PNNL-11933

Survey of Radiological Contaminants in the Near-Shore Environment at the Hanford Site 100-N Reactor Area

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September 1998

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

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

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Summary

Past operations at the Hanford Site 100-N Area reactor resulted in the release of radiological contaminants to the soil column, local groundwater, and ultimately to the near-shore environment of the Columbia River. In September 1997, the Washington State Department of Health (WDOH) and the Hanford Site Surface Environmental Surveillance Project (SESP) initiated a special study of the near-shore vicinity at the Hanford Site's retired 100-N Area reactor. Environmental samples were collected and analyzed for radiological contaminants (^{3}H, ^{90}Sr, and gamma emitters), with both the WDOH and SESP analyzing a portion of the samples. Samples of river water, sediment, riverbank springs, periphyton, milfoil, flying insects, clam shells, and reed canary grass were collected. External exposure rates were also measured for the near-shore environment in the vicinity of the 100-N Area. In addition, samples were collected at background locations above Vernita Bridge.

River water samples were collected from five sites that bracketed the ^{90}Sr groundwater plume. Both ^{3}H and ^{90}Sr were measured above background concentrations for the 100-N Area near-shore river water samples, with the highest ^{3}H concentrations measured at the farthest downstream location and the highest ^{90}Sr concentration measured near the center of the ^{90}Sr groundwater plume. Transect samples of near-shore water showed that ^{3}H and ^{90}Sr concentrations were rapidly diluted by the river. Riverbank spring water contained detectable amounts of ^{3}H and ^{90}Sr. Concentrations of gamma emitters were below levels of detections for both river water and riverbank spring water. Sediment samples collected near the 100-N Area shoreline had detectable concentrations of ^{60}Co, ^{90}Sr, and ^{137}Cs; however, ^{60}Co and ^{90}Sr were the only radionuclides with concentrations above background. Some biota samples collected at the 100-N Area shoreline had concentrations of ^{60}Co and ^{137}Cs above background. In general, the biota results mirrored the localized river water and river sediment concentrations. External exposure rates measured along the shoreline in the vicinity of the 100-N Area ranged from 2 to 14 μR/h, with the highest rates found along the shoreline nearest to the 1301-N and 1325-N liquid waste disposal facilities. The results from this study were used to estimate potential human doses resulting from recreational activity near the 100-N Area shoreline. The estimated doses are small and not expected to be harmful to people engaged in these activities. All estimated doses to aquatic biota were below 1 rad/day.

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1.0 Introduction and Historical Perspective

Radiological contamination of the near-shore vicinity at the Hanford Site's retired 100-N Reactor Area is of considerable public and regulatory interest because of potential contribution to dose to the offsite public and to ecological receptors from residual radioactive materials. The 100-N Area, shown in Figure 1.1, is located in the northern part of the Hanford Site adjacent to the Columbia River in eastern Washington State. The 100-N Reactor operated from 1963 to 1987 to produce materials for nuclear weapons and steam for electric power generation. 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 (from 1963 to 1985) and 1325-N (from 1985 to 1991) Liquid Waste Disposal Facilities (LWDFs), located 250 m and 700 m from the Columbia River (Dirkes and Hanf 1998). Both LWDFs were concrete basins with unlined extension trenches that were covered with concrete pads. The LWDFs received approximately 3,800 liters/minute of contaminated water during reactor operations.

These past effluent streams resulted in the release of radionuclides to the vadose zone, saturated sediments, and groundwater beneath the facilities, and ultimately to the nearby Columbia River. Strontium-90 (^{90}Sr), a beta emitter, is the primary contaminant of concern for 100-N Area groundwater because of its 29-year half-life, large source term, mobility in groundwater, and dosimetric parameters. Because of groundwater migration toward the Columbia River, ^{90}Sr is also the primary radiological contaminant of concern in the near-shore environment.

