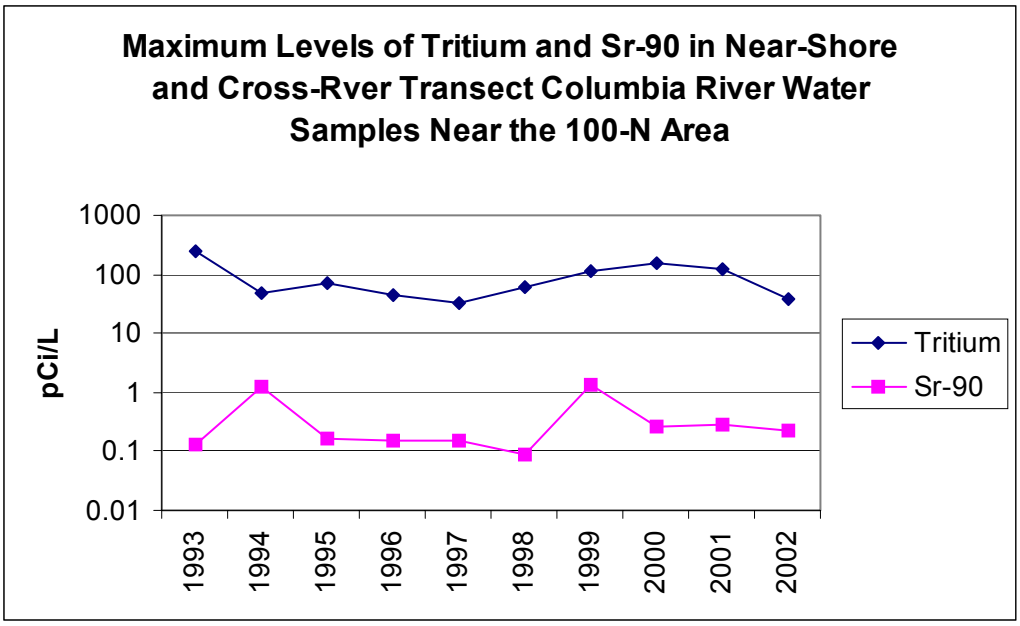


**Figure 13**. Maximum Concentrations of Tritium and Strontium-90 in Near-Shore and Cross-River Columbia River Water Samples Collected Near 100-N Area, 1993 to 2002 (SESP Data)

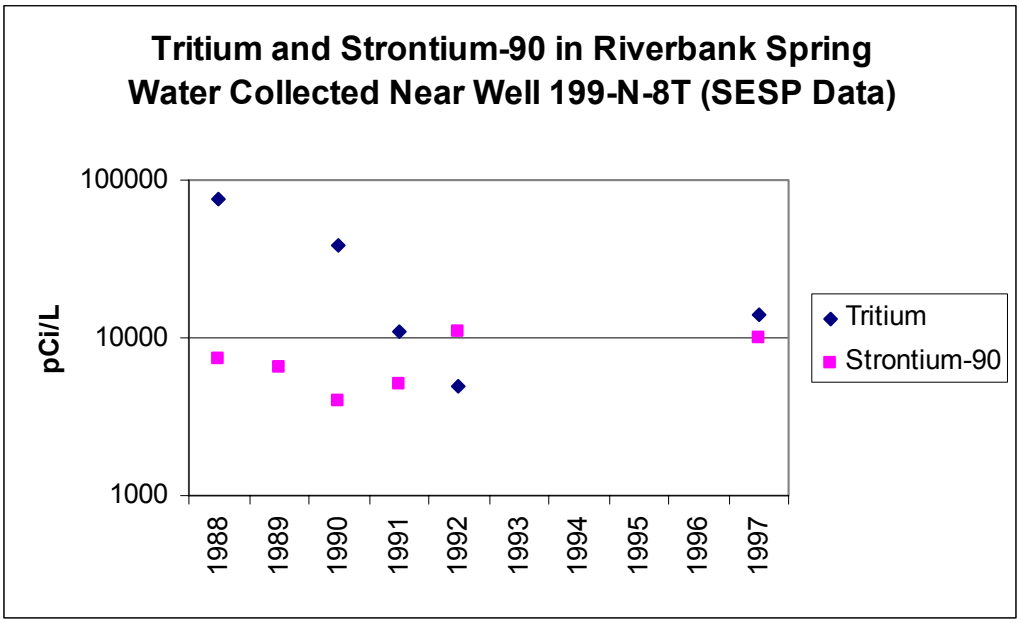


**Figure 14**. Strontium-90 and Tritium Concentrations in the Riverbank Spring Near Well 199-N-8T (This sample site is located near the intersection of the strontium-90 groundwater plume and the Columbia River, Figure 12 Site-3; SESP Data.)

values exceeding the DOE derived concentration guide of 1,000 pCi/L. Figure 15 shows tritium concentrations in riverbank spring water from spring 8-13 for 1993 to present, with the data showing a general decrease from 1992 to 2002. Tritium concentrations at riverbank spring 8-13 exceeded the Washington State ambient water quality criteria of 20,000 pCi/L for several years. Strontium-90 concentrations at spring 8-13 were not plotted because only one value (0.59 pCi/L for 1995) was above a nominal detection limit of 0.1 pCi/L.

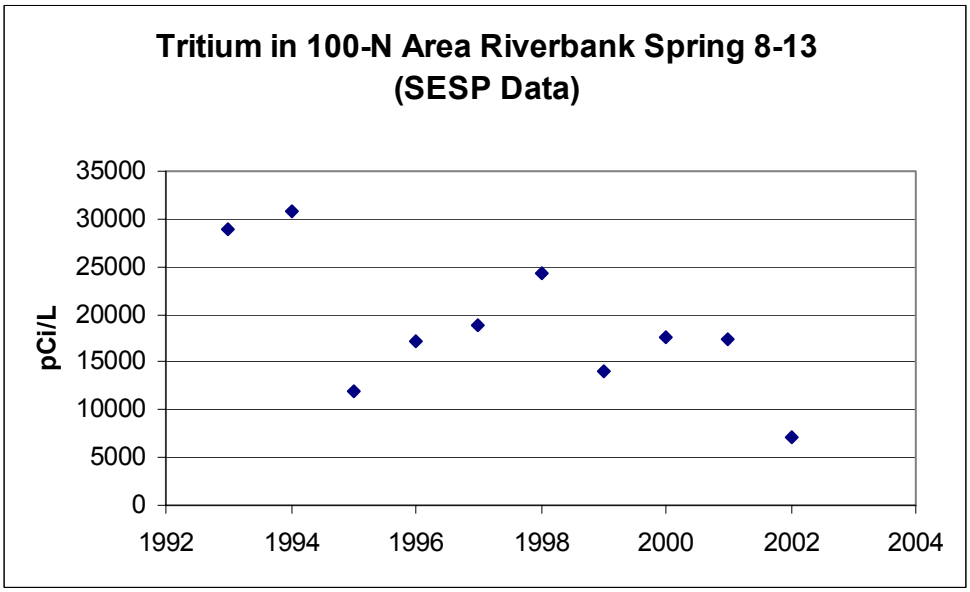


**Figure 15**. Tritium Concentrations in 100-N Area Riverbank Spring 8-13 (This sample site is located near the downstream limit of the strontium-90 groundwater plume and the Columbia River, Figure 12 Site-1; SESP Data.)

## Contaminant Trends in Biota Near the 100-N Area

Contaminants in fish and wildlife that inhabit the Columbia River and Hanford Site are monitored because some animals have access to areas containing elevated levels of radioactive or chemical contamination. In addition, aquatic organisms (fish, bivalves, etc.) can be exposed to contaminated groundwater entering the river along the shoreline. Fish and some wildlife species exposed to Hanford contaminants might be harvested for food and may potentially contribute to offsite public exposure. Detection and monitoring of contaminants in wildlife may indicate changes in exposures through varying source-term emissions or changes in the biological or physical conditions present at the site. Animals like deer, geese, ducks, and pheasant have been traditionally selected for sampling because of potential human consumption; however, these species have large home ranges and do not provide data that is particularly useful for tracking localized trends in contaminant emissions near the 100-N Area.

Evaluations of trends of radionuclide concentrations in biota were conducted in the late 1980s and early 1990s (Eberhardt et al. 1989; Poston 1994; Poston and Cooper 1994; and Poston et al. 1995).

However, these reports focus on samples collected prior to 1993. From a review of the 1993 to present data, goose egg shells and carp provide the best representation of strontium-90 concentration trends in wildlife since 1993.

## Canada Geese

Radiological contaminant monitoring has involved collection of adults, juveniles, and eggshells of the Canada goose (*Branta canadensis*). Adult and juvenile birds have been collected from areas near the Hanford Site reactors and from a few reference areas located approximately 50 kilometers upstream of the Hanford Site (Poston et al. 2002). Radionuclides measured in Canada goose tissues have included egg-shells and bones for strontium-90, whereas muscle tissue has been analyzed for gamma-emitting radio-nuclides, particularly cesium-137. Radiological data reported for goose bone and muscle have been summarized in Hanford Site environmental reports and updates have been published routinely (e.g., Poston et al. 2002).

Goose eggshells were not collected with the specific objective of examining temporal trends near the Hanford Site. Goose eggshell samples obtained on the Hanford Site before 2000 were collected as surveillance media and were collected without regard to nesting fate (i.e., whether all the eggs had hatched or not). In 2001, strontium-90 concentrations were analyzed in eggshells collected from Canada goose nests where at least one egg hatched. Analytical results (Figure 16) show that strontium-90 levels have decreased since the late 1980s. In adult birds, strontium-90 levels in bones have shown a similar decrease. Cesium-137 concentration in the muscle of adult birds has generally been below the level of detection, with the maximum level of 0.04 pCi/g compared to 0.07 pCi/g in control samples.

The amount of radiological contamination measured in fish samples has been well below levels estimated to cause adverse health effects. However, monitoring fish for uptake and exposure to radio-nuclides at both nearby and distant locations continues to be important to track the long-term trends of contamination in the Columbia River environment (Poston et al. 2002). Little long-term monitoring data exists for aquatic biota near the 100-N Area.

## Carp

Adult carp (*Cyprinus carpio*) are common omnivores that utilize both the aquatic and benthic environments along the Hanford Reach of the Columbia River. Carp are also potential contamination pathways to humans via consumption of their tissues (see Appendix C, key species matrix). Beginning in 1990, carp have been routinely collected from near the 100-N Area and from an upstream reference area ~80 kilometers upstream of the Hanford Site near Vantage, Washington. Fillets and the eviscerated remains (carcass or offal) of these fish have been routinely analyzed for a variety of radiological contaminants. Analysis of metal concentrations in carp tissues has been infrequent, and there is currently insufficient data to examine temporal trends. For the most part, strontium-90 has been the only man-made radionuclide consistently detected in the carcass tissue of the carp. The strontium-90 levels observed throughout 1990s near the 100-N Area have been similar to those observed at the upstream reference area (Figure 17).

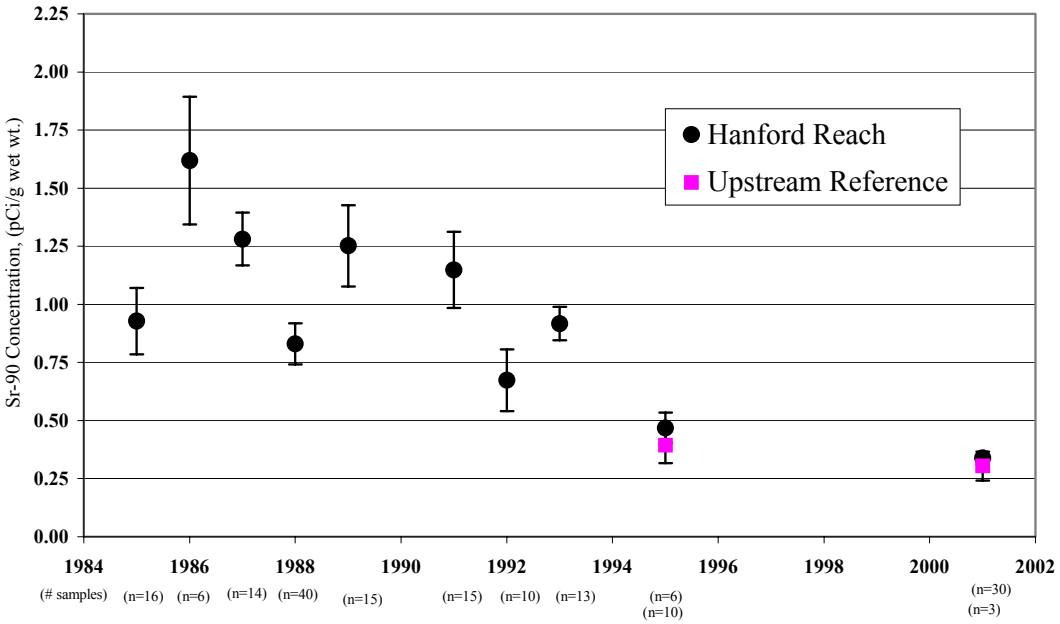


**Figure 16**. Strontium-90 Concentrations (pCi/g wet wt.) in Canada Goose Eggshells Collected on the Hanford Reach of the Columbia River Between 1985 and 2001. Bars represent ±1 standard error about the mean.

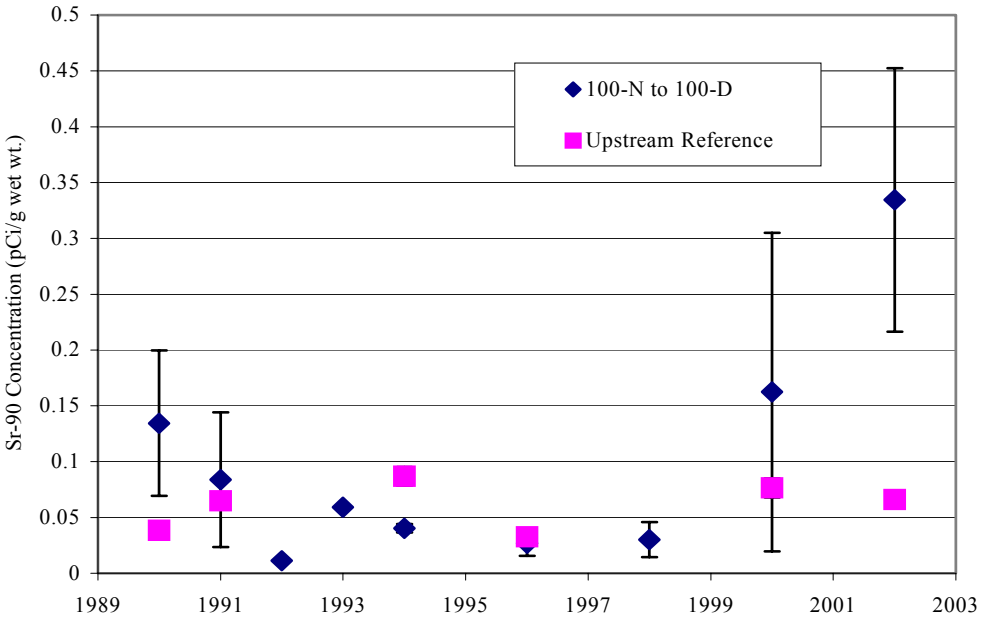


**Figure 17**. Strontium-90 Concentrations in Adult Carp Carcass Samples (Offal) Collected Near and Distant to the 100-N Area, 1989 to 2003. Trends are represented by mean values ±1 standard error.

In 2000, strontium-90 concentrations reported in 1 of 5 carp samples collected near the 100-N Area were nearly seven times greater than the highest value reported from the background area. In 2001, 4 of 5 carp from near the 100-N Area were found to contain elevated levels of strontium-90 (i.e., greater than approximately 0.1 pCi/g wet wt.). The five strontium-90 results reported from the 100-N Area during 2002 were 5 of the 10 highest concentrations reported out of 32 carp tissue samples measured since 1990. The data obtained in 2000 and 2001 near the 100-N Area indicates some of the fish have been exposed to elevated amounts of strontium-90 and have incorporated strontium-90 in their tissues. Although sample sizes are low, increasing strontium-90 concentrations found in carp near the 100-N Area in both 2000 and 2001 may indicate changes in the exposure conditions there.

# Dose and Risk Assessments for 100-N Area Receptors

Risk assessments provide an incidence rate for an expected adverse effect (e.g., a cancer or disease) and differ from dose assessments in that a dose assessment provides an estimate of dose rate that is not tied to an adverse health effect to the receptor. There have been several site-wide reviews of risk and dose assessments and some that are specific to the 100-N Area. There have also been a few toxicity reviews performed specifically on Hanford contaminants of concern. DOE has recently issued guidance for evaluating dose rates to terrestrial and aquatic organisms (DOE 2002b). Bryce et al. (2002) have also developed an ecological risk assessment model for both chemical and radiological contaminants that is based on Hanford-specific parameters. Appendix C provides a potential framework for an ecological assessment process by listing key environments, animal groups, species, and measurement (attributes) that may be suitable for the 100-N Area.

Poston and Soldat (1992) conducted an assessment of radiological doses to aquatic organisms and wildlife at the 100-N Area springs. This dose rate modeling effort was based on samples collected in 100-N Area, estimates based on concentration ratios for tissue, and maximum (undiluted) concentrations in 100-N Area riverbank spring water. The CRITR II code (Baker and Soldat 1992) was used to estimate dose rates. The aquatic reference dose of 1.0 rad/day was used for this assessment for all biota and no biota exceed this level. Based on 50% residence and feeding of worst case fish, the “fish-eating duck” received a hypothetical dose rate of 0.6 rad/day and exceeded the current proposed guideline for riparian biota. Both terrestrial and riparian biota exceeded the 0.1 rad/day dose guideline proposed by DOE (2002). In addition, this report concludes that the reported conservative dose rates may overestimate dose rates by a factor of 10 to 100.

IT Corporation (1994) conducted a qualitative risk assessment for the 100-NR-2 source operable unit. This assessment evaluated risk from tritium, strontium-90, and metals using a frequent and occasional-use scenarios with groundwater ingestion, inhalation of tritium, and dermal absorption of tritium as the exposure pathways. A limited ecologic evaluation indicated the dose rate to plant-eating ducks (2.9 rad/day) would exceed 1 rad/day. This dose estimate was driven in part by using conservative dose modeling factors in the CRITR II code. For example, the bioconcentration factor used in the model for strontium was 3000, whereas, empirical data collected from the 100-N Area for milfoil indicates a bioconcentration factor of 150. This adjustment would reduce the dose rate to below a rad/day guideline. Also, both the Poston and Soldat (1992) screening assessment and the IT assessment (1994) used undiluted seep water

as a source term. In addition to the radiological exposure assessment, the environmental risk from metals was also evaluated. The study found that iron, zinc, and hexavalent chromium would result in chronic environmental health quotients exceeding 1, indicating an elevated risk to biota.

Driver (1994a) conducted a literature review of the ecotoxicity of selected Hanford contaminants. The report reviewed the toxicology of aquatic biota and mammals exposed to radionuclides, chromium, or nitrate. This review has been expanded with a review of additional data and expanded to include additional contaminants; however, the document has not been reissued at present (personal communication, T. M. Poston). Harper et al. (1995) evaluated general toxicology information of specific metals, radionuclides and organic compounds on humans. Some of these contaminants are found at the 100-N Area.

Wells (1994) determined the human health risks for radiation doses from maximum concentrations of radionuclides in Hanford Reach sediment. The calculated doses were low and less than 1% of background dose. No data specific to the 100-N Area was provided in this report. In addition, the report summarizes the literature on Hanford Reach sediment and health effects.

Blanton et al. (1995) conducted an assessment of offsite human exposure to organic and inorganic contaminants. Source terms were identified for each industrialized area of the Hanford Site and groundwater. The Multimedia Environmental Assessment System (MEPA) code was use to estimate exposure and heath impacts (cancer incidence and hazard quotients). While risk was not estimated at the 100-N Area, the overall 100 Areas were one of the source terms used in the assessment.

DOE (1995) produced a limited field investigation report for the 100-NR-2 operable unit. The human health risk assessment identified arsenic, cadmium, chromium, fluoride, manganese, nitrate, tritium, and strontium-90 in the groundwater as constituents of concern for both frequent- and occasional-use scenarios. The environmental risk assessment for aquatic toxicity for fish from non-radioactive contaminants indicated hexavalent chromium, cadmium, zinc and iron in the groundwater exceeded either the acute or chronic toxicity criterion. Total petroleum hydrocarbons in one well exceed an applicable, or relevant and appropriate requirement (ARAR).