Other important contaminants include tritium (^{3}H), cobalt-60 (^{60}Co), and cesium-137 (^{137}Cs). Tritium, a weakly energetic beta emitter with a 12-year half-life, is also found at elevated concentrations in groundwater and the near-shore environment. Gamma emitters such as ^{60}Co and ^{137}Cs are found at high concentrations in soil near the LWDFs, but typically are not detectable in either 100-N Area groundwater or the near-shore environment (Hartman and Dresel 1998).

Historically, the large volume of effluents directed to the LWDFs resulted in groundwater mounding (i.e., localized elevation of the water table), which in turn resulted in liquid discharge to the Columbia River in the form of riverbank springs and groundwater upwelling (Dirkes 1990). During reactor operations, the springs were very active. However, discharge to the LWDFs ceased in 1991, resulting in a dramatic decrease in the number of riverbank springs (Dirkes and Hanf 1997). Although decreased in number and flow rate, riverbank springs and groundwater upwelling continue to discharge a relatively small amount of contamination to the shoreline and river. For example, groundwater flow models estimate that presently between 0.1 and 0.2 curies (Ci) per year of ^{90}Sr enter the Columbia River from the 100-N Area shoreline (DOE 1996; Hartman and Dresel 1998; Knepp et al. 1995). Based on ^{90}Sr background concentrations in the Columbia River and annual average Columbia River flow rates (Dirkes and Hanf 1998), an additional 15 Ci entered the same region of the river from non-Hanford related sources in 1997. This additional strontium is primarily the result of fallout from past atmospheric testing of nuclear weapons (Jaquish 1993). Thus, current models estimate that contaminated 100-N Area shoreline springs and groundwater contribute approximately 1% of the total ^{90}Sr loading to the Hanford Reach of the Columbia River.

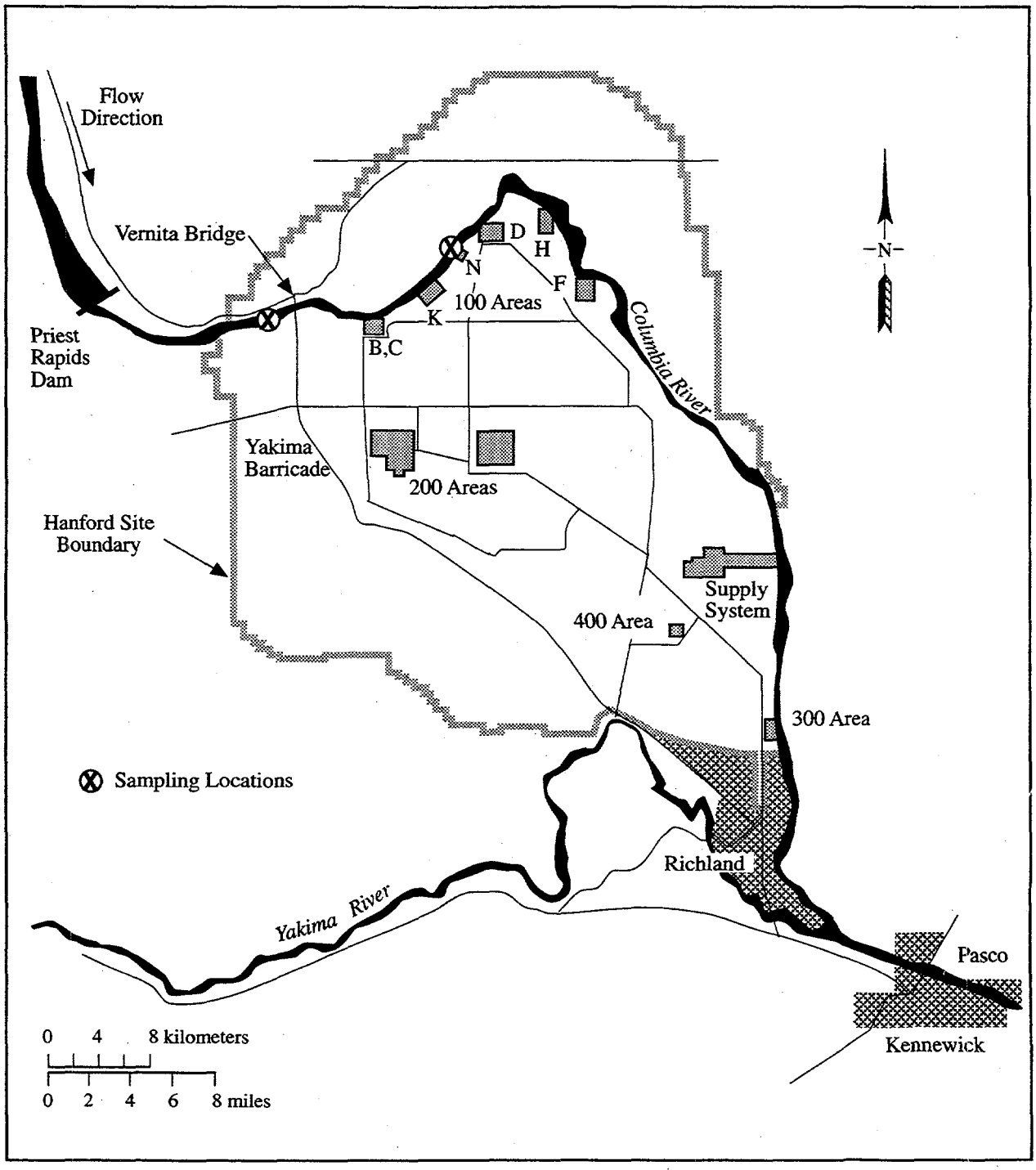

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Figure 1.1. The Hanford Site and Surrounding Area, Showing Locations of the Study Area at the 100-N Area and the Background Control Area Near Vernita Bridge

The migration of contaminated groundwater to the Columbia River may impact offsite humans and biota. Public access to the 100-N Area shoreline is currently restricted. However, fishermen and boaters use the stretch of river adjacent to the 100-N Area. It is possible that individuals may be exposed to contaminants that have migrated through groundwater to the vicinity of the 100-N Area shoreline. Since the primary contaminants of concern along the shoreline are ^{90}Sr and ^{3}H, both beta emitters, the primary exposure pathway to recreational users is from ingestion of contaminated media, resulting in internal exposure.

External exposure to gamma radiation along the 100-N Area shoreline and the adjacent Columbia River is also possible. The gamma radiation originates from ^{60}Co and ^{137}Cs in contaminated near-surface soils located inland at the LWDFs. Some of the gamma radiation emitted from these isotopes are scattered by atoms in the atmosphere and redirected back toward earth (referred to as skyshine), allowing for possible exposure to individuals using the river (Brown and Perkins 1991; Thatcher 1995).