To evaluate the impact to the Columbia River from Hanford-derived contaminants, DOE, EPA, and Washington State Department of Ecology initiated an ecological and human risk assessment study referred to as the Columbia River Comprehensive Impact Assessment (DOE 1998b). This study also received guidance from stakeholder groups (e.g., Native Americans, Oregon State). The general approach was to segment the river into zones corresponding to known groundwater contaminant plumes. Environmental data from groundwater, riverbank springs, sediment, and surface water was collected from a variety of sources. Ecological receptors included over 40 species of aquatic and riparian receptors including steelhead and salmon. For the river segment containing the 100-N Area, cobalt-60 exceed both human and ecological risk thresholds, and carbon-14, cesium-137, chromium, europium-154, strontium-90, and tritium were identified as potentially exceeding the human risk thresholds (greater than 1 in 1,000,000 cancer risk or hazard index of 0.01). In addition, mercury was identified as exceeding the ecological risk threshold.

Van Verst et al. (1998) surveyed radiological contaminants in the near-shore environment adjacent to the 100-N Area during 1997 to 1998. The sampling locations bracketed the location where the maximum

groundwater contours for strontium-90 were reported. River water, sediment, riverbank spring water, and biota samples were analyzed for tritium, strontium-90, and gamma emitters. Background samples were collected upriver from Vernita Bridge. The CRITR II code was used to estimate doses to aquatic biota. The dose to aquatic organisms from tritium and strontium-90 were below the DOE 1 rad/day limit. The plant-eating duck and muskrat scenarios approached the 1 rad/day limit. However, it was noted that the CRITR II code is a tool to aid interpretation of environmental surveillance data and that the exposure scenarios for biota have specific assumptions that may not be representative of all locations. For the 100-N Area dose assessment, it was assumed that the plant-eating duck resided only in the vicinity of the 100-N Area spring, was exposed to 20-fold diluted spring water, and consumed only plants growing in the vicinity of the spring (similar assumptions were used for the muskrat scenario). The estimated dose would decrease if the strontium-90 concentrations were estimated over a more realistic habitat area because of dilution of the source. The study concluded that because of the small spatial extent of the contamination occurring at the 100-N Area, there should be no substantial risk to aquatic biota populations. The report found that there is a small area where macroinvertebrates are exposed to elevated strontium-90 and recommended additional study to understand if localized community-level and individual effects are occurring at the 100-N Area.

Peterson and Poston (2000) reviewed strontium-90 at the Hanford Site and its ecological implications with an emphasis on salmon spawning. The radiation standard for protection of aquatic organisms is 1 rad/day. Suppression of immune response in embryologically exposed rainbow trout at 0.2 rad/day was the most sensitive biological endpoint documented for fish in lab experiments. Washington State Department of Ecology has adopted the 8 pCi/L drinking water standard as ambient water quality standard for freshwater, with the assumption this would ensure protection of the environment. The drinking water standard is designed to protect the most susceptible individuals, whereas dose-based standards for aquatic organisms are based on protecting populations of organisms. This report looked at the 100-H Area in particular, but concluded that risk assessments for aquatic organisms for the entire Hanford Reach would be within or well below established guidelines.

Kelley (2001) evaluated the 100-N Area monitored natural attenuation remediation scenario by reviewing reports concerned with mitigation or cleanup of 100-N Area riverbank springs. The report suggests that monitored natural attenuation at the 100-N Area is a viable remediation alternative. In addition, this report suggests the extent of the contaminated groundwater plume perimeter is static or retreating.

Poston et al. (2003) estimated conservative maximum dose rates and realistic dose rates to developing salmon embryos along the 100 Area shorelines of the Columbia River. The assessment used the proposed DOE Technical Standard (DOE 2002c) to estimate compliance with the DOE guidance level of 1 rad/day of aquatic organisms. It was noted that fall chinook salmon do not spawn along the 100-N Area shoreline. However, for the hypothetical situation that salmon redds were present and exposed to maximum 100-N Area seep water, the Tier I (most conservative dose rate estimate) was estimated at 0.19 rad/day. A more realistic dose rate based on Columbia River concentration factors, dilution in the inter-cobble spaces was about 4 orders of magnitude lower than the maximum screening dose rate.

## Modeling Efforts for Groundwater and River Interactions

Gilmore et al. (1991) evaluated the effects of the Columbia River on the unconfined aquifer beneath the 100-N Area, including interactions between river levels and groundwater levels and impacts to travel times and contaminant concentrations. Gilmore et al. (1992) produced a computer model to calculate volumetric discharge to the Columbia River of a specific cross-sectional area of the aquifer at the 100-N Area.

Strontium-90 transport in groundwater and bank storage effects were modeled for the 100-N Area by Connelly et al. (1991 and 1997). Connelly (2001) also modeled the interaction of the river and groundwater strontium-90 plume over a period of 56 years assuming $K_d$ values of 0 and 15 and suggested that fluctuating water levels did not affect the average yearly release of strontium-90, because the exchange of porewater through the sediment was insufficient to remove strontium-90 from the sediment. A geochemical model was used to look at controls on the mobility of strontium-90 in groundwater, and found the primary controlling factor was sorption onto aquifer sediment. It also found that high sodium and calcium levels in the groundwater could cause desorption of strontium-90 from the sediment, allowing it to move more quickly through the groundwater.

## Other Reports Potentially Useful for 100-N Area Riparian and Aquatic Assessments

Fix (1976) produced a brief report comparing an aerial radiological survey to soil and river water samples (the latter collected over several years on resin filters). The report provides only limited specific site results, but does show where soil samples were taken at the 100-N Area.

During 1992, Cooper and Woodruff (1993) conducted an investigation of exposure rates and radionuclide and trace metal distributions in shoreline soil along the Hanford Reach of the Columbia River. At the 100-N Area, no soil samples or terrestrial exposure rates were determined; however, external radiation exposure rates were determined for the Columbia River adjacent to the 100-N Area. The study determined exposure rates for the Columbia River along the Hanford shoreline, mid-river, and Grant County shoreline. In addition, terrestrial external radiation exposure rates were determined for the Grant County shore. The highest Columbia River exposures were near the 100-N Area turbine generator building (maximum of 20.1 μR/h), the 100-N Reactor building (maximum of 13.6 μR/h), and the 1301-N LWDF (9.1 μR/h). Exposure rates measured on the Columbia River decreased with increasing distant from the 100-N Area facilities. The Columbia River exposure rates adjacent to the Grant County shore were lower than the terrestrial measurements because of shielding from the river.

Eslinger et al. (1994) generated a compendium of all types of data, including databases and a literature search, for the Columbia River Comprehensive Impact Assessment.

DOE (1995c) issued a letter report concerning a sky shine abatement assessment and concluded that it was highly unlikely that individuals from the public would receive a dose above the annual 25 mrem/year limit from 1301-N/1325-N LWDF skyshine. The study used six direct exposure scenarios and one

indirect exposure adjustment. The Washington State Department of Health (Thatcher 1995) surveyed 100-N Area shoreline radiation and conducted a dose evaluation. Skyshine was measured at the 100-N Area in 1994 and 1995 with maximum dose rate of 19 μrem/hour. The potential dose a maximally exposed fisherman could receive was estimated at 5 mrem/year, while a typical fisherman would receive much less than 1 mrem/year.

Serne and Legore (1996) studied strontium-90 adsorption-desorption properties and sediment characterization at the 100-N Area. The study measured $K_d$ values for sediments and discusses applicability of the results to pump and treat and leaching operations at the 100-N Area.

Surface and subsurface sediments from boreholes and wells in the 100-NR-2 Operable Unit were sampled and analyzed (DOE 1996a). Analytical results and dose calculations are provided in the appendices. Background levels of radionuclides in Hanford Site soil are provided in DOE (1996b).

DOE (1998c) discusses exposure scenarios, remediation goals and remedial action objectives for the 100-NR-2 Operable Unit.

Van Verst et al. (1998) surveyed radiological contaminants in the near-shore environment adjacent to the 100-N Area during 1997 to 1998. The sampling locations bracketed the location where the maximum groundwater contours for strontium-90 were reported. River water, sediment, riverbank spring water, and biota samples were analyzed for tritium, strontium-90, and gamma emitters. Background samples were collected upriver from Vernita Bridge. Potential dose for humans was calculated to be below health impact levels and federal regulatory limits. External dose rates were measured for the near-shore vicinity of the 100-N Area. Exposure rates ranged from 2 to 14 μR/hour, with the highest rates found along the shoreline in the vicinity of the liquid waste disposal trenches. Exposure rates from mid-river to the Grant County shore ranged from 2 to 6 μR/hour.

Franz and Evans (2001) issued a report on radioactive biota sampled at Hanford since 1950. The report includes a listing of all samples from the BIOTA database that reported measurable levels of radionuclides.

The cultural, archaeological, and historical resources at the 100-N Area are briefly reviewed in the Hanford Site National Environmental Policy Act (NEPA) characterization report (Neitzel 2002). No historic buildings, archaeological sites, or districts in the 100-N Area are listed, or determined to be eligible for listing, in the National Register of Historic Place or the Washington Heritage Register. However, the Ryegrass Archaeological District, which is listed in the National Register of Historic Places, is located within 2 kilometers of the 100-N Area perimeter. Reconnaissance-level archaeological surveys were conducted in the late 1960s to late 1970s (Rice 1968, 1980a, 1980b).

## Overall Summary from Literature and Data Review

Over 220 reports and technical documents were identified and reviewed for this report. This section provides an overall summary for both the literature and data reviews with particular attention for species of special interest, the major contaminants of concern (tritium, strontium-90, hexavalent chromium, manganese, nitrate, sulfate, and total petroleum hydrocarbons), and risk/exposure assessments.

The major habitat types and species inhabiting the 100-N Area riparian and aquatic environments have been documented and characterized. There are no plant species that are federally listed as endangered or threatened that occur at the 100-N Area, but there are several species listed by Washington State as threatened or sensitive that could be in the area. These species include four state threatened species – awned halfchaff sedge (*Lipocarpha aristulata*), grand redstem (*Ammannia robusta*), lowland toothcup (*Rotala ramosior*), and the persistent sepal yellowcress (*Rorippa columbiae*), and two state sensitive species – the Canadian St. John's wort (*Hypericum majus*) and the shining flatsedge (*Cyperus bipartitus*). All of these species are found near the shoreline in wetland areas; the yellowcress is often found in rockier areas than the other species. None of these species have been reported at the 100-N Area, but relatively little of that shoreline has been extensively studied.

Extensive data was found on contaminant concentrations in water, riverbank spring water, sediment, and biota collected from the 100-N Area riparian and aquatic environments. In addition, external dose rates were measured for a number of studies at the 100-N Area. Data was grouped into two general time periods; the body of the report is generally limited to recent data (1993 to 2003) and the 1973 to 2003 time range is summarized in Appendix B.

Most of the contaminant studies at the 100-N Area riparian and aquatic environments have focused on strontium-90, tritium, gamma-emitting radionuclides (mostly cobalt-60 and cesium-137, which were not listed as contaminants of concern in this report), and chromium (most results are for total chromium, but some hexavalent chromium results are available). Tritium levels were not available for some media because of limited analytical methods (e.g., tritium in fish) and most studies utilized other media to account for tritium cycling in the 100-N Area environment.

Mice and cottontail rabbit samples, taken in the early 1970s, from the 100-N Area trench had the highest levels of strontium-90 contamination in wildlife species. Levels in these samples were as high as 7,800 pCi/g in mice muscle and 6,000 pCi/g in rabbit bones. Since 1993, mule deer, pheasant, and Canada geese have been sampled around the 100-N Area. The average level of strontium-90 found in these species was 0.13 ± 0.19 pCi/g (1 standard deviation). The maximum level (0.72 pCi/g) was found in Canada goose bones collected in 1995 between the 100-N and 100-D Areas.

Fish and macrointervebrates have also been collected near the 100-N Area. Prior to 1993, the maximum concentration of strontium-90 was for clam tissues (1.0 pCi/g) and the maximum level of strontium-90 for clam shell was 260 pCi/g in 1990. Since 1993, the only aquatic species collected near the 100-N Area have been whitefish, sculpin, and carp. The average concentration of strontium-90 found in these species was 0.049 ± 0.14 pCi/g, while the maximum concentration, 0.76 pCi/g, was found in a carp carcass collected in 2002 between the 100-N and 100-D Areas.

During 1988, spawned-out fall chinook salmon were collected at the Priest Rapids Dam (upstream of the 100-N Area) and near the White Bluffs (roughly 8 to 12 kilometers downstream of the 100-N Area). Muscles were analyzed for cobalt-60, strontium-90, and cesium-137 with similar concentrations at each location. These results indicate no observed accumulation in fish muscle from radionuclides released to the Columbia River from Hanford operations.

The average concentration of strontium-90 in soil samples collected around the 100-N Area, during 1993 to 2003, was 3.20 ± 12.0 pCi/g. Soil samples collected near the 100-N Area riverbank springs in 1997 had the highest levels of strontium-90.

Columbia River water samples, riverbank spring water samples, drinking water samples, and groundwater samples in the rooting zone have been collected near the 100-N Area. The maximum concentration of strontium-90 was collected from a riverbank spring below the well building near groundwater monitoring well 199-N-8T during 1997. Changes to the water table resulting from reduced and eliminated discharges of water to the 100-N Area liquid waste disposal facilities has decreased the number and discharge of some 100-N Area springs, and flow has been observed at this spring location only once from 1993 through 2002 (Poston et al. 2002) despite the presence of flowing springs at a several downstream locations.

Vegetation was sampled during 1998 and 1999 along the shoreline and near the springs around the 100-N Area. Mulberry and reed canarygrass samples collected along the shoreline had the highest concentrations of strontium-90. The average concentration of strontium-90 in vegetation samples collected during 1993 to 2003 was 2.1 ± 6.3 pCi/g.

For the other non-radiological contaminants of concern, nitrate, sulfate, and manganese concentrations have been reported from several studies of Columbia River water and riverbank spring water near the 100-N Area. However, little or no data was available for these contaminants in 100-N Area riparian soil and plants, sediment, and aquatic plants and animals. No contaminant data was found for total petroleum hydrocarbons, the most likely source for data on total petroleum hydrocarbons would be from waste site evaluations or possibly the groundwater monitoring efforts; however, these were not reviewed.

Fish and several other aquatic organisms, as well as riverbank spring and river water samples, were collected during 1997 near the 100-N Area to better understand the distribution and significance of metals. Total chromium was measured in caddisflies, clams, sculpin, milfoil, periphyton and reed canarygrass. The average chromium concentration in these species was 10 ± 13 μg/g. The maximum concentrations were found in periphyton and clams.

From 1993 to 2003, levels of chromium in river water samples averaged 6.4 ± 7.4 μg/L and in riverbank spring water samples averaged 25 ± 29 μg/L, which was above the ambient surface water quality criteria of 10 μg/L for chronic exposure (WAC 173-201A). Two river water samples taken near 100-N spring 8-13 in 1996 were analyzed for hexavalent chromium with a maximum value of 5.3 μg/L.

Nitrate and sulfate were also measured in riverbank spring and river water samples from the 100-N Area. The average nitrate concentration in the riverbank spring was 9,600 ± 5,600 μg/L and the average sulfate concentration was 210,000 ± 7,200 μg/L during 1993 to 2002. The average concentration of nitrate and sulfate in river water was 400 ± 33 μg/L and 9,100 ± 260 μg/L. All nitrate concentrations were below the 45,000-μg/L drinking water standard (40 CFR 141). The average sulfate concentrations for riverbank spring water from the 100-N Area approached the secondary (or aesthetic) drinking water standard for sulfate of 250,000 μg/L (40 CFR 141).

Manganese concentrations were reported for 30 Columbia River water samples collected near the 100-N Area, with a maximum concentration of 8.5 μg/L. Manganese levels for three samples of river-bank spring water were reported with a maximum concentration of 680 μg/L, which exceeded the EPA secondary (or aesthetic) drinking water standard of 50 μg/L.

No data was available for total petroleum hydrocarbons in drinking water, Columbia River water, riverbank spring water, or root zone groundwater.

At the 100-N Area, several dose assessments for humans and biota have been conducted; however, most reports do not use the dose assessment information to estimate risk. The 100-N Area dose/risk assessments conducted to date have primarily relied upon the CRITR II computer code (Poston and Soldat 1992; IT 1994; Van Verst et al. 1998) or the DOE Biota Dose Assessment (Peterson and Poston 2002; Poston et al. 2003).

It is difficult to compare the results of the different dose/risk assessments because of varying exposure scenarios. Several of the screening level assessments with conservative exposure scenarios reported dose/risk for 100-N Area biota that approached or exceeded the dose criteria (Poston and Soldat 1992; IT 1994; DOE 1995; Van Verst et al. 1998). Studies with more site-specific data and scenarios generally found dose/risk levels that were below dose criteria (Peterson and Poston 2000; Poston et al. 2003). Strontium-90 was the major radionuclide of concern for 100-N Area dose/risk assessments, with tritium, carbon-14, cobalt-60, cesium-137, and europium-154 included in some assessments. For chemical contaminants arsenic, cadmium, fluoride, hexavalent chromium, iron, manganese, mercury, nitrate, and zinc were identified as contaminants of concern for the 100-N Area.

General conclusions from these dose/risk reports are:

- Modeled dose rates are typically highly conservative compared to measured dose rates calculated using body burdens.
- Site specific assessments were generally orders of magnitude lower than screening assessments.
- Modeled dose rates are highly influenced by exposure scenarios
- When modeled dose rates approach regulatory guidelines the exposure scenarios should be inspected for bias and accuracy.
- Site specific variations in temporal, spatial, and biological factors tend to reduce dose rates from point source releases.

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Sackschewsky, M.R. and D.S. Landeen. 1992. *Fiscal Year 1991 100 Areas CERCLA Ecological Investigations*. WHC-EP 0448, Westinghouse Hanford Company, Richland, Washington.

Sackschewsky, M.R., D.S. Landeen, J.L. Downs, W.H. Rickard, and G.I. Baird. 1992. *Vascular Plants of the Hanford Site*. WHC-EP-0554, Westinghouse Hanford Company, Richland, Washington.

Serne, R.J. and V.L. Legore. 1996. *Strontium-90 Adsorption-Desorption Properties and Sediment Characterization at 100-N Area*. PNL-10899, Pacific Northwest Laboratory, Richland, Washington.

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

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

Tiller, B.L., G.E. Dagle, L.L. Cadwell, T.M. Poston, and A. Oganesian. 1997. *Investigation of Anatomical Anomalies in Hanford Site Mule Deer*. PNNL-11518, Pacific Northwest National Laboratory, Richland, Washington.

Tiller, B.L. and T.M. Poston. 2000. "Mule Deer Antlers as Biomarkers of Strontium-90 on the Hanford Site." *J. Environ. Radioactivity* 47, 29-44.

U.S. Department of Interior. 1996. *United States Department of Interior Record of Decision – Hanford Reach of the Columbia River: Final Environmental Impact Statement for Comprehensive River Conservation*. Washington, D.C.

U.S. Fish and Wildlife Service. 1998. *Hanford Site 100 Area Assessment Plan, Volume I: Columbia River Aquatic Resources Draft*. Prepared for the Hanford Natural Resource Trustee Council, Upper Columbia River Basin Field Office, Spokane and Moses Lake.

Van Verst, S.P., C.L. Albin, G.W. Patton, M.L. Blanton, T.M. Poston, A.T. Cooper, and E.J. Antonio. 1998. *Survey of Radiological Contaminants in the near-Shore Environment at the Hanford Site 100-N Reactor Area*. Prepared by the Washington State Department of Health and Pacific Northwest National Laboratory for the U.S. Department of Energy, Richland, Washington.

WAC 173-201A. "Water Quality Standards for Surface Waters of the State of Washington." Washington Administrative Code, Olympia, Washington.

Weiss, S.G. and R.M. Mitchell. 1992. *A Synthesis of Ecological Data from the 100 Areas of the Hanford Site*. WHC-EP-0601, Westinghouse Hanford Company, Richland, Washington.