Plants and animals of the 100-N Area near-shore environment are part of a complex ecosystem. The base of the aquatic ecosystem is periphyton. Periphyton consists primarily of microflora attached to submerged rocks where sufficient current and light exist. Caddisfly larvae and other aquatic insects live in and feed on periphyton. These aquatic insects may be consumed incidentally by fish (e.g., suckers, whitefish) as they feed on periphyton, or selectively by predatory fish (e.g., sculpin, steelhead, salmon, and bass). Adult caddisfly and other aquatic insects emerge from the water to live briefly in the terrestrial shoreline environment. Peak larval insect densities are found in late fall and winter, with the major emergence of adults occurring in the spring and summer (Wolf 1976). Emergent aquatic insects may be consumed by birds (e.g., swallows, swifts, nighthawks) and bats. Several species of clams live in the Columbia River; the Asiatic clam is the most common species found near the 100-N Area in recent years. Other bottom-dwelling organisms at the 100-N Area include limpets, snails, sponges, and crayfish.

Submergent aquatic plants are dominated by milfoil, an exotic grass-like plant growing near the bottom of shallow parts of the river. Aquatic plants are consumed by some species of fish and waterfowl. Reed canary grass, another exotic species, is common to the terrestrial shoreline; however, other riparian grasses (e.g., rushes and sedges) also occur in the 100-N Area. Numerous animal species (e.g., Canada geese, cottontail rabbits, and mule deer) graze on shoreline grasses.