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

# Appendix A

# Excel Spreadsheet of Documents for the 100-N Area Receptor Literature Review

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Technical Reports** | | | | | | | | | | | | | | |
| | | 1301N Shoreline Dose Reduction Study | WHC-SD-NR-ES-009 | Westinghouse Hanford Company | Richland, WA | | | | | | | | | Not reviewed. |
| Antonio, E.J., T.M. Poston and W.H. Rickard. | 1993 | Radiological Survey of Shoreline Vegetation from the Hanford Reach of the Columbia River, 1990-1992. | PNL-8797 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | vegetation | yes | terrestrial, riparian | | Sampled natural Hanford riparian vegetation that are usable by humans for food or other purposes. This vegetation was sampled in 1990, 1991 and 1992, and pumpkins and tomatoes intentionally planted in 1990 at 100F and Hanford Townsite. 100N vegetation had elevated concentrations of several radionuclides. Full dataset is included in a table. |
| Baker, D.A. and J.K. Soldat | 1992 | Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment | PNL-8150 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | aquatic invertebrates | no | aquatic | no | Presents model to calculate radiation doses to aquatic organisms and their predators. Provides table of Hanford-specific bioaccumulation factors and human biological half-lives and uptake fractions. Also provides table of half-lives and energies for selected effective radii of aquatic organisms and external dose rate factors. |
| Barnthouse, L.W. | 1995 | Effects of Ionizing Radiation on Terrestrial Plants and Animals: A Workshop Report | ORNL/TM-13141 | Oak Ridge National Laboratory | Oak Ridge, TN | pertinent | yes | no | no | | no | terrestrial | no | Workshop concluded dose limits for humans are generally protective of animals and plants except - 1) human access is restricted without restricting biota access, 2) unique exposure pathways exist, 3) rare or endangered species are present, or 4) other stresses are significant. If any exceptions exist, site specific exposures may be needed to develop secondary standards. |
| Bechtel Hanford Inc. | 1995 | N Springs Expedited Response Action Performance Monitoring Plan | BHI-00164 | Bechtel Hanford Inc. | Richland, WA | low | yes | no | no | groundwater | no | groundwater | yes | Describes plan to collect data to monitor the effectiveness of the 100N pump-and-treat effort. Includes DQO development |
| Becker, C.D. | 1973 | Aquatic Bioenvironmental studies in the Columbia River at Hanford 1945-1971 - A Bibliography with Abstracts | BNWL-1734 | Pacific Northwest Laboratory | Richland, WA | moderate | | | | | | | | Annotated bibliography of a lot of references written by Hanford scientists covering aquatic environment. General topics covered are biology and ecology of aquatic organisms, thermal and chemical effects of discharges, radioactivity releases, and hydrology of the Columbia River. Abstracts and citations are given. |
| 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, WA | low | yes | yes | yes | river sediment | no | aquatic | no | Document differences in sediment grain sizes for Priest Rapids Damn, Hanford Reach, and McNary Dam. Discusses associations between grain size, TOC, radionuclides metals and organic pollutants. |
| Blaylock, B.G., M.L. Frank, and B.R. O'Neal | 1993 | Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment | ES/ER/TM-78 | Oak Ridge National Laboratory | Oak Ridge, TN | moderate | yes | no | no | aquatic invertebrates | no | aquatic | no | Methodology for evaluating potential for aquatic biota to incur effects from exposure to chronic low-level radiation, using 1 rad/d as the minimum limit for detrimental effects. Gives tables of reproductive effects in some aquatic biota and citations for those studies. |
| Borghese, J.V., M.J. Hartman, S.P. Luttrell, C.J. Perkins, J.P. Zoric, and S.C. Tindall | 1996 | 100-N-Pilot Project: Proposed Consolidated Groundwater Monitoring Program | BHI-00725 | Bechtel Hanford, Inc. | Richland, WA | low | yes | yes | yes | groundwater, springs | no | groundwater, aquatic | yes | Plan to coordinate and consolidate groundwater and spring sampling in the 100N area. |
| Brandt, C.A., K. Alford, G. McIlveny, and A. Tijerina | 1993 | Plant Reestablishment After Soil Disturbance: Effects of Soil, Treatment, and Time | PNL-8935 | Pacific Northwest Laboratory | Richland, WA | low | no | no | no | vegetation | no | terrestrial | no | Techniques for reestablishing native vegetation in heavily disturbed areas on the Hanford Site. |
| Cadwell, L.L. | 1994 | Wildlife Studies on the Hanford Site: 1993 Highlights Report | PNL-9380 | Pacific Northwest Laboratory | Richland, WA | low | no | no | no | large mammals, small mammals, insects, birds, vegetation, aquatic invertebrates | no | terrestrial, aquatic | yes | Doesn't provide much specific information on location of various species. However, these data are available in the EMC database. |
| Cadwell, L.L. | 1995 | Wildlife Studies on the Hanford Site: 1994 Highlights Report | PNL-10552 | Pacific Northwest Laboratory | Richland, WA | low | no | no | no | large mammals, small mammals, insects, birds, vegetation, aquatic invertebrates | no | terrestrial, aquatic | yes | Doesn't provide much specific information on location of various species. However, these data are available in the EMC database. |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Caplow, F. and K. Beck | 1996 | A Rare Plant Survey of the Hanford Nuclear Reservation, Volume 1. The Hanford Biodiversity Project. | Report to the Nature Conservatory of Washington | The Nature Conservancy | Seattle, WA. | moderate | no | no | no | vegetation | no | terrestrial, riparian | no | Survey of Hanford Site rare plants. |
| Carpenter, G.D. | 1992 | N-Springs Mulberry Data letter report, May 18, 1992 | Letter report | Westinghouse Hanford Company | Richland, WA | pertinent | yes | no | no | vegetation | no | terrestrial | yes | Measured mulberry limbs and trunks were measured in Dec. 1991. All the trees except one were cut down and buried. Levels of Sr-90 and gamma-emitters are reported for each of the 9 trees. |
| Clear Creek Hydrology, Inc. | 1996 | 100-N Area Task II River Level Study N-Springs Access Roadway | | prepared for CH2M Hill | Townsend, MT | moderate | no | no | no | no | no | river | yes | Calculates river level elevations for various potential floods. |
| Cline, J.F. | 1981 | Aging Effects of the Availability of Strontium and Cesium to Plants | Health Physics 41:293-296 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | vegetation | no | terrestrial | no | Barley uptake rates of radionuclides are higher in a freshly mixed nuclide/soil matrix and decline after 30-60 days. Sr-90 is accelerated early in the plant's life cycle. Aging of the soil mixture did not change radionuclide availability much. |
| Cline, J.F. and W.H. Rickard | 1972 | Radioactive Strontium and Cesium in Cultivated and Abandoned Field Plots | Health Physics 23:317-324 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | vegetation | no | terrestrial | no | Sr-90 remains available to plants even after 16 years in old experimental plots that have been abandoned. Sr-90 may have formed a front 5-6 feet below the surface. |
| Connelly, M.P. | 2001 | Strontium-90 Transport in the Near River Environment at the 100-N Area | prepared for Innovative Technology Remediation Demonstration Project | HydroGeoLogic, Inc. | Herndon, VA | moderate | yes | no | no | no | no | groundwater, river | yes | Models the interaction of the river and groundwater Sr-90 plume over a period of 56 years assuming a Kd of 0 and one of 15. The modeling suggest the fluctuating water levels did not affect the average yearly release of Sr-90, because the exchange of porewater through the sediments was insufficient to remove Sr-90 from the sediments. |
| Connelly, M.P., A.J. Knepp, R.E. Peterson, K.R. Simpson, and A.S, Burgess | 1994 | Modeling Evaluation of N-Springs Barrier and Pump-and-Treat Systems | BHI-00109 | Bechtel Hanford, Inc. | Richland, WA | moderate | yes | no | no | modeling groundwater | no | groundwater | yes | Modeling to justify barrier placement and location of extraction wells; describes results of pump tests at three wells. |
| Connelly, M.P., C.R. Cole, and M.D. Williams | 1997 | Bank Storage Modeling at the 100-N Area | unpublished white paper for PNNL | CH2MHILL Hanford Inc. | Richland, WA | low | no | no | no | no | no | groundwater, river | yes | Models interaction between river and groundwater at the 100-N Area. |
| Connelly, M.P., J.D. Davis and P.D. Rittmann | 1991 | Numerical Simulation of Strontium-90 Transport from the 100-N Area Liquid Waste Disposal Facilities | WHC-SD-ER-TA-001 | Westinghouse Hanford Company | Richland, WA | pertinent | yes | no | no | NA | no | riparian, aquatic | yes | Modeling results of movement of Sr-90 in groundwater from 100N liquid waste disposal facilities to the river. |
| Cooper, A.T. and R.K. Woodruff | 1993 | Investigations of Exposure Rates and Radionuclide and Trace Metal Distributions Along the Hanford Reach of the Columbia River | PNL-8789 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | yes | TLD, soil | yes | riparian | no | Exposure rates were measured from 4 transects on the river and parallel to the shore. No soil samples were taken from the 100N area. |
| Cote, S.L. | 1994 | 100-N Area Technical Baseline Report | WHC-SD-TI-251 | Westinghouse Hanford Company | Richland, WA | | | | | | | | | Not reviewed. |
| Cushing, C.E. | 1979 | Trace Elements in a Columbia River Food Web | Northwest Science 53(2):118-125 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | yes | insects, fish | no | aquatic | not spec | Discusses uptake and bioaccumulation of various metals. Gives biomagnification values for metals in Columbia River caddis fly larvae and phytoplankton |
| Cushing, C.E. | 1993 | Aquatic Studies at the 100-HR-3 and 100-NR-1 Operable Units | PNL-8584 | Pacific Northwest National Laboratory | Richland, WA | pertinent | yes | no | yes | periphyton, aquatic invertebrates | no | aquatic | yes | Sampled periphyton and caddis fly larvae for Cr and 60Co, 90Sr, and 137Cs in 100N area. Found concentrations of all 4 contaminants essentially below detection limits in both species. Cr is not considered a problem at 100N. Mentions 1 clam and 1 snail as occurring near 100N that are aquatic candidate threatened and endangered species. |
| Cushing, C.E., D.G. Watson, A.J.Scott and J.M. Gurtisen | 1981 | Decrease of Radionuclides in Columbia River Biota Following Closure of Hanford Reactors | Health Physics 41:5967 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | seston, periphyton, aquatic invertebrates, fish, shironomids | no | aquatic | no | Measured radionuclide concentrations in several aquatic species after reactors were shut down. Documented decrease in radioactivity due to decay and decrease in input of contamination, as well as dilution. |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cushing, C.E., W.H. Rickard and D.G. Watson | 1988 | Radionuclide Accumulation by Aquatic Biota Exposed to Contaminated Water in Artificial Ecosystems before and after Its Passage through the Ground | NUREG/CR5047 PNL-5590 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | fish, aquatic invertebrates, algae, riparian vascular plants | no | aquatic, riparian | yes, alth | Uptake was measured in carp, goldfish, clams, algae, an aquatic emergent vascular plant species and tomato plants were exposed to water from 100N trench, diluted with river water by a factor of 10 (personal communication), from springs/seeps near the trench, and with upstream river water. The different water sources contained 60Co and 90Sr (as well as other constituents) in varying concentrations. Concentration ratios were calculated for each of the biota. In spring water, algae accumulated 125Sb, 60Co, 54Mn and 59Fe, clams accumulated 125Sb, 60Co, 90Sr and 59Fe, goldfish accumulated 106Ru, 60Co, and 90Sr while carp accumulated 125Sb, 60Co, 54Mn, 137Cs, 141Ce and 144Ce. Veronica roots showed different accumulations than the foliage, as did tomatoes. Verionica roots accumulated 124 and 125Sb, 60Co, 90Sr, 65Zn , 95Nb, 103 and 106Ru, 137Cs, 238 and 240 Pu and 59Fe, while the foliage 54Mn, 125Sb, 60Co, 90Sr, 65Zn , 95Nb, and 103 and 106Ru. Concentrations in tomato roots, foliage and stems, and fruit are also provided. |
| Dauble, D.D., T.M. Poston, and R.L. Newell | 1988 | Assessment of Aquatic Organisms as Bioindicators of Historical Radionuclide Release to the Columbia River | PNL-6795 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | fish, aquatic invertebrates | no | aquatic | no | Not specific to 100N, purpose of report was to look at options for dose reconstruction, not necessarily current conditions. Report determines that Sr-90 is the only radionuclide suitable for further study. Recommends white sturgeon and common mussel as suitable candidates for bioindicators in dose reconstruction scenarios. |
| Dauble, D.D. and D.G. Watson | 1990 | Spawning and Abundance of Fall Chinook Salmon (Oncorhynchus tshawytscha) in the Hanford Reach of the Columbia River, 1948-1988 | PNL-7289 | Pacific Northwest Laboratory | Richland, WA | low | no | no | no | fish | no | aquatic | no | Provides information on spawning habitat for Fall Chinook Salmon, but does not discuss where in the Hanford Reach this habitat may or does occur. Can't tell if there could be redds in the vicinity of 100N based on this report. |
| Dauble, D.D., K.R. Price, and T.M. Poston | 1993 | Radionuclide Concentrations in White Sturgeon from the Columbia River | PNL-8221, rev. 1 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | fish | yes | aquatic | no | Sampled sturgeon to look at dose reconstruction and evaluate current body burdens in the Columbia River. Concluded there was no risk to human health from consuming sturgeon muscle in1991. |
| Dauble, D.D., G.W. Patton, T.M. Poston, and R.E. Peterson | 2003 | *Evaluation of the Effects of Chromium on* | PNNL-14008 | Pacific Northwest Laboratory | Richland, WA. | moderate | no | no | yes | fish | no | aquatic | no | Review of recent studies on hexavalent chromium toxicity to early-life stage salmon, some Hanford Reach and Hanford Site specific information is provided. Hexavalent chomium is a contaminant of concern at the 100-N Area. |
| Davis, J.J. | 1962 | Accumulation of Radionuclides by Aquatic Insects | HW-SA-2848 | General Electric | Richland, WA | pertinent | yes | no | no | aquatic insects | no | aquatic | no | The 5 most abundant radionuclides in insect larvae are P-32, Cu-64, Cr-51, Zn-65 and Na-24, which was different from river water collected at the same time. Caddis fly larvae from within 3 miles of reactors had gross beta levels 1400 times greater than the water. Gives accumulation factors for several radionuclides, radionuclide ratios between life stages for caddis fly, differences in rad content with season. Contains info on several insects and plankton |
| Dirkes, R.L. | 1990 | 1988 Hanford Riverbank Springs Characterization Report | PNL-7500 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | yes | yes | springs, river | | aquatic | yes | Radionuclide concentrations were below DOE DCG's except for Sr-90. Tritium, gross beta and Sr-90 were above EPA drinking water standards in several springs. All other were below drinking water standards. Nonrad contaminants were generally undetectable in spring water, with nitrate above background levels but below drinking water standards. River water concentrations of rads and nonrads away from springs were below drinking water standards. |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dirkes, R.L. | 1992 | Columbia River Monitoring Data Compilation | WHC-SD-EN-DP-024 | Westinghouse Hanford Company | Richland, WA | low | | | | river | | aquatic | yes | Detailed annotated bibliography of many of the Hanford Site monitoring reports from the 1940's. Discusses quality of data as well as what was sampled, where it was sampled, and what was analyzed. |
| Dirkes, R.L., G.W. Patton, and B.L. Tiller | 1993 | Columbia River Monitoring: Summary of Chemical Monitoring Along Cross Sections at Vernita Bridge and Richland | PNL-8654 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | yes | yes | river | no | aquatic | no | Sampled metals, anion, volatile organic compounds, pH, temp and conductance at cross-river transects at Vernita Bridge and Richland Pumphouse. Analyses can provide background levels if necessary. |
| Doctor, P.G. | 1998 | 100 Area River Effluent Pipelines Risk Assessment | BHI-01141 | Bechtel Hanford, Inc. | Richland, WA | moderate | yes | no | yes | NA | yes | aquatic | yes | Describes cooling water pipeline from 100N into river. Minimal to no risk to human or aquatic life is anticipated if this pipeline is left in place. |
| Doctor, P.G. | 2003 | 100-B/C Area Ecological Risk Assessment Data Quality Objectives | BHI-01673 | Bechtel Hanford Inc. | Richland, WA | pertinent | | | | | | | no | Data quality objectives for 100-B/C ecological risk assessment may provide useful starting point for upcoming 100-N ecological risk DQO planning. |
| Doctor, P.G. | | title page was missing | BHI-00583 | Bechtel Hanford Inc. | Richland, WA | moderate | yes | no | no | sediment | no | aquatic | no | 100B and 100D pipelines were investigated as worst case. 100N discharge pipeline is expected to have very little contamination. |
| Downs, J.L., W.H. Rickard, C.A. Brandt, L.L. Cadwell, C.E. Cushing, D.R. Geist, R.M. Mazaika, R.A. Neitzel, L.E. Rogers, M.R. Sackschewsky, and J.J. Nugent | 1993 | Habitat Types on the Hanford Site: Wildlife and Plant Species of Concern | PNL-8942 | Pacific Northwest Laboratory | Richland, WA | pertinent | no | no | no | vegetation | | terrestrial, riparian | yes | Identifies primary habitat types for the Hanford Site and describes vegetation association and topography. These habitats are relates to species which may be threatened, endangered or sensitive. |
| Driver, C.J. | 1994 | Sediment Quality Criteria: A Review with Recommendations for Developing Criteria of the Hanford Site | PNL-9799 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | NA | no | aquatic | no | Looks at different methods to develop sediment quality criteria for river sediments. These criteria would be used to determine whether contaminants are within acceptable limits for protection of human and aquatic life. |
| Driver, C.J. | 1994 | Ecotoxicity Literature Review of Selected Hanford Site Contaminants | PNL-9394 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | yes | NA | no | aquatic and terrestrial | no | Looks at ionizing radiation, uranium, plutonium, cesium, strontium, cobalt, chromium, technetium, tritium, europium and nitrate toxicities in aquatic biota and mammals as reported in various literature. |
| Eberhardt, L.E., E.E. Hanson, and L.L. Cadwell | 1982 | Analysis of Radionuclide Concentrations and Movement Patterns of Hanford Site Mule Deer | PNL-4420 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | large mammals | no | terrestrial | no | Tracked deer from the 200 Areas and then looked a radionuclide concentrations. The river does not prevent movement of the deer. |
| Eberhardt, L.E., L.L. Cadwell, K.R. Price, and D.W. Carlile | 1989 | Trends in Radionuclide Concentrations for Selected Wildlife and Food Products Near the Hanford Site from 1971 through 1988 | PNL-6992 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | large mammals, small mammals, birds, fish, food products | no | terrestrial, aquatic | yes | No upward trends in radionuclide concentrations were detected during this time period in any of the wildlife species or food products examined. Data reside in Environmental Monitoring Program database. |
| Eldred, D. | 1970 | Steelhead Spawning in the Columbia River, Ringold to Priest Rapids Dam, September 1970 Progress Report. | | Washington Department of Game | Ephrata, WA | moderate | no | no | no | fish | no | aquatic | ? | Discusses steelhead spawning in the Hanford Reach above Ringold. |
| Eliason, J.R. | 1967 | Field Evaluation of Ground Disposal of Reactor Coolant--1301-N Crib. | BNWL-CC-1032 | Battelle-Northwest | Richland, WA | high | yes | no | no | wells, springs | no | riparian, aquatic | yes | Analyses of reactor effluent disposal to LWDF, including sampling wells and springs. |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emery, R.M. and M. Colleen McShane | 1980 | Nuclear Waste Ponds and Streams on the Hanford Site: An Ecological Search for Radiation Effects | Health Physics 38:787-809 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | invertebrates, algae, | yes | aquatic | yes | 100N trench - levels of contamination in 100N trench do not seem to affect colonization of algae in the trench but may affect variety of algae. Inconclusive on whether contamination inhibits vascular plant life. Study did not produce conclusive evidence that aqueous nuclear wastes affected invertebrates, vascular plants, or algae in 100N trench. Calculated dose rates form trench sediments indicate possible harmful effects to aquatic organisms and terrestrial communities, but the communities did not show direct evidence of such harm. Based on general biological profile, 100N trench can't be differentiated from offsite ecological systems. |
| Eslinger, P.W., L.R. Huesties, A.D. Maughn, T.B. Miley, and W.H. Walters | 1994 | Data Compendium for the Columbia River Comprehensive Impact Assessment | PNL-9785 | Pacific Northwest Laboratory | Richland, WA | pertinent | no | no | no | no | no | | yes | Compendium of all types of data, including databases and a literature search. |
| Fickeisen, D.H., D.D. Dauble, D.A. Neizel, W.H. Rickard, R.L Skaggs, and J.L. Warren | 1980 | Aquatic and Riparian Resource Study of the Hanford Reach, Columbia River, WA | prepared for U.S. Army Corps of Engineers, Seattle District | Pacific Northwest Laboratory | Richland, WA | pertinent | no | no | no | fish, vegetation | no | aquatic, riparian | no | Mentions the 100N area, but is mostly a general description of riparian and terrestrial plant and fish species and the effects the proposed Ben Franklin dam would have had on them. |
| Fickeisen, D.H., R.E. Fitzner, R.H. Saure, and J.L. Warren | 1980 | Wildlife Usage, Threatened and Endangered Species and Habitat Studies of the Hanford Reach, Columbia River, WA | BNW 2311104244 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | NA | no | terrestrial, riparian, aquatic | no | Description of wildlife utilization, threatened and endangered species and there species of concern, and critical habitats within and adjacent to the Hanford Reach, with emphasis on changes that would occur if Ben Franklin dam was built. |
| Fitzner, R.E. and R.H. Gray | 1990 | Status, Distribution and Ecology of Wildlife on the U.S. DOE Hanford Site: A Historical Overview of Research Activities | Environmental Monitoring and Assessment 18:173-202 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | small mammals, large mammals, birds, amphibians and reptiles | no | terrestrial, riparian | no | Not specific to 100N, list species of various wildlife found on the Hanford site since 1943, and the types of places they have been found. |
| Fitzner, R.E., S.G. Weiss, and J.A. Stegen | 1994 | Threatened and Endangered Wildlife Species of the Hanford Site Related to CERCLA Characterization Activities | WHC-EP-0513 | Westinghouse Hanford Company | Richland, WA | pertinent | no | no | no | birds, small mammal, aquatic invertebrate | no | terrestrial, aquatic | yes | Not specific to 100N, but lists special-status wildlife species and their habitats, some of which use the 100N area. |
| Fix, J.J. | 1976 | Association of Long-Lived Radioactivity with Sediment Along the Columbia River Shoreline, Islands, Bottom and Slough Area | BNWL-SA-5484 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | shoreline and river sediment | no | riparian, aquatic | yes | Brief report on comparison of aerial radiological survey and soil and river samples (the latter collected over several years on resin filters). Does not give much specific site results, does show where soil samples were taken at 100N, gives one Co-60 result from soil sample. |
| Foster, R.F. and D. McConnon | | Relationships Between the Concentration of Radionuclides in Columbia River Water and Fish | | | | low | yes | no | no | river, fish | no | aquatic | no | Discusses a number of radionculides, but not Sr-90 specifically. Was written during reactor operation. |
| Franz, G.R. and C.B. Evans | 2001 | Hazard Categorization Considerations for Hanford Radioactive Biota | HNF-8876 | Fluor Hanford | Richland, WA | pertinent | yes | no | no | small mammal, soil, invertebrates, vegetation, large mammal, birds, reptiles | no | terrestrial | yes | A data dump from the BIOTA database of all environmental samples collected since 1950 and analyzed for radionuclides, sorted in descending order of radionuclide contamination. |
| Geist, D.R., T.M. Poston, and D.D. Dauble | 1994 | Assessment of Potential Impacts of Major Groundwater Contaminants to Fall Chinook Salmon (*Oncorhynchus tshawytscha*) in the Hanford Reach, Columbia River | PNL-9990 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | fish | no | aquatic | yes | Tritium is not expected to affect fall chinook salmon because the observed radiotoxicity levels are higher than the maximum seep water concentrations. |
| Gilmore, T.J., D.R. Newcomer, S.K. Wurstner, and F.A. Spane, Jr. | 1992 | Calculation of Groundwater Discharge to the Columbia River in the 100-N Area | PNL-8057 | Pacific Northwest Laboratory | Richland, WA | pertinent | no | no | no | groundwater | no | groundwater | yes | Computer code description which can calculate volumetric discharge to a specific cross-sectional area of the aquifer. |
| Gilmore, T.J., J.V. Borghese, and D.R. Newcomer | 1991 | Evaluations of the Effects of the Columbia River on the Unconfined Aquifer Beneath the 100N Area | PNL-7646 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | groundwater, river | no | groundwater, aquatic | yes | Looks at interaction between river levels and groundwater levels and impacts to travel times and contaminant concentrations. |
| Gray, R.H. | 1988 | Overview of a Comprehensive Environmental Monitoring and Surveillance Program: The Role of Fish and Wildlife | PNL-SA-15922 | Pacific Northwest Laboratory | Richland, WA | low | | | | | no | | no | Very general presentation material, not really useful |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gray, R.H. | 1989 | Monitoring Fish, Wildlife, Radionuclides and Chemicals at Hanford Washington | PNL-SA-15238 | Pacific Northwest Laboratory | Richland, WA | low | | | no | | no | | no | Very general presentation material, not really useful |
| Gray, R.H. and D.D. Dauble | 1977 | Checklist and Relative Abundance of Fish Species from the Hanford Reach of the Columbia River | Northwest Science 51:208-215 | Pacific Northwest Laboratory | Richland, WA | pertinent | no | no | no | fish | no | aquatic | no | Provides species list of fish found in the Columbia River Hanford Reach over 30 year period. |
| Hakonson, T.E. and W.H. Rickard | 1969 | Radionuclide Deposition and Elimination in a Darkling Beetle | Northwest Science 43(1):23-28 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | insects | no | terrestrial | no | Beetles fed a diet containing Sr-85, and may accumulate in tissue and eggs similar to calcium. There was a rapid elimination component after the radioactive diet ceased, followed by a slow elimination component. |
| Hall, J.A. | 1998 | Biodiversity Inventory and Analysis of the Hanford Site | | The Nature Conservancy of Washington | Seattle, WA | moderate | no | no | no | biota populating | no | terrestrial riparian | no | Hanford Site biodiversity assessment, 100-N Area not specifically assessed. |
| Hanson, W.C. and R.L. Browning | 1957 | Role of Food Habits in Wildlife Contamination at Hanford | HW-47500 | General Electric Company | Richland, WA | pertinent | yes | no | no | birds | no | aquatic, terrestrial | no | Not specific to 100N. Lists some resident and non-resident birds, the category of bird (diving duck, shorebirds, etc.), the types of foods they eat, and general uptake and accumulation of radionuclides through those foods. |
| Harper, B.L., D.L. Strenge, R.D. Stenner, A.D. Maughn, and M.K. Jarvis | 1995 | Toxicology Profiles of Chemical and Radiological Contaminants at Hanford | PNL-10601 | Pacific Northwest Laboratory | Richland, WA | Pertinent | yes | yes | yes | no | yes | | no | Not specific to 100N. Summarizes toxicology information relevant to humans for a list of metals, radionuclides and organic compounds for use in the dose-response step of a risk assessment process. |
| Hedlund, J.D., D.T. McCullugh and W.H. Rickard | 1975 | Mouse Populations on Knob and Kettle Topography in South-Central Washington | Northwest Science 49(4):253-260 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | small mammal | no | terrestrial | yes | Sparse small mammal population adjacent to 100N believed to be due to stony soil rather than 100N facilities. |
| Isaacs, J.D. | 1996 | Laboratory Scale Stabilization of N-Springs Groundwater Strontium-90 Using Phosphatic Materials | BHI-00864 | Bechtel Hanford, Inc. | Richland, WA | moderate | yes | no | yes | subsurface soil | on | soil | yes | Summary of experiment to try different phosphate sources for removal of Sr-90 from N-springs groundwater. Clinoptilite and bone char worked best. Mentions some effluent constituents, such as higher fluorine from one of the tested phosphates that may be of ultimate concern. Also mentions above background levels of some metals in the borehole sediments they used in the experiment. |
| IT Corporation | 1994 | Qualitative Risk Assessment for 100-NR-2 Source Operable Unit | BHI-00055 | prepared for Bechtel Hanford, Inc. by IT Corporation | Richland, WA | pertinent | yes | no | yes | groundwater, springs, river | yes | terrestrial, aquatic | yes | Evaluated risk from tritium, Sr-90, and metals using a frequent and occasional-use scenarios with groundwater ingestion, inhalation of tritium, and dermal absorption of tritium as pathways. A limited ecologic evaluation indicated dose rate to plant-eating ducks would exceed 1 rad/d level, and iron, zinc and Cr+6 would result in chronic environmental health quotients exceeding 1. |
| Jaquish, R.E. | 1993 | Contribution of Hanford Liquid Effluents to Strontium -90 Levels in Offsite Soils | PNL-8817 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | | yes | terrestrial | no | Concludes about 2% or Sr-90 in soils in the vicinity of Hanford can be attributed to Hanford liquid effluents. Alfalfa has higher concentrations of Sr-90 than other farm crops. |
| Johnson, V.G., J.J. Wagner, and N.H. Cutshall | 1994 | Sediment Quality and Ecorisk Assessment Factors for a Major River System | WHC-SA-1989-FP | Westinghouse Hanford Company | Richland, WA | low | yes | no | yes | sediment | yes | aquatic | no | This paper describes contaminant-sediment transport and behavior using Hanford radionuclides as well as heavy metals. |
| Kelley, M.J. | 2001 | Hanford 100-N Monitored Natural Attenuation Remedial Scenario | prepared for Innovative Treatment and Remediation Demonstration Program | Sandia National Laboratories | Albuqueque, NM | moderate | yes | no | no | no | yes | subsurface soil, groundwater, springs | yes | Refers to reports concerned with mitigation and/or cleanup of N-Springs. Looks at using Monitored Natural Attenuation at 100N as a viable alternative to further remediation efforts. Suggest plume perimeter is static or retreating |
| Kelley, M.J., L. Maffitt, Y. McClellan, M.D. Siegel, and C.V. Williams (eds.) | 2002 | Hanford 100-N Area Remediation Options Evaluation Summary Report | none | prepared for the Innovative Treatment and Remediation Demonstration Program, Sandia National Laboratories | Albuqueque, NM | low | | | | | | | yes | Discusses remediation and treatment options for 100N |
| Krupka, K.M. and W.J. Martin | 2001 | Subsurface Contaminant Focus Area: Monitored Natural Attenuation (MNA) -- Programmatic, Technical, and Regulatory Issues | PNNL-13569 | Pacific Northwest National Laboratory | Richland, WA | low | | | | | | | no | Contains a literature search for documents related to monitored natural attenuation. Also refers to a protocol for monitored natural attenuation at a chlorinated solvent site, one of the few available. |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Landeen, D.S., A.R. Johnson, R.M. Mitchell, and M.R. Sackschewsky | 1994 | Comparison of Radionuclide Levels in Soil, Sagebrush, Plant Litter, Cryptogams, and Small Mammals | WHC-EP-0771 | Westinghouse Hanford Company | Richland, WA | moderate | yes | no | no | vegetation, soil, litter, cryptogams, small mammals | no | terrestrial | no | Evaluated various biota as media for environmental monitoring of radionuclide contamination. Samples from 200 East Area may indicate plant litter and cryptogams may be better environmental indicators than soil or vegetation. Small mammals did not show did not show significant amounts of radionuclides in this study. |
| Landeen, D.S., M.R. Sackschewsky and S. Weiss | 1993 | 100 Areas CERCLA Ecological Investigations | WHC-EP-0620 | Westinghouse Hanford Company | Richland, WA | pertinent | yes | no | yes | birds, small mammal, large mammal identified by not sampled; vegetation, soil and scat were sampled | no | terrestrial, riparian, aquatic | yes | Provides list of birds (including waterbirds), small and large mammals, insects and plants found at 100N (and other areas). Briefly discusses food chains. Soil samples from burrow and ant mounds showed very low or undetectable levels of contaminants. Metals and radionuclides in coyote scat and raptor pellets were generally very low, although lead was somewhat elevated in both. Asparagus, reed canary grass both had generally very low to undetectable values of radionuclides and metals. Milfoil sampled at N-Springs contained lead and zinc at levels above the control levels, and Sr-90 was also detected. |
| Lee, D.R., D.R. Geist, K. Saldi, D. Hartwig, and T. Cooper | 1997 | Locating Ground-Water Discharge in the Hanford Reach of the Columbia River | PNNL-11516, RC-M-22 | Prepared by the Atomic Energy of Canada Ltd. Chalk River Laboratories and Pacific Northwest Laboratory for the U.S. Department of Energy | Richland, WA | low | yes | no | yes | porewater | no | aquatic | no | Used electrical conductivity probe mounted on sled pulled behind a boat to detect underwater seeps in Hanford Reach. Only works where groundwater conductivity is greater than that of+O25 river water. Piezometers were used to confirm groundwater seeps. |
| Marr, N.V., C.A. Brandt, R.E. Fitzner, and L.D. Poole | 1988 | Habitat Associations of Vertebrate Prey Within the Controlled Area Study Zone | PNL-6495 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | small mammal | no | terrestrial | no | Found 8 species of small mammals, 6 species of reptiles and one species of amphibian in 9 habitat types, some of which may be similar to those at 100N. |
| McCormack, W.D. and J.M.V. Carlile | 1984 | Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River | PNL-5289 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | yes | springs, river | no | aquatic, riparian | yes | Identified and sampled springs/seeps along the Hanford Reach and analyzed samples for tritium, nitrate and uranium in places as indicators of Hanford contamination. Also sampled the river 2-4 m from shore to look for undetected effects or underwater seeps. |
| Mueller, R.P. and D.R. Geist | 1998 | Evaluation of Fall Chinook Salmon Spawning Adjacent to the in-Situ Redox Manipulation Treatability Test Site, Hanford Site, WA | PNNL-12025 | Pacific Northwest National Laboratory | Richland, WA | Moderate | no | no | no | fish | no | aquatic | close | Identified areas of potential salmon spawning near 100D area, some of these areas get close to 100N |
| Neitzel, D.A. and T.J. Frest | 1989 | Survey of Columbia River Basin Streams for Giant Columbia River Spire Snail Fluminicola columbiana and Great Columbia River Limpet Fisherola nutallii | PNL-7103 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | aquatic invertebrates | no | aquatic | yes | Found rare pebblesnail and shortface lanx near 100F, cannot conclude thee species do not exist at 100N. |
| Neitzel, D.A. and T.J. Frest | 1993 | Survey of Columbia River Basin Streams for Columbia Pebblesnail Fluminicola columbiana and Shortface Lanx Fisherola nuttallii | PNL-8229, rev. 1 | Pacific Northwest Laboratory | Richland, WA | moderate | no | no | no | aquatic invertebrates | no | aquatic | yes | Looked along Hanford Reach for these 2 potentially threatened species. Identified sampling locations near 100N but skipped sampling there although good habitat was found below fluctuating water levels. |
| Neitzel, D.A., T.L. Page, and R.W. Hanf | 1982 | Mid-Columbia River Microflora | J. Freshwater Ecology 1(5):495-505 | Pacific Northwest Laboratory | Richland, WA | | no | no | no | zooplankton | no | aquatic | no | Sampled multiple places along the Hanford Reach to identify species and seasonal densities. |
| Opresko, D.M., B.E. Sample and G.W. Suter | 1994 | Toxicological Benchmarks for Wildlife: 1994 Revision | ES/ER/TM-86/R1 | Oak River National Laboratory | Oak River, TN | moderate | no | yes | yes | large mammals, small mammals, birds | no | terrestrial | no | These mammals and birds are not necessarily found at Hanford. Report presents toxicological benchmarks for assessment of effects of 76 chemicals on 8 representative mammalian wildlife species and 31 chemical on 9 avian wildlife species. No rads. |
| Parnell, S.E. and T.M. Routt | 2000 | Technical Memorandum for the 100-N Area ITRD Bank Stabilization Evaluation | BHI-01324 | Bechtel Hanford Inc. | Richland, WA | moderate | no | no | no | no | no | terrestrial, riparian | yes | Shoreline slope has been stable in the 100N area for thousands of years and will probably continue to be if construction vibrations are minimized. Discusses water levels and flow rates from 10-year up to 500-year floods. |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Patton, G.W. and E.A. Crecelius | 2001 | Simultaneously Extracted Metals/Acid-Volatile Sulfide and Total Metals in Surface Sediment from the Hanford Reach of the Columbia River and the Lower Snake River | PNNL-13417 | Pacific Northwest National Laboratory | Richland, WA | low | no | no | yes | soil | no | aquatic | no | Looked upstream and downstream of 100N at metals concentrations in river sediments and related those levels to availability in porewater and to aquatic biota. Cadmium, nickel and zinc in Columbia River sediment were near or above some probable effect levels. |
| Peterson, R.E and G.W. Patton | in prepar | Monitoring Locations and Shoreline Features Along the Columbia River on the Hanford Site | in preparation | Pacific Northwest National Laboratory | Richland, WA | moderate | no | no | no | no | no | shoreline features | yes | Catalog of shore features (well, drive points, springs and includes shoreline features for the 100-N Area. |
| Peterson, R.E. | 1998 | Aquifer Sampling Tube Completion Report: 100 Area and Hanford Townsite Shorelines | BHI-01153 | Bechtel Hanford, Inc. | Richland, WA | pertinent | yes | no | yes | springs | | aquatic | no | Mentions porcupines and raccoons as possible animals chewing on polyethylene tubing used in aquifer sampling tubes at 100D area and/or Hanford townsite. Some of these sampling tubes are just upstream of 100N area. |
| Peterson, R.E. | 1998 | N-Springs Expedited Response Action Performance Monitoring Plan: Update | BHI-01165, Rev. 1 | Bechtel Hanford, Inc. | Richland, WA | low | yes | no | yes | groundwater | no | groundwater | yes | Expedited response monitoring plan for wells and tubes, doesn't discuss dose or impacts of effluent. |
| Peterson, R.E. and M.P. Connelly | 2001 | Zone of Interaction between Hanford Site Groundwater and Adjacent Columbia River | PNNL-13674 | Pacific Northwest National Laboratory | Richland, WA | moderate | no | no | no | river, groundwater | no | aquatic, subsurface | no | Continued work on models to look at changes in groundwater characteristics in the area of groundwater/river water mixing. Also continued work on flow path modeling. |
| Peterson, R.E. and T.M. Poston | 2000 | Stronitium-90 at the Hanford Site and its Ecological Implications | PNNL-13127 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | no | yes | groundwater, aquatic organisms, fish | yes | Standard for aquatic organisms for protection from radiation exposure is 1 rad/d. Suppression of immune response in rainbow trout at 0.2 rad/d is the most sensitive biological endpoint documented for fish in lab experiment. WDOE has adopted the 8 pCi/L drinking water standard as ambient water quality standard for freshwater, with the assumption this would ensure protection of the environment. The drinking water standard is designed to protect the most susceptible individuals, whereas dose-based standards for aquatic organisms are based on protecting populations of organisms. Looked at 100H in particular, but conclude that risk assessments for the entire Hanford Reach would be within or well below established guidelines (referring to aquatic organisms) |
| Peterson, R.E. and V.G. Johnson | 1992 | Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site | WHC-EP-0609 | Westinghouse Hanford Company | Richland, WA | | yes | no | yes | groundwater, springs, soil | no | groundwater, aquatic | yes | Impacts of N-Springs on streambank sediment is very localized, with gross beta above background occurring only a short distance downstream. Sr-90 is associated with seepage sediment. |
| Poston, T.M. | 1995 | Concentration of Radionuclides in Terrestrial Vegetation on the Hanford Site of Potential Interest to Native Americans | PNL-10397 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | vegetation | no | terrestrial | no | Looked at radionuclides in leaves and/or roots in balsamroot and 2 species of desert parsley, which are abundant in shrub steppe on Hanford and historically used by Native Americans. Co-60, Cs-137, and Sr-90 in these species were near background levels in the 100 Areas. |
| Poston, T.M. | 1994 | Trends in Radionuclide Concentrations in Hanford Reach Fish, 1982 through 1992 | PNL-9960 | Pacific Northwest National Laboratory | Richland, WA | moderate | yes | no | no | fish | yes | aquatic | no | Concentrations of Sr-90 and Cs-137 gradually decreased in small mouth bass and whitefish between 1982 ad 1992, following trends in Hanford Site releases. Many other gamma-emitters were not observed, most notably Co-60. Background levels of these 2 contaminants in fish sampled far away were actually higher than those sampled in the Hanford Reach. Dose estimates from consumption of fish were less than guidelines by the National Council on Radiation Protection and Measurements and DOE. |
| Poston, T.M. | 2000 | Risk of Sr-90 to Salmon in the Hanford Reach 100-N Springs | presentation to Hanford Natural Resource Trustee Council Meeting, Nov. 2002 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | | | | no | aquatic | yes | Concludes no risk to spawning salmon from Sr-90 from 100-N Springs. |