Each species that frequents the near-shore is a potential receptor of radiological contaminants from the 100-N Area. As such, they may be impacted by exposure to contaminants and also serve as a vector of exposure to other organisms found in the food web. Certain fish and birds (waterfowl) may also contribute to human exposure via the food chain pathway.

Section 2.0 presents the objective of this study, and Section 3.0 presents a detailed description of the sample collection process. Analytical results are discussed in Section 4.0 and tabulated in Appendix A. Sections 5.0 and 6.0 present human and ecological dose assessments based on the sampling results. The conclusions of this study are presented in Section 7.0

2.0 Objective

The objective of this study was to evaluate the extent of radiological contamination in the 100-N Area near-shore environment and assess the potential impact on ecological receptors and people that may visit this part of the Hanford Site boundary. Additional objectives were to provide data to assess impacts to individuals with specific lifestyles not addressed here, to help determine the fate of ^{90}Sr discharged to the Columbia River, and to evaluate models that predict groundwater discharge and contamination flux to the Columbia River.

A reasonable body of current and historical information exists on the concentrations of radionuclides in the 100-N Area groundwater, 100-N riverbank springs, and Columbia River water collected between 10 and 50 m from the 100-N Area shoreline (Hartman and Dresel 1998; Dirkes and Hanf 1997; Johnson et al. 1996). However, data were needed to determine radionuclide concentrations in near-shore river water. Near-shore is defined for this study as the area from several meters above the high water line to a depth in the river where an adult human could reasonably wade, approximately 1.5 m. In addition, limited information exists on the current concentrations of radionuclides in other environmental media present in the near-shore area. Many previous ecological studies of this area were conducted while the LWDFs were in operation, when the 100-N Area riverbank springs were more active. These facilities have not been in operation for the past six years. The radiological character of the 100-N Area shoreline vicinity is likely to be quite different today than it was a decade ago.

3.0 Sample Collection

Environmental samples were collected from the 100-N Area near-shore vicinity in 1997 to meet the aforementioned objectives through a cooperative effort between the Hanford Site Surface Environmental Surveillance Project (SESP)[1] and the Washington State Department of Health's Division of Radiation Protection (WDOH). The following samples were collected as available: near-shore river water, river-bank spring water, river sediment, periphyton, milfoil, reed canary grass, caddisfly, clam shells, and fish. The relative locations of the sample media, which represented the predominant media available during the sampling period, are shown in Figures 3.1a and 3.1b. All samples were analyzed for ^{90}Sr and gamma emitters, and selected samples were analyzed for ^{3}H (see Appendix A).

In addition, background samples of periphyton, milfoil, reed canary grass, clam shells, and caddisfly were collected at control stations located upstream of the Hanford Site reactors above Vernita Bridge. The background sampling locations are shown in Figure 1.1. Background data for river water, fish, and sediment were taken from the Hanford Site's routine environmental surveillance database. This study also measured near-shore and offshore external radiation levels. Other samples, such as routine river transects and near-shore well monitoring, were also considered for comparison purposes in this study.

Five sampling locations were selected along the shoreline adjacent to the 100-N Area, labeled as Sites 1 - 5 in Figure 3.2 (see Appendix B). Several important features of the 100-N Area, such as the 100-N reactor building, the LWDFs, near-shore groundwater monitoring wells, and the ^{90}Sr groundwater plume are also shown. The sample locations were chosen to span the length of shoreline where the ^{90}Sr groundwater plume intersects the Columbia River (Hartman and Dresel 1998), and to encompass the historical locations of riverbank springs (DOE/RL-92-12).