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| Poston, T.M. and A.T. Cooper | 1994 | A Qualitative Evaluation of Radionuclide Concentrations in Hanford Site Wildlife, 1983 through 1992 | PNL-10174 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | birds, small mammal, large mammal | yes | terrestrial | yes | Looked at 90Sr and 137Cs in rabbits, ducks and deer in the 100N area. None of the measured concentrations were high enough to pose any risk to theoretical human consumers who ate 40 kg/yr of game animals inhabiting the Hanford Site based on the DOE guideline of 100 mrem/yr and the National Council on Radiation Protection and Measurements Concentrations of 90Sr in rabbit and deer bones was higher in areas adjacent to industrialized areas |
| Poston, T.M. and J.K. Soldat | 1992 | Scoping Assessment of Radiological Doses to Aquatic Organisms and Wildlife - N Springs | PNL-8360 | Pacific Northwest Laboratory | Richland, WA | Pertinent | yes | no | no | large mammal, small mammal, birds, fish, aquatic invertebrates, aquatic vegetation | yes | aquatic | yes | Dose rate modeling effort based on real samples collected in 100N area and on estimates based on concentration ratios for tissue and concentrations in N-Springs water. Estimated dose rates to endemic biota do not exceed administrative dose rate for native aquatic biota set by US DOE. Conservative dose rates may be overestimated by factor of 10 to 100. |
| Poston, T.M., E.J. Antonio and A.T. Cooper | 1995 | Radionuclide Concentrations in Terrestrial Vegetation and Soil On and Around the Hanford Site, 1983 through 1993 | PNL-10728 | Pacific Northwest National Laboratory | Richland, WA | pertinent | yes | no | no | soil, vegetation | no | terrestrial, riparian | yes | Sampled soil and vegetation at or near 100N and compared the combined results with the other Hanford areas and offsite. For shoreline sampled, it refers to Antonio et al. 1993 for that. 90Sr and 3H are the only radionuclides that accumulated significantly above background in shoreline vegetation up or downstream of N-Springs. Contaminated vegetation from N-Springs was removed in 1992. |
| Poston, T.M., R.E. Jaquish, E.J. Antonio, and G.W. Patton | 1998 | "Strontium-90 in Alfalfa (Medicago sativa) Around the Hanford Site in southeastern Washington State: An Evaluation of Surveillance Data" | J. Environ. Radioactivity, 39(1):87-105 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | vegetation | yes | no | yes | Levels of Sr-90 are slightly higher in fields using irrigation water downstream of the Hanford Site. Monitoring data do not support Hanford discharges to the river as the source of the increase. Dose calculations indicate levels 0.03% of the annual dose resulting from natural sources of radiation through human consumption of milk. |
| Price, K.R. | 1971 | Vascular Plants of Waste Storage Sites in the 200 Areas of the Hanford Reservation | BNWL-1796 | Pacific Northwest Laboratory | Richland, WA | low | no | no | no | vegetation | no | terrestrial, riparian, aquatic | no | List of plants occurring on or near waste sites in the 200 Areas. Probably some of these occur in 100 Areas, but this is not discussed. |
| Price, K.R. | 1988 | A Review of Historical Data on the Radionuclide Content of Soil Samples Collected from the Hanford Site and Vicinity | PNL-6734 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | soil | no | terrestrial | yes | Review of soil samples collected routinely for environmental sampling programs both on and near the Hanford Site. Although 100N data are not very comprehensive, does provide offsite and other control results for Sr-90, Cs-137, Pu-238, -239 and -240, Am-241, and uranium. |
| Price, K.R. and R.R. Kinneson | 1982 | Uranium and Other Heavy Metals in Soil and Vegetation from the Hanford Environs | PNL-4466 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | yes | soil/sediment | no | terrestrial | no | Soil and vegetation samples were collected downwind of the 300 Area to look at wind-blown contamination. |
| Probasco, K.M. | 1986 | Characterization of Radionuclide Concentrations of the N-Springs Along the Columbia River Shoreline. | UNI-3866 | UNC Nuclear Industries | Richland, WA | high | yes | no | no | seep water | no | riparian aquatic | yes | Determine concentration of radionuclides in 100-N Springs. |
| Probasco, K.M. and C.J. Perkins | 1987 | Characterization of Radionuclide Concentrations of the N-Springs Along the columbia River Shoreline | UNI-4217 | UNC Nuclear Industries | Richland, WA | high | yes | no | no | seep water | no | riparian aquatic | yes | Determine concentration of radionuclides in 100-N Springs. |
| Rice, D.G | 1968 | Archaeological Reconnaissance: Hanford Atomic Works. | None | U.S. Atomic Energy Commission, National Parks Service, and Washington State University | Pullman, WA | low | no | no | no | cultural review | no | terrestrial, riparian | yes | This report was referenced in the 100-N section of the 2002 Hanford NEPA report (Neitzel 2002). |
| Rice, D.G | 1980a | Overview of Cultural Resources on the Hanford Reservation in South Central Washington Sate | None | US Department of Energy | Richland, WA | low | no | no | no | cultural review | no | terrestrial, riparian | yes | This report was referenced in the 100-N section of the 2002 Hanford NEPA report (Neitzel 2002). |
| Rice, D.G | 1980b | Cultural Resources Assessment of the Hanford Reach of the Columbia River, State of Washington. | None | US Army Corp of Engineers | Seattle, WA | low | no | no | no | cultural review | no | terrestrial, riparian | yes | This report was referenced in the 100-N section of the 2002 Hanford NEPA report (Neitzel 2002). |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reiman, R.T. and T.S. Dahlstrom | 1990 | An Aerial Radiological Survey of the Hanford Site and Surrounding Area | EGG-10617-1062 | EG&G Energy Measurements | Las Vegas, NV | pertinent | yes | no | no | aerial radiological measurements | no | terrestrial, riparian | yes | Helicopters were used to measure gamma exposure rates across the 100N area, among others. A map of isoradiation for the 100N area is shown. This cannot be converted to a meaningful exposure level due to the complexity of the nuclides. |
| Rickard, W.H. and K.R. Pric | 1984 | Iodine in Terrestrial Wildlife on the U.S. Department of Energy's Hanford Site in Southcentral Washington | Environmental Monitoring and Assessment 4:379-388 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | small mammals, large mammals, soil | no | terrestrial | no | I-129 and I-131 were taken up into thyroid glands of deer and jackrabbits during the 50's and 60's. Soil concentrations of stable iodine are greater at higher elevations than they are at lower elevations. Jackrabbits could be used as indicators of terrestrial iodine in the future. |
| Rickard, W.H. and K.R. Price | 1989 | Tritium Uptake from Groundwater by Black Locust Trees | Northwest Science 63(3):87-89 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | vegetation | no | terrestrial or riparian | no | Locust trees took up tritium from groundwater 7.7m deep, utilizing more groundwater during the hottest summer months and less in the winter. Leaf water was used to determine tritium content. |
| Rickard, W.H. and K.R. Price | 1990 | Stronitium-90 in Canada Goose eggshells and Reed Canary Grass from the Columbia River, WA | Environmental Monitoring and Assessment 14:71-76 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | bird eggs, vegetation | no | riparian | yes | Found increased levels of Sr-90 in goose eggs on an island near 100N compared to other islands further downstream. Not all goose eggs or reed canary grass had higher concentrations, but there was a relationship between proximity to 100N and the levels of Sr-90. |
| Sackschewsky, M.R. | 1992 | Biological Assessment for Rare and Endangered Plant Species Related to CERCLA Characterization Activities | WHC-EP-0526 | Westinghouse Hanford Company | Richland, WA | pertinent | no | no | no | vegetation | no | riparian, terrestrial | no | Does not discuss specific locations where rare and endangered plant species occur. Lists the endangered or rare plants and their general environment. |
| Sackschewsky, M.R. | 2001 | Vascular Plants of the Hanford Site | PNNL-13688 | Pacific Northwest National Laboratory | Richland, WA | high | no | no | no | vegetation | no | terrestrial | some | List roughly 725 plant species found on the Hanford Site. |
| Sackschewsky, M.R. and D.S. Landeen | 1992 | Fiscal Year 1991 100 Areas CERCLA Ecological Investigations | WHC-EP 0448 | Westinghouse Hanford Company | Richland, WA | pertinent | no | no | no | birds, mammals, invertebrates, vegetation | no | riparian, terrestrial | no | Primarily surveys of biota, with some vegetation samples analyzed for radionculides and a few metals. 100N was not one of the areas surveyed, but areas to either side were surveyed. |
| Schramke, J. and P.E. Dresel | 1996 | Letter Report on Geochemical Modeling of Ground Water in the 100-N Area of the Hanford Site | Letter report | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | groundwater, sediment | no | terrestrial, groundwater | yes | Geochemical computer modeling results for controls on mobility of Sr-90 movement in groundwater. Results suggest Sr-90 distribution is controlled primarily by sorption to aquifer sediments, and that high sodium and calcium levels in the contaminated groundwater cause desorption of the Sr-90 from the sediments. |
| Serne, R.J. and V.L. Legore | 1996 | Strontium-90 Adsorption-Desorption Properties and Sediment Characterization at 100-N Area | PNL-10899 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | no | no | soil | yes | Measured Kd values for sediments and discusses applicability of the results to pump and treat and leaching efforts at 100N. |
| Simmons, M.A., J.J. Bromenshenk, and J.L. Gudatis | 1990 | Honeybees as Monitors of Low Levels of Radioactivity | PNL-7348 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | insects | no | terrestrial | no | Honeybee hives were placed around the Hanford for 1 month. Tritium was above detection limits in 2 hives and gamma-emitters were measured at Gable Mtn. Pond. Bees utilize air, water, vegetation and soil. |
| Soldat, J.K., K.R. Price, and W.H. Rickard | 1990 | Methodology Used to Compute Maximum Potential Doses from Ingestion of Edible Plants and Wildlife Found on the Hanford Site | PNL-7539 | Pacific Northwest Laboratory | Richland, WA | moderate | yes | no | no | NA | yes | terrestrial, riparian, aquatic | no | Gives estimated hunter kill of wildlife in areas adjacent to Hanford and those wildlife population densities on Hanford, examples of edible native plants and their onsite distribution, and provides one way to calculate dose if these are consumed. |
| Stegen, J.A. | 1992 | Biological Assessment for State Candidate and Monitor Species | WHC-SD-EN-EE-009 | Westinghouse Hanford Company | Richland, WA | moderate | no | no | no | NA | no | terrestrial, riparian, aquatic | no | Lists rare and endangered, state candidate and monitored species of plants, animals, invertebrates, fish and birds and the habitats they tend to live in. Not specific to 100N. |
| Stegen, J.A. | 1993 | Vegetation Communities Associated with the 100 Area and the 200 Area Facilities on the Hanford Site | WHC-SD-EN-TI-216 | Westinghouse Hanford Company | Richland, WA | pertinent | no | no | no | vegetation | no | terrestrial | yes | Plant surveys identify 4 vegetation communities in the 100N Area, excluding riparian areas. Transects provide specific plant occurrences in the area. Root depths and percent cover are also given. |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sula, M.J. | 1980 | Radiological Survey of Exposed Shoreline and Islands of the Columbia River between Vernita and the Snake River Confluence | PNL-3127 | Pacific Northwest Laboratory | Richland, WA | pertinent | yes | no | no | air | yes | riparian | yes | External exposure rates were measured along the exposed shoreline of the Hanford Reach to Snake River confluence. From 100K to 100N, average exposure rate was 11 (+-2) uR/hr, and from 100N to 100D the average was 8 (+-2) uR/hr with maximum of 880. This is due to skyshine form 100N facilities. Also sampled vegetation and soil for gamma-emitting radionuclides. No discrete particles of Co-60 contaminated metal were found near 100N. |
| Thatcher, A.H. | 1995 | 100N Area Shoreline Radiation Survey and Dose Evaluation | WDOH/ERS-95-501 | State of Washington Department of Health, Division of Radiation Protection | Olympia, WA | pertinent | yes | no | no | no | yes | air | yes | Skyshine was measured in 1994 and 1995 along 100N shoreline. Areas were identified with maximum dose rate of 19 urem/hr. However, the potential dose a maximally exposed fisherman could receive is 5 mrem/yr, while a typical fisherman would receive much less than 1 mrem/yr. |
| Tiller, B.L. and T.M. Poston | 1992 | Uranium Concentrations in Asparagus | PNL-8068 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | vegetation | yes | terrestrial | no | Sampled asparagus for uranium on and off site. The highest concentration was off site. Report concludes this higher concentration is due to naturally occurring levels of uranium in that area. |
| Tiller, B.L., L.E. Eberhardt and T.M. Poston | 1995 | Location Analysis and Strontium-90 Concentrations in Deer Antlers on the Hanford Site | PNL-10711 | Pacific Northwest Laboratory | Richland, WA | low | yes | no | no | large mammal | qualitativ ely | terrestrial | no | Sampled deer antlers for Sr-90 in 100 areas. Antlers from the 100 Areas had higher 90Sr than those from the Hanford townsite. 90Sr in antlers can be an indicator of other radionuclides that may be present in tissue consumed by humans. Deer movement is not restricted by the Columbia River. General information, not specific to N-Springs. |
| Tiller, B.T., G.E. Dagle, L.L. Cadwell, T. M. Poston, and A. Oganesian. | 1997 | Investigation of Anatomical Anomalies in Hanford Site Mule Deer | PNNL-111518 | Pacific Northwest National Laboratory | Richland, WA | low | yes | yes | yes | large mammal | no | terrestrial | no | Evaluation of Hanford Site deer after observations of a relatively large number of deer with antler and testicle anomalies. No 100-N specific data is provided but some of these deer inhabitated the 100 N Area. No cause of the anomalies was identified but radiation contamination was investigated and ruled out. |
| Tiller, B.L and T.M. Poston | 2002 | Mule deer antlers as biomonitors of strontium-90 on the Hanford Site. | J. Environ. Radioactivity, 47, 29-44 | Pacific Northwest National Laboratory | Richland, WA | high | yes | no | no | large mammal | no | terrestrial | yes | Sampled deer antlers for Sr-90 in 100 areas, other Hanford locations, and central Oregon site. Antlers from the 100 Areas had higher 90Sr than those from the Hanford townsite, but levels at the central OR location were 5 times higher (likely from difference atmospheric fallout patterns). The data was for the 100-Area in general, not specific to the 100-N- Area. |
| U.S. Department of Energy | 1992 | Sampling and Analysis of 100-Area Springs | DOE/RL-92-12, Rev. 1 | Richland Operations Office | Richland, WA | pertinent | yes | no | no | springs, river | no | aquatic | yes | Sampled 5 springs in 100N area, with results in attached table. Concentrations in the springs had decreased since 1988. |
| U.S. Department of Energy | 1994 | Bald Eagle Site Management Plant for th | DOE/RL 94-150 | Richland Operations Office | Richland, WA | moderate | no | no | no | no | no | terrestrial, riparian | no | Management plan for bald eagles on the Hanford Site. Threated and endangered species issues. |
| U.S. Department of Energy | 1995 | Letter Report for Skyshine Abatement Assessment | DOE/RL-94-131 | Richland Operations Office | Richland, WA | pertinent | yes | no | no | no | yes | air | yes | Conclusion is "It is highly unlikely that individuals from the public would receive a dose above the annual 25 mrem /yr limit from1301-N/1325-N skyshine." Used 6 direct exposure scenarios and one indirect exposure adjustment. |
| U.S. Department of Energy | 1995 | Limited Field Investigation Report for the 100-NR-1 Operable Unit | DOE/RL93-080 | Richland Operations Office | Richland, WA | low | yes | yes | yes | soil | yes | terrestrial | yes | Results of boreholes, test pits, and excavations in the 100-NR-1 operable unit. Although nearby, it does not deal with 100-N Springs. Risk assessments are probably similar to those that will be performed for N-Springs. |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U.S. Department of Energy | 1995 | Limited Field Investigation Report for the 100-NR-2 Operable Unit | DOE/RL93-81 | Richland Operations Office | Richland, WA | pertinent | yes | yes | yes | groundwater | yes | groundwater | yes | Human health risk assessment identified arsenic, cadmium, chromium, fluoride, manganese, nitrate tritium and Sr-90 in the groundwater as constituents of concern for both frequent -and occasional-use scenarios. The environmental risk assessment for aquatic toxicity for fish from nonradioactive contaminants indicated chromium VI, cadmium, zinc and iron in the groundwater exceeded either an acute or chronic toxicity level. Total petroleum hydrocarbons in one well exceed an ARAR. |
| U.S. Department of Energy | 1996 | 1301-N and 1325-N Liquid Waste Disposal Facilities Limited Field Investigation Report | DOE/RL-96-11 | Richland Operations Office | Richland, WA | pertinent | yes | yes | yes | surface and subsurface sediment | yes | terrestrial | yes | Drilled boreholes and wells to investigate subsurface contamination at these 2 facilities. Results of analyses are included in appendices, as are dose calculations. |
| U.S. Department of Energy | 1996 | Hanford Site Background: Part2, Soil Background for Radionuclides | DOE/RL-96-12 | Richland Operations Office | Richland, WA | pertinent | yes | no | no | surface and subsurface sediment | no | terrestrial | no | Provides Hanford Site specific background surface and subsurface sediment values for both natural and anthropogenic sources of radionuclides. |
| U.S. Department of Energy | 1998 | Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units | DOE/RL-95-111 | Richland Operations Office | Richland, WA | pertinent | | | | | yes | | | Discusses exposure scenarios, remediation goals and remedial action objectives for the 100N Operable Units |
| U.S. Department of Energy | 1998 | Screening Assessment and Requirement | DOE/RL-96-16, rev. 1 | prepared by Pacific Northwest National Laboratory for U.S. Department of Energy | Richland, WA | pertinent | yes | | yes | | yes | terrestrial, aquatic, riparian | yes | Screening assessment to evaluate human health risk, ecological risk to the Columbia River and adjacent riparian zone for radionuclides, carcinogenic and toxic chemicals. There are several use scenarios identified. Details how estimates are made. Section on 100N is on pg. I-5.120. |
| U.S. Department of Energy | 2000 | 100 Area Remedial Action Sampling and Analysis Plan | DOE/RL-96-22, rev. 2 | Richland Operations Office | Richland, WA | low | yes | yes | yes | NA | no | terrestrial | no | Provides plan for cleaning up waste sites in many of the 100 Area operable units, although it does not discuss 100N. Gives remedial action goals protective of the river and groundwater, as well as to human life. |
| U.S. Department of Energy | 2000 | Remedial Design Report/Remedial Action Work Plan for the 100 Area | DOE/RL-96-17, rev. 2 | Richland Operations Office | Richland, WA | low | yes | yes | yes | NA | yes | terrestrial, aquatic | no | Gives remedial action criteria for many of the 100 Area operable units cleanup, although it does not discuss 100N. |
| U.S. Department of Energy | | DOE Standard - A grad Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota (Proposed) | DOE-STD-XXXX-YR PROPOSED | U.S. Department of Energy | Washington D.C. | pertinent | yes | no | no | NA | no | terrestrial, aquatic | no | Draft standard to be used by DOE to evaluate radiation doses to a variety of terrestrial, riparian, and aquatic plants, animals, fish and birds. |
| U.S. Department of Interior | 1996 | U.S. Department of Interior Record of Decision – Hanford Reach of the Columbia River: Final Environmental Impact Statement for Comprehensive River Conservation Studies | | U.S. Department of Interior | Washington D.C. | | | | | | | | | Not reviewed. |
| U.S. Environmental Protection Agency | 1992 | Evaluation of Terrestrial Indicators for Use in Ecological Assessments at Hazardous Waste Sites | EPA/600/R-92/183 | Environmental Protection Agency | Washington D.C. | moderate | | | | soil | | aquatic, terrestrial | no | Report compiles and summarizes numerous methods that are currently available for evaluating soil toxicity to animals, wetland and terrestrial plants, soil biota, a few aquatic organisms, and amphibians. |
| U.S. Environmental Protection Agency | 1999 | Columbia River Basin Fish Contaminant Survey 1996-1998 | EPA 910-R-02-006 | U.S. Environmental Protection Agency, Region 10 | Seattle, WA | pertinent | yes | yes | yes | fish | yes | aquatic | no | Sampled mountain whitefish, white sturgeon, large-scale sucker and fall chinook salmon below Priest Rapids dam and in the Hanford Reach for radionuclides, organic and inorganic pollutants. Samples were taken above Vernita Bridge and from 100-H to 100-F. |
| U.S. Fish and Wildlife Service | 1998 | Hanford Site 100 Area Assessment Plan, Volume I: Columbia River Aquatic Resources DRAFT | prepared for the Hanford Natural Resource Trustee Council | Upper Columbia River Basin Field Office | Spokane and Moses Lake | es | yes | yes | yes | soil, aquatic, river, groundwater | | | yes | Reviewed existing data to develop assessment plan for the 100 Areas. Identifies some data gaps. |
| U.S. National Park Service | 1990 | Hanford Reach Study | Resource Assessment, Summary of Findings | U.S. National Park Service | Seattle, WA | | | | | | | | | Not reviewed. |
| Van Verst, S.P. | 2000 | Hanford Site Shoreline Vegetation Study 1999 | WDOH/320-023 | State of Washington Department of Health, Division of Radiation Protection | Olympia, WA | low | yes | no | no | vegetation, groundwater | yes | riparian | no | Sampled vegetation and groundwater at 100H and Hanford Townsite as comparison to PNNL samples collected simultaneously over a broader area. |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Van Verst, S.P., C.L. Albin, G.W. Patton, M.L. Blanton, T.M. Poston, A.T. Cooper and E.J. Antonio | 1998 | Survey of Radiological Contaminants in the near-Shore Environment at the Hanford Site 100-N Reactor Area | | prepared by the Washington State Department of Health and Pacific Northwest National Laboratory for the U.S. Department of Energy | Richland, WA | pertinent | yes | no | no | river, soil, springs, aquatic vegetation, aquatic invertebrates, riparian vegetation, insects | yes | aquatic, riparian | yes | River water, sediment, riverbank springs, periphyton, milfoil, flying insects, clam shells, and reed canary grass from the 100N near-shore were analyzed for tritium, strontium and gamma emitters. Background samples from above Vernita Bridge. Sr90 from seeps is rapidly diluted by the Columbia River. Biota samples show Sr90 transfers throughout the local ecosystem. Dose/risk for people is calculated to be below health impact levels and federal regulatory limits. Dose to aquatic organisms is calculated to be below 1 rad/day limit set by U.S. DOE. |
| Watson, D.G., C.E. Cushing, C.C. Coutant, and W.L. Templeton | 1970 | Radioecological Studies on the Columbia River, Parts I and II | BNWL-1377 | Pacific Northwest National Laboratory | Richland, WA | low | yes | no | no | fish, plankton, periphyton, aquatic invertebrates | no | aquatic | no | Sampled near 100F. Measured radionuclide concentrations in relation to seasonal fluctuations in river level and possibly metabolic uptake. |
| Weiss, S.G. | 1993 | 100 Area Columbia River Sediment Sampling | WHC-SD-EN-TI-198 | prepared by IT corporation for Westinghouse Hanford Company | Richland, WA | moderate | yes | no | yes | river sediment | no | aquatic | no | Samples from every place but near 100N, includes background samples of river sediments analyzed for metals, radionuclides, and particle size. |
| Weiss, S.G. | 1994 | 100-N and 100-F Areas Operable Unit Aquatic Scoping | | Westinghouse Hanford Company | | | | | | | | | | Not reviewed. |
| Weiss, S.G. and R.M. Mitchell | 1992 | A Synthesis of Ecological Data from the 100 Areas of the Hanford Site | WHC-EP-0601 | Westinghouse Hanford Company | Richland, WA | pertinent | yes | yes | yes | aquatic, riparian and terrestrial vegetation, waterfowl, small mammal, large mammal, invertebrates | yes | aquatic, terrestrial, groundwater | yes | This is a compilation/summary of data, much of which was reported in various annual Environmental Monitoring Reports. Gives terrestrial and aquatic major and indicator species lists for flora and fauna, levels of rads (mostly) with some metals and organics found in various samples |
| Wells, D. | 1994 | Radioactivity in Columbia River Sediments and Their Health Effects | Special Report | Environmental Radiation Program, WA State Department of Health | Olympia, WA | pertinent | yes | no | no | river, sediment | yes | aquatic | no | Established human health risks for radiation doses for maximum concentrations observed in the Hanford Reach as a whole, as well as the lower Columbia River and Columbia estuary. In all cases, calculated doses are low and less than 1% of natural background. Did not address skyshine, seeps or removal of reactor discharge pipes. |
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| **Annual DOE status reports on remedial actions at 100-N** | | | | | | | | | | | | | | |
| U.S. Department of Energy | 1998 | Calendar Year 1997 Annual Summary Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units | DOE/RL-98-38 | Richland Operations Office | Richland, WA | | | | | | | | yes | |
| U.S. Department of Energy | 1999 | Calendar Year 1998 Annual Summary Report for the 100-HR-3, 100-KR-4 and 100-NR-2 Operable Unit Pump-and-Treat Operations | DOE/RL-99-02 | Richland Operations Office | Richland, WA | | | | | | | | yes | |
| U.S. Department of Energy | 2001 | Calendar Year 2000 Annual Summary Report for the 100-HR-3, 100-KR-4 and 100-NR-2 Operable Unit Pump-and-Treat Operations | DOE/RL-2001-04 | Richland Operations Office | Richland, WA | | | | | | | | yes | |
| U.S. Department of Energy | 2002 | Calendar Year 2001 Annual Summary Report for the 100-HR-3, 100-KR-4 and 100-NR-2 Operable Unit Pump-and-Treat Operations, Decisional Draft | DOE/RL-2002-05 | Richland Operations Office | Richland, WA | | | | | | | | yes | |
| U.S. Department of Energy | 2003 | Calendar Year 2002 Annual Summary Report for the 100-HR-3, 100-KR-4 and 100-NR-2 Operable Unit Pump-and-Treat Operations, Decisional Draft | DOE/RL-2003-09, Decisional Draft | Richland Operations Office | Richland, WA | | | | | | | | yes | |
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| **Annual PNNL Environmental Monitoring reports** | | | | | | | | | | | | | | |
| Foster, R. F., and Environmental Studies and Evaluation Staff | 1965 | Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964 | AEC Research and Development Report BNWL 90 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Foster, R. F., and Environmental Studies and Evaluation Staff | 1966 | Evaluation of Radiological Conditions in the Vicinity of Hanford for 1965 | BNWL-316 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |

| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foster, R. F., and Environmental Studies and Evaluation Staff | 1967 | Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966 | BNWL-439 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Sula, M. J., W. D. McCormack, R. L. Dirkes, K. R. Price, and P. A. Eddy | 1982 | Environmental Surveillance at Hanford for CY 1981 | PNL-4221 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Sula, M. J., J.M.V. Carlile, K. R. Price, and W. D. McCormack | 1983 | Environmental Surveillance at the Hanford Site for CY 1982 | PNL-4657 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Price, K. R., J.M.V. Carlile, R. L. Dirkes, and M. S. Trevathan | 1984 | Environmental Surveillance at Hanford for 1983 | PNL-5038 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Price, K. R., P. J. Blumer, J.M.V. Carlile, R. L. Dirkes, M. S. Trevathan | 1984 | Environmental Status of the Hanford Site for CY 1983 | PNL-5039 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Price, K. R., J.M.V. Carlile, R. L. Dirkes, R. E. Jaquish, M. S. Trevathan, and R. K. Woodruff | 1985 | Environmental Monitoring at Hanford for 1984 | PNL-5407 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Price, K. R | 1986 | Environmental Monitoring at Hanford for 1985 | PNL-5817 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Price, K. R., J.M.V. Carlile, R. L. Dirkes, R. E. Jaquish, M. S. Trevathan, and R. K. Woodruff | 1986 | Environmental Monitoring at Hanford for 1984 Supplement | PNL-5407Suppl. | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Pacific Northwest Laboratory (no author listed) | 1987 | Environmental Monitoring at Hanford for 1986 | PNL-6120 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Jaquish, R. E., and P. J. Mitchell | 1988 | Environmental Monitoring at Hanford 1987 | PNL-6464 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Jaquish, R. E., and R. W. Bryce | 1989 | Hanford Site Environmental Report for Calendar Year 1988 | PNL-6825 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Jaquish, R. E., and R. W. Bryce | 1990 | Hanford Site Environmental Report for Calendar Year 1989 | PNL-7346 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Woodruff, R. K., R. W. Hanf, M. G. Hefty, and R. E. Lundgren | 1991 | Hanford Site Environmental Report for Calendar Year 1990 | PNL-7930 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Woodruff, R. K., R. W. Hanf, and R. E. Lundgren | 1992 | Hanford Site Environmental Report for Calendar Year 1991 | PNL-8148 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Woodruff, R. K., R. W. Hanf, and R. E. Lundgren | 1993 | Hanford Site Environmental Report for Calendar Year 1992 | PNL-8682 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Dirkes, R. L., R. W. Hanf, R. K. Woodruff, and R. E. Lundgren | 1994 | Hanford Site Environmental Report for Calendar Year 1993 | PNL-9823 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Dirkes, R. L., and R. W. Hanf | 1995 | Hanford Site Environmental Report for Calendar Year 1994 | PNL-10574 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Dirkes, R. L., and R. W. Hanf | 1996 | Hanford Site Environmental Report for C | PNL-11139 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Dirkes, R. L., and R. W. Hanf | 1997 | Hanford Site Environmental Report for C | PNL-11472 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Dirkes, R. L., and R. W. Hanf | 1998 | Hanford Site Environmental Report for C | PNL-11795 | Pacific Northwest Laboratory | Richland, WA | | | | | | | | | |
| Dirkes, R. L., R. W. Hanf, and T. M. Poston | 1999 | Hanford Site Environmental Report for Calendar Year 1998 | PNNL-12088 | Pacific Northwest National Laboratory | Richland, WA | | | | | | | | | |
| Poston, T. M., R. W. Hanf, and R. L. Dirkes | 2000 | Hanford Site Environmental Report for Calendar Year 1999. | PNNL-13230 | Pacific Northwest National Laboratory | Richland, WA | | | | | | | | | |
| Poston, T. M., R. W. Hanf, R. L. Dirkes, and L. F. Morasch (eds.) | 2001 | Hanford Site Environmental Report for Calendar Year 2000. | PNNL-13487 | Pacific Northwest National Laboratory | Richland, WA | | | | | | | | | |
| Poston, T. M., R. W. Hanf, R. L. Dirkes, and L. F. Morasch (eds.) | 2002 | Hanford Site Environmental Report for Calendar Year 2001 | PNNL-13910 | Pacific Northwest National Laboratory | Richland, WA | | | | | | | | | |
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| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
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| **Annual Groundwater Monitoring reports** | | | | | | | | | | | | | | |
| Eddy, P.A., and J.S. Wilbur | 1980 | Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1979. | PNL-3346 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Eddy, P.A., and J.S. Wilbur | 1981 | Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1980.PNL-3768 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | | |
| Eddy, P.A., C.S. Cline, and L.S. Prater | 1982 | Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1981. | PNL-4237, Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | | |
| Eddy, P.A., L.S. Prater, and J.T. Rieger | 1983 | Ground-Water Surveillance at the Hanford Site for CY 1982 | PNL-4659 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Prater, L.S., J.T. Rieger, C.S. Cline, E.J. Jensen, T.L. Liikala, K.R. Oster, and P.A. Eddy | 1984 | Ground-Water Surveillance at the Hanford Site for CY 1983 | PNL-5041 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Cline, C.S., J.T. Rieger, J.R. Raymond, and P.A. Eddy | 1985 | Ground-Water Monitoring at the Hanford Site, January-December 1984 | PNL-5408 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., P.J. Mitchell, and D.I. Dennison | 1988 | Hanford Site Ground-Water Monitoring for April through June 1987 | PNL-6315-1 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., D.I. Dennison, R.W. Bryce, P.J. Mitchell, D.R. Sherwood, K.M. Krupka, N.W. Hinman, E.A. Jacobson, and M.D. Freshley | 1988 | Hanford Site Ground-Water Monitoring for July Through December 1987 | PNL-6315-2 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., R.W. Bryce, and D.R. Sherwood | 1989 | Hanford Site Ground-Water Monitoring for January through June 1988 | PNL-6886 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., R.W. Bryce, D.R. Sherwood, M.L. Kemner, and D.R. Newcomer | 1989 | Hanford Site Ground-Water Monitoring for July through December 1988 | PNL-7120 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., R.W. Bryce, and M.L. Kemner | 1990 | Hanford Site Ground-Water Surveillance for 1989 | PNL-7396 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., R.W. Bryce, and D.J. Bates | 1992 | Hanford Site Ground-Water Monitoring for 1990 | PNL-8073 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Evans, J.C., R.W. Bryce, and D.J. Bates | 1992 | Hanford Site Ground-Water Monitoring for 1991 | PNL-8284 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Dresel, P.E., D.J. Bates, and J.K. Merz | 1993 | Hanford Site Environmental Data for Calendar Year 1990 - Ground Water | PNL-8582 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Dresel, P.E., D.J. Bates, and J.K. Merz | 1993 | Hanford Site Environmental Data for Calendar Year 1991 - Ground Water | PNL-8581 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Dresel, P.E., D.R. Newcomer, J.C. Evans, W.D. Webber, F.A. Spane, Jr., R.G. Raymond, and B.E.Opitz | 1993 | Hanford Site Ground-Water Monitoring for 1992 | PNL-8716 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Merz, J.K., and P.E. Dresel | 1993 | Hanford Site Environmental Data for Calendar Year 1992 - Ground Water | PNL-8884 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Dresel, P.E., S.P. Luttrell, J.C. Evans, W.D. Webber, P.D. Thorne, M.A. Chamness, B.M. Gillespie, B.E. Opitz, J.T. Rieger, and J.K. Merz | 1994 | Hanford Site Ground-Water Monitoring for 1993 | PNL-10082 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dresel, P.E., P.D. Thorne, S P. Luttrell, B.M. Gillespie, W.D. Webber, J.K. Merz, J T. Rieger, M.A. Chamness, S.K. Wurstner, and B.E. Opitz | 1995 | Hanford Site Ground-Water Monitoring for 1994 | PNL-10698 | Pacific Northwest Laboratory | Richland, WA. | | | | | | | | | |
| Dresel, P.E., J.T. Rieger, W.D. Webber, P.D. Thorne, B.M. Gillespie, S.P. Luttrell, S.K. Wurstner, and T.L. Liikala | 1996 | Hanford Site Ground-Water Monitoring for 1995 | PNNL-11141 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
| Hartman, M.J., and P.E. Dresel (eds.) | 1997 | Hanford Site Groundwater Monitoring for Fiscal Year 1996 | PNNL-11470 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
| Hartman, M.J., and P.E. Dresel (eds.) | 1998 | Hanford Site Groundwater Monitoring for Fiscal Year 1997 | PNNL-11793 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
| Hartman, M.J. (ed.) | 1999 | Hanford Site Groundwater Monitoring for Fiscal Year 1998 | PNNL-12086 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
| Hartman, M.J., L.F. Morasch, and W.D. Webber (eds.) | 2000 | Hanford Site Groundwater Monitoring for Fiscal Year 1999 | PNNL-13116 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
| Hartman, M.J., L.F. Morasch, and W.D. Webber (eds.) | 2001 | Hanford Site Groundwater Monitoring for Fiscal Year 2000 | PNNL-13404 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
| Hartman, M.J., L.F. Morasch, and W.D. Webber (eds.) | 2002 | Hanford Site Groundwater Monitoring for Fiscal Year 2001 | PNNL-13788 | Pacific Northwest National Laboratory | Richland, WA. | | | | | | | | | |
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| **Annual Near-Field Monitoring reports** | | | | | | | | | | | | | | |
| Poppe, L.K. | 1979 | Onsite Environmental Surveillance Progr | UNI-1347 | UNC Nuclear Industries, Inc. | Richland, WA. | | | | | | | | | |
| Greager, E.M. | 1980 | Radiological Surveillance Report for the 100-N Area Environment - 1980 | UNI-1581 | UNC Nuclear Industries | Richland, WA | | | | | | | | | |
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| Perkins, C.J. | 1989 | Characterization of Radionuclide Concentrations of the N-Springs Shoreline for 1988 | WHC-SP-0480 | Westinghouse Hanford Company | Richland, WA | | | | | | | | | |
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| Author | Year | Title | Report Number | Institution | City | Pertinence | Rad | Organics | Inorganic | Media Sampled | Human Dose | Environment | 100-N? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perkins, C.J., B.M. Markes, S.M. McKinney, R.M. Mitchell and R.C. Roos | 1999 | Hanford Site Near-Facility Environmental Monitoring Annual Report, Calendar Year 1998 | PNNL-12088 | prepared by Waste Management Federal Services, Inc. for Fluor Daniel Hanford Inc., published by Pacific Northwest National Laboratory | Richland, WA | | | | | | | | | |
| Perkins, C.J., R.M. Mitchell, B.M. Markes, S.M. McKinney, and R.C. Roos | 2001 | Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 1000 | PNNL-113487, Appendix 2 | prepared by Waste Management Technical Services for Pacific Northwest National Laboratory | Richland, WA | | | | | | | | | |
| | | | | | | | | | | | | | | |
| **HEDR documents** | | | | | | | | | | | | | | |
| Hanf, R.W., R.L. Dirkes and J.P. Duncan | 1992 | Radionuclide Contamination of Fish, Shellfish, and Waterfowl Exposed to Hanford Effluents: Annual Summaries, 1945-1972 | PNWD-2223 HEDR | Pacific Northwest Laboratory | Richland, WA | moderate | | | | | | | | need to review |
| | | | | | | | | | | | | | | |
| **NEPA Documents** | | | | | | | | | | | | | | |
| D.A. Neitzel, editor | 2002 | Hanford Site National Environmental Policy Act (NEPA) Characterization | PNNL-6415 Rev. 14 | Pacific Northwest National Laboratory | Richland | moderate | yes | yes | yes | brief reviews of Hanford monitoring activities | no | general review of overall Hanford envi-ronment, socio-economics, cultural resources | some 100-N spe-cific data | Annual document describing the Hanford environs, climate/meteorology, ecology, socioeconomics, geology, air quality, hydrology, cultural, noise, safety, and statutory and regulatory requirements. |