Site 1 is upstream of the ^{90}Sr plume, just outside the 8 pCi/L contour line for ^{90}Sr in groundwater. Site 2 lies between the 8 and 100 pCi/L ^{90}Sr contours. Sites 3 and 4 are within the 1,000 pCi/L ^{90}Sr contour, and Site 5 lies just downstream and outside the 8 pCi/L ^{90}Sr contour. Site 1, farthest upstream, is adjacent to the stack at the 100-N Area reactor. Site 2 is located downstream of Site 1 near well 199-N-96A. Site 3 is located adjacent to groundwater monitoring well 199-N-46, which has the highest ^{90}Sr concentrations in 100-N Area groundwater. In addition, a riverbank spring was observed flowing in this area. Site 3 was chosen as the location most likely to have the highest concentrations of ^{90}Sr entering the Columbia River. Site 4 is located near well 199-N-99A. Site 5 is located farthest downstream, near groundwater well 199-N-92A.

3.1 Columbia River Water Samples

Obtaining representative samples of Columbia River water near the shoreline is difficult. Sampling is complicated by large daily fluctuations in the volume of water released by Priest Rapids Dam upstream of

[1] Conducted by Pacific Northwest National Laboratory for the U.S. Department of Energy.

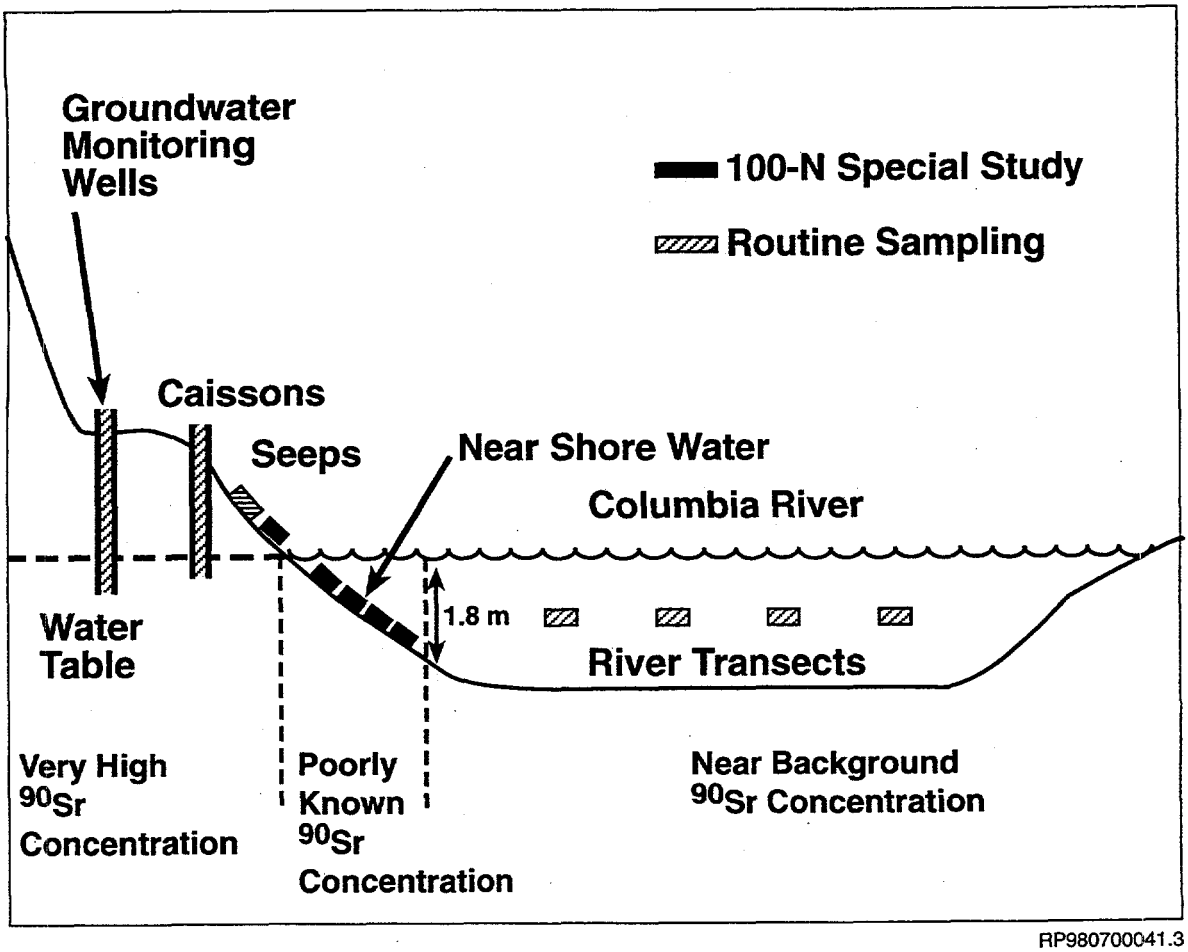

Figure 3.1a. Schematic Cross Section of the Near-Shore Environment in the Vicinity of the 100-N Area, Showing Sampling Locations for Groundwater, Riverbank Spring Water, and Columbia River Water. The solid boxes are samples collected for this special study; the dashed boxes are samples collected in routine sampling by other programs.

the site, which in turn leads to large fluctuations in the height of the water line along the shore. During times of high water, river water flows into the riverbanks (bank storage). Bank storage water may become contaminated as radionuclides desorb from the contaminated soil and by mixing with contaminated groundwater, thus contaminating near-shore river water as bank storage water returns to the river during times of low water. This process has been verified by measuring conductivity, which significantly differs for groundwater and river water. Past studies have shown that periods of low water are best for detecting the maximum concentrations of contaminants entering the river (Peterson and Johnson 1992). Historically, the Columbia River has the lowest monthly average flow in September or October. Hence, the water samples were collected at low river stage on September 8, 1997, at a time when groundwater was assumed to be flowing into the river.

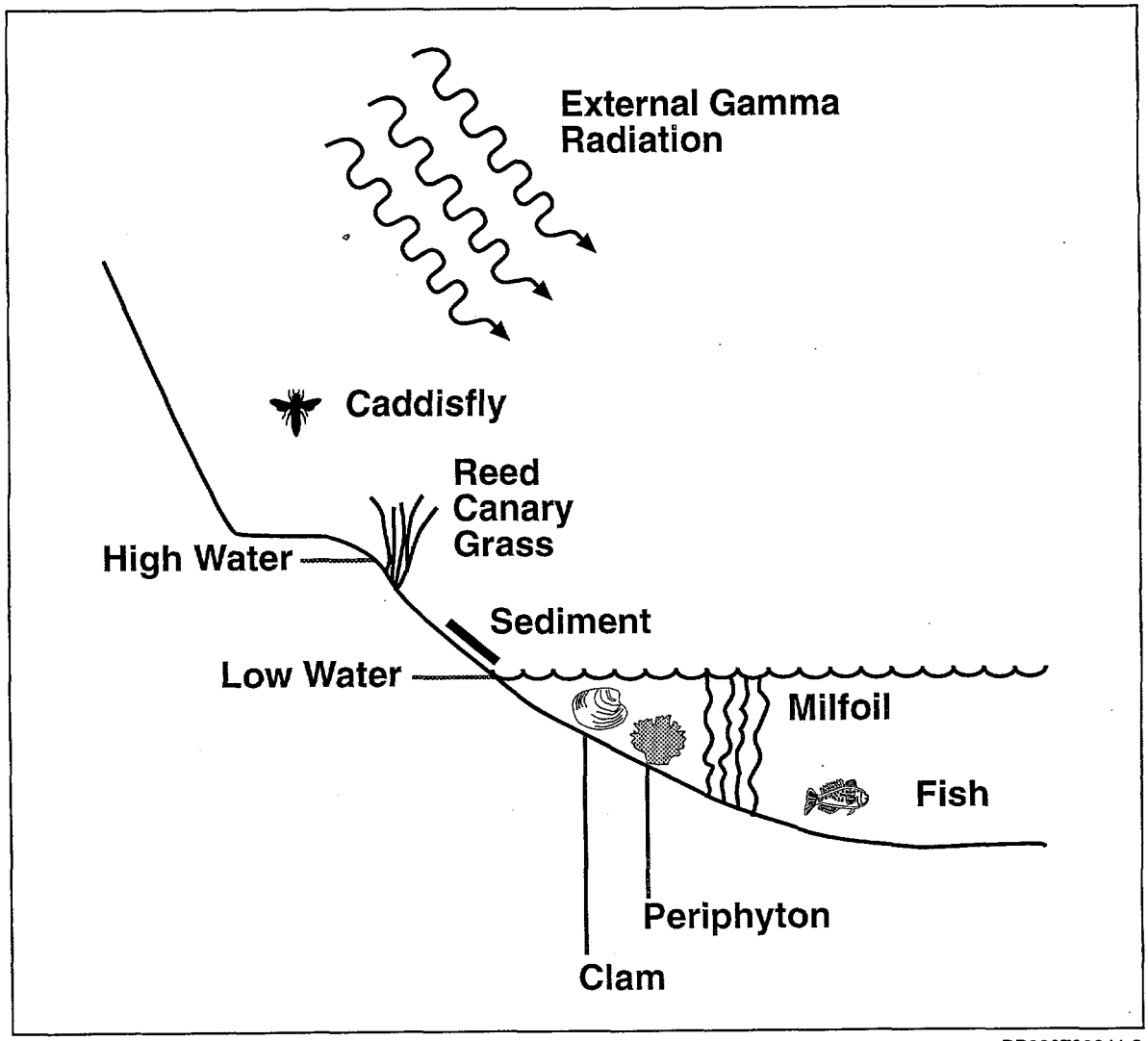

Figure 3.1b. Schematic Cross Section of the Near-Shore Environment in the Vicinity of the 100-N Area, Showing Sampling Locations for Biota, Sediment, and External Radiation

Columbia River water was collected near the shoreline at all five sampling sites. In addition, Sites 2, 3, and 5 were used to establish near-shore transects, consisting of four sampling stations set up perpendicular to the shore at increasing river water depth, labeled as stations 'a' - 'd'. The first of the transect stations at each site, 'a', was collected 1 m from the shoreline, typically at a water depth of 30 cm. The farthest station from the shoreline ('d') was collected at a location where the water was from 1.5 to 2 m deep. The distance from shore of this last station varied at each site depending on the slope of the river bottom. The geographic positions of the sampling locations were documented using a geographic positioning system. A boat was used for some of the water sample collection.