# Appendix B

# Maximum Concentrations of Radionuclides and Metals in Wildlife, Vegetation, Soil, and Water Samples, 1970 to Present

**Table B.1**. Maximum Concentration (pCi/g, wet wt.) of Radionuclides in Wildlife Samples around 100-N Area, 1973 to Present

| Radionuclide | Carp (pCi/g) | Clams (pCi/g) | Cottontail Rabbit (pCi/g) | Dove (pCi/g) | Hungarian Partridge (pCi/g) | Mallard (pCi/g) | Merganser, Common (pCi/g) | Mouse (pCi/g) | Mule Deer (pCi/g) | Pheasant (pCi/g) | Quail (pCi/g) | Sculpin (pCi/g) | Teal, Green Winged (pCi/g) | Whitefish (pCi/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ba-140 | | | | | | | | 114 (1)* | | | | | | |
| BaLa-140 | | | | | | | | 23300(9) | | | | | | |
| Be-7 | 0.696(35)* | 1.05(2)* | 19.3(15) | | | | | | 0.54(22)* | 0.0344(2)* | | 0.229(1)* | 0.394(8)* | 0.771(62)* |
| BETA | | | | | | | | 31100(1) | | | | | | |
| Ce-141 | | | | | | | | 4060(7) | | | | | | |
| Ce-144 | | | | | | | | 9210(7) | | | | | | |
| Ce/Pr-144 | 0.233(19) | 0.015(2)* | 0.761(10)* | | | | | 14600(9) | 0.0922(12) | -0.00974(2)* | | | 0.157(8)* | 0.236(35)* |
| Co-58 | | | | | | | | 1510(10) | | | 0.065(1) | | | |
| Co-60 | 0.0225(35)* | 0.0573(2) | 230(83) | 3.98(1) | 0.0000749(1)* | 7340(16) | 0.00225(1)* | 30600(23) | 0.0481(26) | 0.0207(3) | 4.25(4) | 0.0234(1)* | 0.0965(17) | 0.0407(62)* |
| Cr-51 | | | | | | | | 3850(2) | | | | | | |
| Cs-134 | 0.0301(35)* | 0.00858(2)* | 315(32) | | | 4810(3) | | 5300(12) | 0.0103(23)* | 0.0622(3) | 7.93(2) | 0.0203(1)* | 0.00368(8)* | 0.118(63) |
| Cs-137 | 0.0591(35) | 0.0183(2)* | 3740(83) | 0.299(1) | 0.0399(1) | 17100(16) | -0.007(1)* | 5560(26) | 0.126(26) | 1.99(3) | 118(4) | 0.0128(1)* | 0.032(17) | 0.169(62) |
| Eu-152 | | | | | | | | | | | | | | 0.00457(5)* |
| Eu-154 | 0.0691(35)* | 0.0201(2)* | 0.226(15)* | | | | | | 0.0386(22)* | 0.0136(2)* | | -0.0436(1)* | 0.0646(8)* | 0.101(62)* |
| Eu-155 | 0.037(35)* | 0.0184(2)* | 0.149(15)* | | | | | -1410(1)* | 0.0173(22)* | 0.00797(2)* | | 0.00912(1)* | 0.0345(8)* | 0.103(62) |
| Fe-59 | | | | | | | | 32100(15) | | | | | | |
| I-131 | | | | | | | | 6000(9) | | | | | | |
| K-40 | 4.82(35) | 0.338(2)* | 28.3(83) | 5(1) | 2.63(1) | 30.6(15) | 3.87(1) | 586(18) | 3.86(26) | 3.56(3) | 5.22(4) | 2.6(1) | 4.79(17) | 5.54(62) |
| La-140 | | | | | | | | 96.1(1) | | | | | | |
| Mn-54 | | | 327(17) | | | 21000(4) | | 13600(22) | 0.0182(1) | | 2.26(2) | | | |
| Mo-99 | | | | | | | | 93.2(2) | | | | | | |
| Nb-95 | | | | | | | | 12400(4) | | | | | | |
| Np-239 | | | | | | | | 978(1) | | | | | | |
| P-32 | | | | | | 157000(2) | | | | | | | | |
| Pb-212 | | | | | | | | | | | | | | 0.0593(1) |
| Pu | | | 0.000366(1) | | | 0.704(2) | | 1.46(5) | 0.0301(4)* | | | | | |
| Pu-238 | | | 0.991(47) | | | | | | 0.000238(10)* | | | | | |
| Pu-239/240 | | | 6.7(47) | | | | | | 0.000042(10)* | | | | | |
| Ru-103 | | | | | | | | 6390(8) | | | | | | |
| Ru-106 | 0.125(35)* | 0.0732(2)* | 0.118(15)* | | | | | 4980(14) | 0.0757 (22)* | 0.142(2)* | | -0.477(1)* | 0.14(8)* | 0.286(54)* |
| Sb-124 | | | | | | | | 430(1) | | | | | | |
| Sb-125 | 0.0913(35)* | 0.0194(2)* | 0.109(15)* | | | | | | 0.0252(22)* | 0.0275(2)* | | -0.0161(1)* | 0.0175(8)* | 0.131(54) |
| Sr-89 | | | 493(14) | | | | | | | | | | | |
| Sr-90 | 0.765(54) | 0.0492(2) | 6000(68) | | | 1.44(2) | | 7760(27) | 58.3(32) | 0.0799(4) | | 0.754(1) | 0.00558(17) | 0.464(105) |
| Te-132 | | | | | | | | 130(1) | | | | | | |
| U | | | | | | | | 0.0335(2) | | | | | | |
| U-234 | 0.0143(6) | | | | | | | | | | | | | 0.0222(8) |
| U-235 | 0.00182(6)* | | | | | | | | | | | | | 0.00178(8) |
| U-238 | 0.02(6) | | | | | | | | | | | | | 0.0166(8) |
| Zn-65 | 0.036(19) | 0.0544(2)* | 12.7(77) | -0.0593 (1)* | -0.0471(1)* | 0.0721(12) | 0.0118(1)* | 958(14) | 0.0436(16)* | 0.0617(3) | 0.699(4) | | 0.0398(17) | 0.059(35) |
| Zr-95 | | | | | | | | 23200(4) | | | | | | |
| Zr/Nb-95 | 0.357(19) | 0.189(2)* | 0.465(11)* | | | | | 6210(12) | 0.0585(12)* | 0.0191(2)* | | | 0.0918(8)* | 0.34(35) |

(a) (#) signifies the total number of samples collected.
* = Undetected.

**Table B.2**. Maximum Concentration (pCi/g, dry wt.) of Radionuclides in Vegetation Samples Collected in the Vicinity of 100-N Area, 1973 to Present

| Radionuclides | Balsam Root (pCi/g) | Cymopteris (pCi/g) | Grass and Weeds (pCi/g) | Milfoil (pCi/g) | Mulberry (pCi/g) | Perennial Vegetation (pCi/g) | Reed Canarygrass (pCi/g) |
|---|---|---|---|---|---|---|---|
| BaLa140 | | | | | | 0.184(2) | |
| Be-7 | 3.67(10) | 4.04(1) | | 4.16(5) | 4.28(10)[b,c] | 6.95(17) | 0.661(1) |
| Ce-141 | | | | | | 0.125(3) | |
| Ce-144 | | | | | | 1.41(2) | |
| Ce/Pr144 | 0.125(10)[d] | 0.0579(1)[d] | 59.6(9) | -0.0834(3)[d] | | 0.0523(8)[d] | |
| Co-58 | | | 3.4(2) | | | 0.0183(2) | |
| Co-60 | 0.0441(10) | 0.012(1)[d] | 11.8(11) | 0.12(5)[d] | 0.337(11)[b] | 3.43(31) | 0.00354(1)[d] |
| Cr-51 | | | 2.41(1) | | | | |
| Cs-134 | 0.0209(10)[d] | 0.0034(1)[d] | | 0.0129(5)[d] | 0.000541(4)[d] | 0.0785(30) | -0.0147(1)[d] |
| Cs-137 | 0.087(10) | -0.00372(1)[d] | 3.23(11) | 0.147(5) | 0.244(11)[b] | 0.209(31) | 0.0151(1)[d] |
| Eu-154 | 0.0607(10)[d] | 0.114(1)[d] | | 0.246(5) | 0.218(11)[b] | 0.27(29) | -0.0325(1)[d] |
| Eu-155 | 0.0216(10)[d] | 0.0441(1)[d] | | 0.1(5)[d] | 0.00584(11)[b] | 0.082(29) | 0.0121(1)[d] |
| I-131 | | | 226(10) | | | -0.0393(2)[d] | |
| K-40 | 39.9(10) | 32.8(1) | 19.5(9) | 21.7(5) | 17.5(11)[b] | 65.1(31) | 12.8(1) |
| Mn-54 | | | 2.8(6) | | | 1.07(5) | |
| Na-22 | | | | | | 0.0811(2) | |
| Pb-212 | | | | | | 0.0348(3) | |
| Pu-238 | | | | | 0.000251(6)[b] | 0.000607(30) | |
| Pu-239/240 | | | | | 0.000168(6)[b] | 0.00268(30) | |
| Ra-226 | | | | 0.441(1) | | | |
| Ra-228 | | | | 0.447(1) | | | |
| Ru-103 | | | | | | 0.0876(1) | |
| Ru-106 | 0.221(10)[d] | -0.062(1)[d] | 78.1(9) | 0.341(5)[d] | 2.11(11)[b,d] | 0.119(31) | -0.0422(1)[d] |
| Sb-125 | 0.0376(10)[d] | 0.0158(1)[d] | 68.3(4) | 0.0972(5)[d] | 0.657(11)[b] | 0.102(13)[d] | -0.00412(1)[d] |
| Sr-89 | | | | | | 0.00319(2)[d] | |
| Sr-90 | 0.0578(10) | 0.00737(1) | | 0.161(5) | 437(10)[b] | 0.408(30) | 11.1(1)[d] |
| U | | | | | | 0.0254(21) | |
| U-234 | | | | 0.819(3) | | 0.0103(9) | |
| U-235 | | | | 0.0253(3) | | 0.00223(9)[d] | |
| U-238 | | | | 0.669 (3) | | 0.00574(9)[d] | |
| Zn-65 | 0.137(10) | 0.126(1) | 13(10) | 0.121(3) | | 0.0468(10) | |
| Zr/Nb-95 | 0.0419(10)[d] | 0.0129(1)[d] | 7.68(9) | 0.109(3)[d] | | 1.54(26) | |

(a) (#) Signifies the total number of samples collected.
(b) Includes values from Antonio et al. (1993); these values were not entered into the Hanford Environmental Information System database.
(c) Excludes one suspect Be-7 value of 141 pCi/g (Antonio et al. 1993). Note: Be-7 is a cosmogenic radionuclide that is not expected to have a significant 100-N Area source.
(d) Undetected value.

**Table B.3**. Radionuclide Concentrations for Vegetation Samples at the 100-N Area and Vernita Bridge (Background) from Antonio et. al (1993)

| Location | Radionuclide | Data | Chicory | Dogbane | Milkweed | Mulberry | Mulberry Fruit | Willow | Yarrow |
|---|---|---|---|---|---|---|---|---|---|
| 100-N Area | Be-7 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 1.82 | 3.69 | 6.49 | 141 | 0.00282 | 3.89 | 5.52 |
| | | Average | 1.45 | 0.989 | 6.49 | 14.8 | 0.00282 | 3.89 | 3.9 |
| | | Std Dev | 0.523 | 2.44 | | 58.1 | | | 2.29 |
| | Ce/Pr-144 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 0.00166 | 0.131 | -0.0136 | 1.77 | -0.135 | 0.0482 | 0.0816 |
| | | Average | -0.112 | 0.096 | -0.0136 | 0.101 | -0.135 | 0.0482 | -0.0407 |
| | | Std Dev | 0.161 | 0.0315 | | 0.912 | | | 0.173 |
| | Co-60 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | -0.0001 | 0.00724 | -0.0202 | 0.337 | 0.0251 | 0.00842 | 0.0219 |
| | | Average | -0.0107 | 0.00477 | -0.0202 | 0.105 | 0.0251 | 0.00842 | 0.0160 |
| | | Std Dev | 0.0149 | 0.00298 | | 0.134 | | | 0.00842 |
| | Cs-134 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | -0.007 | 0.0065 | -0.00636 | 0.172 | -0.0059 | 0.00176 | 0.00649 |
| | | Average | -0.0145 | -0.00169 | -0.00636 | -0.00291 | -0.0059 | 0.00176 | 0.00266 |
| | | Std Dev | 0.0105 | 0.00742 | | 0.0884 | | | 0.00542 |
| | Cs-137 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 0.0126 | 0.0143 | 0.0101 | 0.244 | 0.00019 | 0.0205 | 0.0602 |
| | | Average | 0.0112 | 0.00783 | 0.0101 | 0.0519 | 0.00019 | 0.0205 | 0.0464 |
| | | Std Dev | 0.00092 | 0.00659 | | 0.0922 | | | 0.0195 |
| | Eu-154 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 0.0121 | 0.0246 | 0.132 | 0.218 | 0.00271 | 0.0368 | 0.0641 |
| | | Average | 0.00947 | -0.0196 | 0.132 | -0.0726 | 0.00271 | 0.0368 | 0.0203 |
| | | Std Dev | 0.00372 | 0.0384 | | 0.250 | | | 0.0619 |
| | Eu-155 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 0.0247 | 0.0198 | -0.00748 | 0.0447 | -0.00891 | 0.00157 | 0.0731 |
| | | Average | 0.0124 | 0.00518 | -0.00748 | -0.157 | -0.00891 | 0.00157 | 0.0371 |
| | | Std Dev | 0.0175 | 0.0146 | | 0.243 | | | 0.0509 |
| | H-3 | Count | | | | 7 | 1 | | 2 |
| | | Max | | | | 19900 | 518 | | 177 |
| | | Average | | | | 6600 | 518 | | 130.7 |
| | | Std Dev | | | | 7500 | | | 65.5 |
| | K-40 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 19.6 | 18.1 | 19.8 | 17.5 | 2.34 | 9.86 | 23.2 |
| | | Average | 16.5 | 13.3 | 19.8 | 14.1 | 2.34 | 9.86 | 19.2 |
| | | Std Dev | 4.38 | 4.65 | | 1.69 | | | 5.59 |

**Table B.3**. (contd)

| Location | Radionuclide | Data | Chicory | Dogbane | Milkweed | Mulberry | Mulberry Fruit | Willow | Yarrow |
|---|---|---|---|---|---|---|---|---|---|
| 100-N Area (contd) | Pb-212 | Count | | | | | | 1 | 1 |
| | | Max | | | | | | 0.00893 | 0.0391 |
| | | Average | | | | | | 0.00893 | 0.0391 |
| | | Std Dev | | | | | | | |
| | Pb-214 | Count | | | | | | | 1 |
| | | Max | | | | | | | 0.0594 |
| | | Average | | | | | | | 0.0594 |
| | | Std Dev | | | | | | | |
| | Pu-238 | Count | 2 | 2 | 1 | 3 | | 1 | 2 |
| | | Max | 0.00014 | 0.00544 | -0.00001 | 0.000251 | | 0.0000168 | 4.41E-05 |
| | | Average | 5.6E-05 | 0.00288 | -0.00001 | 6.8E-05 | | 0.0000168 | 1.56E-05 |
| | | Std Dev | 0.00011 | 0.00362 | | 0.000159 | | | 4.04E-05 |
| | Pu-239/240 | Count | 2 | 2 | 1 | 3 | | 1 | 2 |
| | | Max | 0.00176 | 0.00528 | 0.000127 | 0.000118 | | -1.02E-05 | 0.000317 |
| | | Average | 0.00099 | 0.00306 | 0.000127 | 7.15E-05 | | -1.02E-05 | 0.000162 |
| | | Std Dev | 0.00109 | 0.00314 | | 4.72E-05 | | | 0.00022 |
| | Ra-226 | Count | | | | | | | 1 |
| | | Max | | | | | | | 0.102 |
| | | Average | | | | | | | 0.102 |
| | | Std Dev | | | | | | | |
| | Ru-106 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | 0.108 | -0.0174 | -0.166 | 2.11 | -0.00825 | 0.182 | -0.00116 |
| | | Average | 0.0987 | -0.0913 | -0.166 | 0.563 | -0.00825 | 0.182 | -0.0128 |
| | | Std Dev | 0.0132 | 0.111 | | 0.894 | | | 0.0165 |
| | Sb-125 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | -0.0515 | -0.00453 | -0.0142 | 0.657 | 0.00504 | 0.0298 | 0.00255 |
| | | Average | -0.0562 | -0.0137 | -0.0142 | 0.144 | 0.00504 | 0.0298 | -0.00673 |
| | | Std Dev | 0.00658 | 0.0103 | | 0.248 | | | 0.0131 |
| | Sr-90 | Count | 2 | 3 | 1 | 6 | 1 | 1 | 3 |
| | | Max | 0.276 | 2.61 | 0.15 | 437 | 0.138 | 0.852 | 2.59 |
| | | Average | 0.236 | 1.14 | 0.15 | 88.3 | 0.138 | 0.852 | 0.903 |
| | | Std Dev | 0.0566 | 1.28 | | 172 | | | 1.46 |
| | Th-232 | Count | 1 | | | | | | |
| | | Max | 0.127 | | | | | | |
| | | Average | 0.127 | | | | | | |
| | | Std Dev | | | | | | | |

**Table B.3**. (contd)

| Location | Radionuclide | Data | Chicory | Dogbane | Milkweed | Mulberry | Mulberry Fruit | Willow | Yarrow |
|---|---|---|---|---|---|---|---|---|---|
| 100-N Area (contd) | U-234 | Count | 2 | 2 | 1 | 3 | | 1 | 2 |
| | | Max | 0.118 | 0.168 | 0.00364 | 0.0436 | | 0.00885 | 0.0454 |
| | | Average | 0.100 | 0.0906 | 0.00364 | 0.0171 | | 0.00885 | 0.0218 |
| | | Std Dev | 0.0254 | 0.110 | | 0.0238 | | | 0.0334 |
| | U-235 | Count | 2 | 2 | 1 | 3 | | 1 | 2 |
| | | Max | 0.00456 | 0.00573 | -0.00036 | 0.00158 | | -0.000905 | 0.00174 |
| | | Average | 0.00371 | 0.00270 | -0.00036 | 0.000118 | | -0.000905 | 0.000684 |
| | | Std Dev | 0.0012 | 0.00429 | | 0.00129 | | | 0.00149 |
| | U-238 | Count | 2 | 2 | 1 | 3 | | 1 | 2 |
| | | Max | 0.0235 | 0.0306 | 0.00288 | 0.00819 | | 0.0056 | 0.0365 |
| | | Average | 0.0208 | 0.0167 | 0.00288 | 0.00439 | | 0.0056 | 0.0179 |
| | | Std Dev | 0.00382 | 0.0197 | | 0.00493 | | | 0.0264 |
| | Zn-65 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | -0.0419 | -0.0113 | -0.0246 | 0.627 | -0.00367 | -0.0188 | 0.0192 |
| | | Average | -0.0755 | -0.0422 | -0.0246 | -0.0178 | -0.00367 | -0.0188 | -0.0061 |
| | | Std Dev | 0.0474 | 0.0268 | | 0.397 | | | 0.0358 |
| | Zr/Nb-95 | Count | 2 | 3 | 1 | 7 | 1 | 1 | 2 |
| | | Max | -0.0205 | 0.562 | 0.00046 | 0.356 | 0.0229 | -0.0158 | 0.125 |
| | | Average | -0.324 | 0.178 | 0.00046 | -3.72 | 0.0229 | -0.0158 | 0.0944 |
| | | Std Dev | 0.430 | 0.346 | | 6.42 | | | 0.0433 |
| Vernita Bridge | Be-7 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 1.05 | 4.11 | 3.96 | | 5.37 | 4.67 |
| | | Average | | 0.862 | 4.11 | 2.78 | | 4.425 | 4.67 |
| | | Std Dev | | 0.267 | | 1.67 | | 1.34 | |
| | Ce/Pr-144 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.00154 | 0.00506 | -0.0379 | | -0.0626 | -0.0579 |
| | | Average | | -0.0147 | 0.00506 | -0.0724 | | -0.0730 | -0.0579 |
| | | Std Dev | | 0.0229 | | 0.0489 | | 0.0148 | |
| | Co-60 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.0136 | 0.0543 | 0.012 | | -0.000804 | 0.0145 |
| | | Average | | 0.00421 | 0.0543 | 0.00494 | | -0.00665 | 0.0145 |
| | | Std Dev | | 0.0133 | | 0.009984 | | 0.00827 | |

**Table B.3**. (contd)

| Location | Radionuclide | Data | Chicory | Dogbane | Milkweed | Mulberry | Mulberry Fruit | Willow | Yarrow |
|---|---|---|---|---|---|---|---|---|---|
| Vernita Bridge (contd) | Cs-134 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | -0.00963 | -0.0177 | -0.00198 | | 0.00684 | 0.0257 |
| | | Average | | -0.0199 | -0.0177 | -0.0188 | | -0.00163 | 0.0257 |
| | | Std Dev | | 0.0145 | | 0.0238 | | 0.0120 | |
| | Cs-137 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.0148 | -0.00723 | 0.00401 | | 0.0194 | 0.00923 |
| | | Average | | 0.00760 | -0.00723 | 0.00247 | | 0.0112 | 0.00923 |
| | | Std Dev | | 0.0102 | | 0.00217 | | 0.0116 | |
| | Eu-154 | Count | | 1 | 1 | 2 | | 2 | 1 |
| | | Max | | -0.0249 | -0.0472 | -0.0317 | | 0.0641 | -0.0093 |
| | | Average | | -0.0249 | -0.0472 | -0.0319 | | 0.0418 | -0.0093 |
| | | Std Dev | | | | 0.000283 | | 0.0315 | |
| | Eu-155 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.00167 | -0.0137 | 0.0122 | | -0.0146 | 0.000891 |
| | | Average | | -0.00767 | -0.0137 | 0.00780 | | -0.0226 | 0.000891 |
| | | Std Dev | | 0.0132 | | 0.00622 | | 0.0114 | |
| | H-3 | Count | | 2 | 1 | 2 | 1 | 2 | |
| | | Max | | 319 | 189 | 359 | 172 | 36.5 | |
| | | Average | | 258 | 189 | 210 | 172 | 17.6 | |
| | | Std Dev | | 86.3 | | 211 | | 26.7 | |
| | K-40 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 21.5 | 27.9 | 14.1 | | 10.5 | 16.9 |
| | | Average | | 15.6 | 27.9 | 11.3 | | 10.1 | 16.9 |
| | | Std Dev | | 8.37 | | 3.95 | | 0.622 | |
| | Pu-238 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.000065 | -1.1E-05 | 0.000135 | | 0.000008 | -0.00007 |
| | | Average | | 2.75E-05 | -1.1E-05 | 5.65E-05 | | -0.000009 | -0.00007 |
| | | Std Dev | | 5.3E-05 | | 0.000111 | | 2.404E-05 | |
| | Pu-239/240 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.000141 | 0.000271 | 0.000126 | | 0.000267 | 0.00007 |
| | | Average | | 0.000124 | 0.000271 | 7.45E-05 | | 0.000132 | 0.00007 |
| | | Std Dev | | 2.47E-05 | | 7.28E-05 | | 0.000192 | |
| | Ru-106 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.0266 | -0.4 | 0.0509 | | 0.0625 | -0.053 |
| | | Average | | -0.00785 | -0.4 | 0.0164 | | 0 | -0.053 |
| | | Std Dev | | 0.0487 | | 0.0487 | | 0.0884 | |

**Table B.3**. (contd)

| Location | Radionuclide | Data | Chicory | Dogbane | Milkweed | Mulberry | Mulberry Fruit | Willow | Yarrow |
|---|---|---|---|---|---|---|---|---|---|
| Vernita Bridge (contd) | Sb-125 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.0375 | 0.00724 | 0.0129 | | 0.0273 | -0.0513 |
| | | Average | | 0.0236 | 0.00724 | 0.011 | | 0.0192 | -0.0513 |
| | | Std Dev | | 0.0197 | | 0.00260 | | 0.0115 | |
| | Sr-90 | Count | | 2 | 1 | 2 | | 1 | 1 |
| | | Max | | 0.0543 | 0.0557 | 0.172 | | 0.087 | 0.0183 |
| | | Average | | 0.0444 | 0.0557 | 0.164 | | 0.087 | 0.0183 |
| | | Std Dev | | 0.0139 | | 0.0106 | | | |
| | Tc-99 | Count | | 2 | 1 | 2 | | 1 | 1 |
| | | Max | | -0.195 | -0.00232 | -0.088 | | -0.186 | -0.00356 |
| | | Average | | -0.230 | -0.00232 | -0.0975 | | -0.186 | -0.00356 |
| | | Std Dev | | 0.0488 | | 0.0134 | | | |
| | U-234 | Count | | 2 | 1 | 1 | | 2 | 1 |
| | | Max | | 0.00425 | 0.00972 | 0.00968 | | 0.0146 | -0.0003 |
| | | Average | | 0.00384 | 0.00972 | 0.00968 | | 0.00836 | -0.0003 |
| | | Std Dev | | 0.000573 | | | | 0.00883 | |
| | U-235 | Count | | 2 | 1 | 1 | | 2 | 1 |
| | | Max | | -0.00087 | -0.0005 | 0.000112 | | 0.00031 | -0.00119 |
| | | Average | | -0.00103 | -0.0005 | 0.000112 | | -7.35E-05 | -0.00119 |
| | | Std Dev | | 0.000229 | | | | 0.000542 | |
| | U-238 | Count | | 2 | 1 | 1 | | 2 | 1 |
| | | Max | | 0.00308 | 0.00781 | 0.0064 | | 0.00853 | -0.00014 |
| | | Average | | 0.00252 | 0.00781 | 0.0064 | | 0.00526 | -0.00014 |
| | | Std Dev | | 0.000785 | | | | 0.00463 | |
| | Zn-65 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.00777 | 0.0417 | 0.0131 | | 0.00521 | -0.0228 |
| | | Average | | -0.00242 | 0.0417 | -0.0340 | | 0 | -0.0228 |
| | | Std Dev | | 0.0144 | | 0.0665 | | 0.00737 | |
| | Zr/Nb-95 | Count | | 2 | 1 | 2 | | 2 | 1 |
| | | Max | | 0.0144 | -0.0319 | 0.013 | | 0.0443 | -0.0405 |
| | | Average | | 0.0111 | -0.0319 | 0.00512 | | 0.00495 | -0.0405 |
| | | Std Dev | | 0.00466 | | 0.0111 | | 0.0556 | |

Note: This data was not included in the Hanford Environmental Information System database.

**Table B.4**. Maximum Concentration (pCi/g, dry wt.) of Radionuclides in Soil and Sediment Samples at 100-N Area, 1975 to Present

| Radionuclide | Total Number of Samples Collected | Maximum Concentration (pCi/g) | Lab Qualifier |
|---|---|---|---|
| Be-7 | 20 | 0.479 | -- |
| Ce-141 | 1 | 0.0724 | -- |
| Ce-144 | 2 | 0.362 | -- |
| Ce/Pr-144 | 11 | 0.11 | U |
| Co-58 | 2 | 0.0307 | -- |
| Co-60 | 38 | 2.14 | -- |
| Cs-134 | 38 | 0.473 | -- |
| Cs-137 | 38 | 1.18 | -- |
| Eu-152 | 3 | 0.899 | -- |
| Eu-154 | 38 | 0.157 | -- |
| Eu-155 | 37 | 0.171 | -- |
| K-40 | 38 | 17.7 | -- |
| Mn-54 | 4 | 0.181 | -- |
| Na-22 | 2 | 0.0285 | -- |
| Pb-212 | 5 | 0.977 | -- |
| Pb-214 | 7 | 0.78 | -- |
| Pu-238 | 35 | 0.00182 | -- |
| Pu-239/240 | 35 | 0.034 | -- |
| Ra-224 | 16 | 1.45 | -- |
| Ra-226 | 21 | 0.9 | -- |
| Ra-228 | 5 | 1 | -- |
| Ru-106 | 38 | 0.337 | -- |
| Sb-125 | 20 | 0.0597 | U |
| Sr-89 | 2 | 0.119 | -- |
| Sr-90 | 38 | 46.7 | -- |
| Th-232 | 2 | 0.876 | -- |
| U | 14 | 0.487 | -- |
| U-234 | 9 | 0.757 | -- |
| U-235 | 22 | 0.384 | -- |
| U-238 | 22 | 1.45 | -- |
| Zn-65 | 14 | 0.227 | -- |
| Zr/Nb-95 | 29 | 0.053 | -- |

-- = No lab qualifier.
U = Undetected.

**Table B.5**. Maximum Concentration of Radionuclides in Water Samples from Riverbank Springs and the Columbia River Near 100-N Area, 1971 to Present

| Radionuclide | Total Number of Samples Collected | Maximum Concentration (pCi/L) | Lab Qualifier |
|---|---|---|---|
| Alpha | 42 | 8.92 | U |
| Be-7 | 49 | 27.5 | U |
| Beta | 411 | 24100 | -- |
| Ce/Pr-144 | 17 | 45.3 | U |
| Co-58 | 7 | 1000 | -- |
| Co-60 | 101 | 389 | -- |
| Cr-51 | 43 | 1240 | -- |
| Cs-134 | 50 | 2.42 | U |
| Cs-137 | 99 | 150 | -- |
| Eu-154 | 49 | 13.3 | -- |
| Eu-155 | 49 | 2.49 | U |
| Fe-59 | 2 | 42.6 | -- |
| I-131 | 28 | 5630 | -- |
| I-133 | 1 | 36.9 | -- |
| K-40 | 49 | 324 | -- |
| Mn-54 | 10 | 732 | -- |
| Mn-56 | 1 | 1030 | -- |
| Ra-226 | 2 | 0.0302 | -- |
| Ra-228 | 2 | 0.668 | -- |
| Ru-106 | 48 | 6590 | -- |
| Sb-125 | 38 | 9.9 | -- |
| Sc-46 | 42 | 46 | -- |
| Sr-90 | 129 | 10900 | -- |
| Tc-99 | 27 | 2.44 | -- |
| Tritium | 168 | 308000 | -- |
| U-234 | 106 | 1.35 | -- |
| U-235 | 106 | 0.0405 | -- |
| U-238 | 106 | 1.08 | -- |
| Zn-65 | 62 | 278 | -- |
| Zr/Nb-95 | 26 | 273 | -- |

-- = No lab qualifier.
U = Undetected.

**Table B.6**. Maximum Concentration of Metals, Anions and Volatile Organic Compounds Found in Seeps Near 100-N Area, 1971 to Present

| Chemical | Total Number of Samples Collected | Maximum Concentration (µg/L) | Lab Qualifier |
|---|---|---|---|
| **Volatile Organics** | | | |
| 1,1,1-Trichloroethane | 1 | 0.36 | U |
| 1,1,2-Trichloroethane | 1 | 0.53 | U |
| 1,1-Dichloroethane | 1 | 0.37 | U |
| 1,2-Dichloroethane | 1 | 0.43 | U |
| 1,4-Dichlorobenzene | 1 | 0.5 | U |
| 1-Butanol | 1 | 25 | U |
| Acetone | 1 | 1.4 | -- |
| Benzene | 1 | 0.38 | U |
| Carbon Disulfide | 1 | 0.33 | U |
| Carbon Tetrachloride | 1 | 0.35 | U |
| Chloroform | 3 | 1.5 | L |
| Cis-Dichloroethylene | 1 | 0.47 | U |
| Ethylcyanide | 1 | 2.1 | U |
| Hexone | 1 | 1.1 | U |
| Methone | 1 | 3.4 | U |
| Methylene Chloride | 2 | 1.3 | B, L |
| Perchloroethylene | 2 | 1.4 | L |
| Tetrahydrofuran | 1 | 2.5 | U |
| Toluene | 1 | 0.44 | U |
| Trans-Dichloroethylene | 1 | 0.48 | U |
| Trichloroethylene | 1 | 0.39 | U |
| Vinyl Chloride | 1 | 1.3 | U |
| Xylenes | 1 | 1.3 | U |
| **Metals** | | | |
| Ag | 1 | 4.5 | U |
| Al | 2 | 9400 | -- |
| As | 1 | 3.6 | L |
| Ba | 3 | 140 | -- |
| Be | 1 | 0.2 | U |
| Ca | 3 | 32000 | -- |
| Cd | 1 | 0.31 | U |
| Co | 1 | 5 | U |
| Cr | 2 | 45 | B |
| Cr+6 | 2 | 5.3 | -- |
| Cu | 2 | 30 | -- |

**Table B.6**. (contd)

| Chemical | Total Number of Samples Collected | Maximum Concentration (µg/L) | Lab Qualifier |
|---|---|---|---|
| **Metals** (contd) | | | |
| Fe | 3 | 12000 | -- |
| K | 3 | 3000 | -- |
| Mg | 3 | 10000 | -- |
| Mn | 3 | 680 | -- |
| Na | 3 | 8500 | -- |
| Ni | 2 | 25 | B, L |
| Pb | 1 | 4.9 | -- |
| Sb | 2 | 43 | U |
| Se | 1 | 3.8 | U |
| Sn | 2 | 85 | L |
| Sr | 2 | 150 | -- |
| Tl | 1 | 3.7 | U |
| V | 3 | 42 | -- |
| Zn | 3 | 460 | -- |
| **Anions** | | | |
| Bromide | 1 | 21 | L |
| Chloride | 3 | 10000 | D |
| Fluoride | 3 | 600 | -- |
| Nitrate | 3 | 15000 | D |
| Nitrite | 1 | 11 | U |
| Phosphate | 1 | 83 | U |
| Sulfate | 3 | 26000 | D |

-- = No lab qualifier.
B = Detected in the analytical blank.
D = Dilution required prior to final analysis.
L = Detected value, but below the contract required quantitation limit.
U = Undetected.

**Table B.7**. Maximum Concentration of Metals, Anions and Volatile Organic Compounds Measured in Water Samples from the Columbia River Near 100-N Area, 1971 to Present

| Chemical | Total Number of Samples Collected | Maximum Concentration (µg/L) | Lab Qualifier |
|---|---|---|---|
| **Volatile Organics** | | | |
| 1,1,1-Trichloroethane | 10 | 0.36 | U |
| 1,1,2-Trichloroethane | 10 | 0.53 | U |
| 1,1-Dichloroethane | 10 | 0.37 | U |
| 1,2-Dichloroethane | 10 | 0.43 | U |
| 1,4-Dichlorobenzene | 10 | 0.5 | U |
| 1-Butanol | 10 | 25 | U |
| Acetone | 10 | 7.9 | B, L |
| Benzene | 10 | 0.38 | U |
| Carbon Disulfide | 10 | 0.33 | U |
| Carbon Tetrachloride | 10 | 0.35 | U |
| Chloroform | 10 | 0.41 | U |
| Cis-Dichloroethylene | 10 | 0.47 | U |
| Ethylcyanide | 10 | 2.1 | U |
| Hexone | 10 | 1.1 | U |
| Methone | 10 | 3.4 | U |
| Methylene Chloride | 18 | 0.51 | B, L |
| Perchloroethylene | 10 | 0.35 | U |
| Tetrahydrofuran | 10 | 2.5 | U |
| Toluene | 10 | 0.44 | U |
| Trans-Dichloroethylene | 10 | 0.48 | U |
| Trichloroethylene | 10 | 0.39 | U |
| Vinyl Chloride | 10 | 1.3 | U |
| Xylenes | 10 | 1.3 | U |
| **Metals** | | | |
| Ag | 10 | 4.5 | U |
| Al | 22 | 91 | B, L |
| As | 10 | 2.6 | U |
| Ba | 30 | 33 | -- |
| Be | 10 | 0.2 | U |
| Ca | 30 | 18000 | -- |
| Cd | 17 | 2.1 | B, L |
| Co | 11 | 7.6 | L |
| Cr | 15 | 19 | B, L |
| Cu | 21 | 8.7 | U |
| Fe | 30 | 130 | -- |

**Table B.7**. (contd)

| Chemical | Total Number of Samples Collected | Maximum Concentration (µg/L) | Lab Qualifier |
|---|---|---|---|
| **Metals** (contd) | | | |
| K | 20 | 1500 | B |
| Mg | 30 | 4600 | -- |
| Mn | 30 | 8.5 | L |
| Na | 30 | 3100 | -- |
| Ni | 11 | 16 | L |
| Pb | 11 | 1.7 | U |
| Sb | 10 | 43 | U |
| Se | 10 | 3.8 | U |
| Sn | 12 | 49 | L |
| Sr | 20 | 99 | -- |
| Tl | 10 | 3.7 | U |
| V | 13 | 3.1 | L |
| Zn | 25 | 25 | -- |
| **Anions** | | | |
| Bromide | 10 | 15 | U |
| Chloride | 30 | 1300 | -- |
| Fluoride | 30 | 400 | -- |
| Nitrate | 22 | 1600 | -- |
| Nitrite | 10 | 18 | L |
| Phosphate | 10 | 83 | U |
| Sulfate | 30 | 10000 | D |

-- = No lab qualifier.
B = Detected in the analytical blank.
D = Dilution required prior to final analysis.
L = Detected value, but below the contract required quantitation limit.
U = Undetected.

**Table B.8**. Dose Rates from Penetrating Radiation Measured with Thermoluminescent Dosimeters Near 100-N Area, 1970 to Present

| TLD Location | Total Number of Samples Collected | Maximum Dose Rates (mR/d) |
|---|---|---|
| 100-N river | 66 | 0.38 |
| 100-N trench spring | 249 | 2.0 |
| 100-N 1325 crib | 3 | 14 |
| 100-N WPPSS area | 597 | 0.97 |
| 100-N spring shoreline | 1 | 0.60 |
| Above tip 100-N BERM | 196 | 2.7 |
| Below 100 NE river | 134 | 2.2 |
| Below 100-N outfall | 195 | 2.9 |
| Below 100-N stack | 172 | 1.1 |
| Below 100-N trench | 12 | 0.55 |

# Appendix C

# Draft Ecological Assessment Process

# Appendix C

# Draft Ecological Assessment Process

The U.S. Environmental Protection Agency (EPA) defines an ecological assessment as a process to evaluate the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. An important first step is deciding which aspect of the environment will be selected for a field-based evaluation. An assessment endpoint is defined by the EPA as an expression of the environmental value to be protected, operationally defined as an ecological entity and its attributes (EPA 1998). An example of one ecological entity on the Hanford Site would be fall chinook salmon, with its attributes being survival or recruitment.

Assessment endpoints have been identified by EPA as useful metrics for an ecological assessment as they represent valued attributes of ecological entities (species or groups of species) upon which risk-management actions are focused. EPA guidelines for an ecological assessment suggest three general criteria for selecting the appropriate endpoints – ecological relevance, susceptibility (exposure plus sensitivity), and relevance to management goals. Some ecological assessments use a weight-of-evidence approach in which multiple endpoints are related to a specific assessment to evaluate whether significant risk of harm is posed to the environment (Menzi et al. 1996). The data may include lab-based toxicity test results, assessment of existing impacts on-site (tissue residue and health results compared to suitable reference areas), or risk calculations that compare estimated exposure doses with toxicity values obtained from the literature.

Beginning in 2002, efforts were initiated to develop a process for conducting ecological assessments on the Hanford Site. The process includes (1) identification of the distinct environments present on the Hanford Site, (2) identification of ecologically distinct groups of organisms guilds, (3) identification the most suitable species chosen for ecological assessments entities, and (4) identification of the key end-points attributes (e.g., recruitment, fertility, body condition index) suitable for ecological assessments on the Hanford Site (B. Tiller, PNNL, personal communication).

Table C.1 depicts key environments, animal groups, species, and measurements (attributes) that have been developed for conducting ecological assessments on the Hanford Site. Biological metrics were divided into (A) general assessment endpoints that may directly represent impacts/injury to the receptors and (B) more sensitive assessment endpoints that may be used more as an index of injury/stress to the receptor species. Biota guilds for terrestrial environments were segregated based on the Washington State Model Toxic Control Act guilds. This approach was adopted and adjusted for functional groups (guilds) identified for the riparian and aquatic environments. Table C.1 provides the species that best fit several considerations of life-history characteristics (feeding location, movements, size) that influence the organism's likelihood of contaminant exposure from Hanford sources and ability of field-based studies to detect and measure corresponding biological effects (ideal sentinels/ indicator species). Multiple species

**Table C.1**. Key Environments, Functional Groups, Species and Health Measurements Identified for Ecological Assessments on the Hanford Site

| Environment | Ecological Guilds and MTCA-Based Guilds | Target Receptor Species | Potential Biological Screening Endpoints |
|---|---|---|---|
| Terrestrial/Riparian | Soil biota | Beetles, spiders, | None |
| Terrestrial/Riparian | Shallow-root plants | Cheatgrass, reed canarygrass | Reproductive fitnesss, Photosynthetic efficiencies<br>DNA damage index, germination experiments |
| | Deep-root plants | Russian thistle, rabbitbrush, sagebrush, mulberry, willow | |
| Terrestrial/Riparian | Mammalian herbivore/omnivore | Deer mouse, cottontail rabbits, porcupine | Body wts, % lactating, juv/adult ratios, # new captures per trap night histology, Placental scars, enzyme induction, blood (PCV, WBC), DNA damage index |
| Terrestrial/Riparian | Mammalian predator | Deer mouse, bats | Body wt, general condition, histology, % lactation, Enzyme induction blood (PCV, WBC), DNA damage index, |
| Terrestrial/Riparian | Avian herbivore/omnivore | Song sparrow, morning dove horned lark | Body wt, general condition, histology, reproductive success<br>Enzyme induction, blood (PCV, WBC), DNA damage index |
| Terrestrial | Avian predator | W. kingbird, swallows W. meadowlark, horned lark | Body wt, general condition, histology, reproductive success<br>Enzyme induction, blood (PCV, WBC), DNA damage index |
| Riparian | Avian predator | E. kingbird, swallows, b. oriole, | Body wt, general condition, histology, reproductive success<br>Enzyme induction, blood (PCV, WBC), DNA damage index |
| Riparian/aquatic | Amphibians | Toads: Woodhouse's, spadefoot | Early-life stage: Morphology and histology<br>Adult-Stage: General condition, morphology, histology<br>Experimental hatching rates, addn't morphological anomaly investigations |
| Aquatic | Soil biota | | Animal occurrence, density, demographics, histology, general condition<br>Growth, survival, reproductive performance |
| | Macro invertebrate | Crayfish, clams | None<br>Lab-based hatch rate |
| | Micro invertebrate | Caddis fly, mayfly | Anatomical anomalies |
| Aquatic | Plant/algae | Millfoil, periphyton | Productivity, Chloropyll A:B ratio<br>DNA damage index |

**Table C.1**. (contd)

| Environment | Ecological Guilds and MTCA-Based Guilds | Target Receptor Species | Potential Biological Screening Endpoints | |
|---|---|---|---|---|
| Aquatic | Avian herbivore/omnivore | grebes, goldeneye | General condition, body wts, histology, Enzyme induction, blood (PCV, WBC), DNA damage index | |
| Aquatic | Avian predator | E. kingbird, swallows g.b. herons | Reproductive success, general condition, histology Enzyme induction, blood (PCV, WBC), DNA damage index | |
| Aquatic | Pelagic Fish herbivore/omnivore | A. carp, j. suckers | General condition, body wts, length/wt. ratios (C.I.), histology Enzyme induction, blood (PCV, WBC), DNA damage index, lab-based hatch rate | |
| Aquatic | Pelagic Fish Predator | J. fall chinook, J. pikeminnow, J./a. bass | General condition, body wts, length/wt. Ratios (C.I.), histology Enzyme induction, blood (PCV, WBC), DNA damage index, lab-based hatch rate | |
| Aquatic | Benthic Fish herbivore/omnivore | A. suckers, A. carp | General condition, body wts, length/wts. ratios (C.I.), histology Enzyme induction, blood (PCV, WBC), DNA damage index, lab-based hatch rate | |
| Aquatic | Benthic Fish Predator | Prickly sculpin | Presence, density, General condition, body wts, length/wt. Ratio (C.I.), histology | Enzyme induction, blood (PCV, WBC), DNA damage index, lab-based hatch rate |

CI = Condition index.
DNA = Deoxyribonucleic acid.
PCV = Packed cell volume.
WBC = White blood cell.

were included in guilds where no single species is thought to exist at all areas of interest on the Hanford Site. Multiple species lists are in order of preference. Biological attributes are consistent with draft guidelines proposed by EPA for conducting field-based measurements as part of a weight-of-evidence approach for ecological assessments. Specific considerations for species and the biological metrics are being summarized in a PNNL report with an expected publication date in fiscal year 2004 (B. L. Tiller, PNNL, personal communication).

## C.1 References

EPA – U.S. Environmental Protection Agency. 1998. *Guidelines for Ecological Risk Assessment*. EPA/630/R-95/002F, EPA Risk Assessment Forum, Washington, D.C.

Menzie, L., M.H. Henning, J. Lura, K. Finkelstein, J. Gentile, J. Manghan, D. Mitchell, S. Petron, B. Potocki, S. Suirsky, and P. Tyler. 1996. *Special Report on the Massachusetts Weight-of-Evidence Approach for Evaluating Ecological Risk*. Human and Ecological Risk Assessment, 2, 277-304.

WAC 173-340. *Model Toxics Control Act – Cleanup*. Washington Administrative Code, Olympia, Washington.