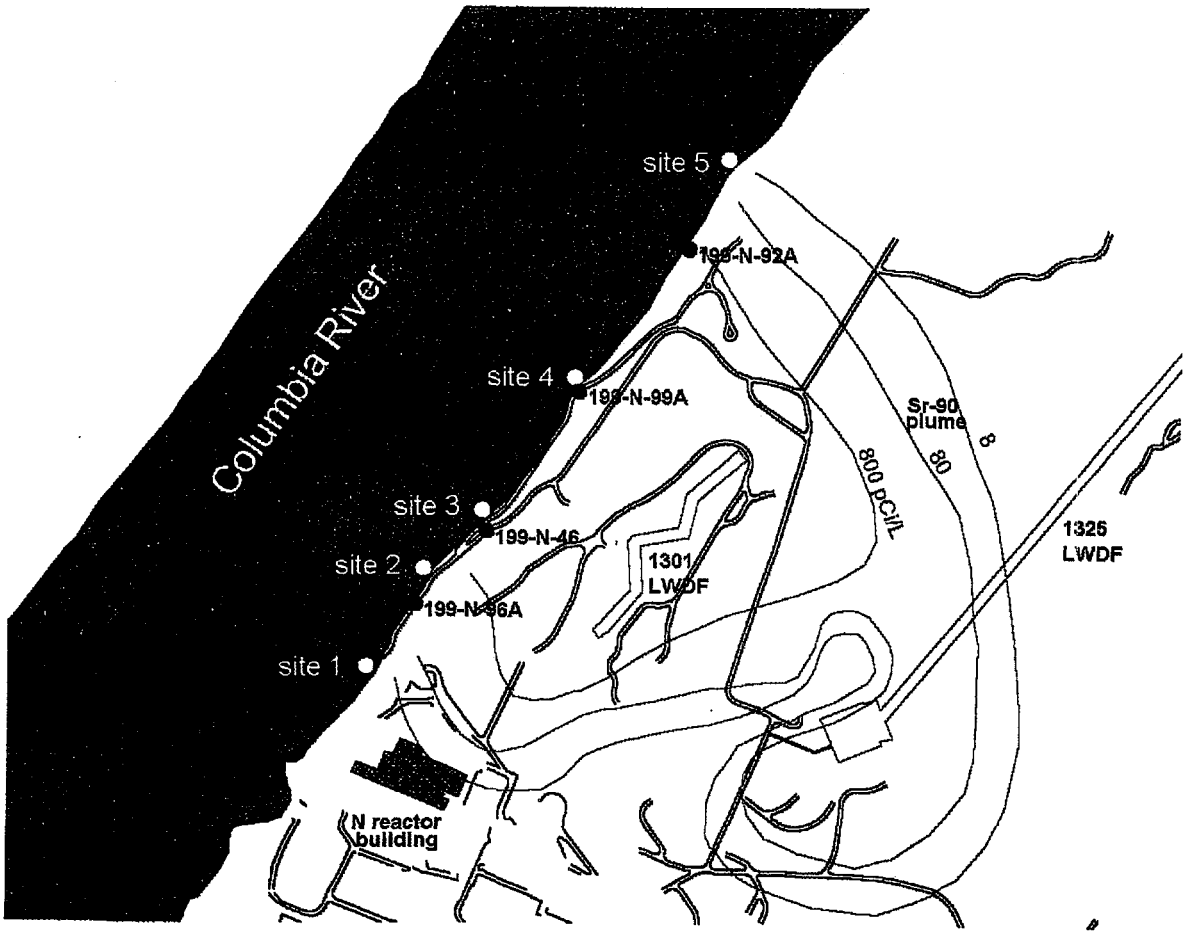

Figure 3.2. Location of the Five Sampling Sites Along the Shoreline in the Vicinity of the 100-N Area. Also shown are the 100-N reactor building, the 1301 and 1325 liquid waste disposal facilities, near-shore groundwater monitoring wells, the estimated concentration contours of the ^{90}Sr groundwater plume, and major roads in the area.

Additional river water samples were collected at station 3a on October 29, 1997, March 30, 1998, June 11, 1998, and July 20, 1998. These additional samples were collected to investigate the concentrations of radionuclides at various river stages. Station 3a was chosen for these additional samples because of its proximity to well 199-N-46, which typically has a high concentration of ^{90}Sr, and its proximity to a riverbank spring. By the October 1997 sampling, the river had been low for seven weeks. Thus, it is

assumed that bank storage effects were at a minimum, and contaminated groundwater flow into the river would be maximized. The initial sampling date, September 8, was at the beginning of the period of low water.

For the 1998 samples, the river level had been consistently higher than during the 1997 sampling periods. Average daily flow rates of the Columbia River at Priest Rapids Dam during the sampling periods are shown in Table 3.1 to provide a general indication of river stage on the sampling dates. Visual inspection of the 100-N Area shoreline confirmed that water levels were higher than at the September and October 1997 dates. The spring at sampling site 3a was no longer visible, and if it still existed, was underwater. The purpose of this additional river sampling was to estimate the range of contaminant concentrations in near-shore river water.

All river water samples were unfiltered water collected near the river bottom. Tygon tubing was positioned 15 cm from the bottom of a rod. The end of the rod was placed on the river bottom, and water was pumped through the tubing. Water samples were collected in plastic containers.

The SESP collected routine 100-N Area transect samples on August 22, 1997 (Dirkes and Hanf 1998). Samples were collected perpendicular to Site 5 at four locations ranging from approximately 10 m from the Hanford shoreline to mid-river. Routine transect water samples are collected at mid-depth of the river (Figure 3.1a). The 100-N Area transect samples were analyzed for ^{3}H, ^{90}Sr, and gamma-emitting radionuclides.

Background concentrations for radionuclides in river water were obtained from the SESP routine river transect program at Vernita Bridge (four stations collected on August 22, 1997) and monthly composite water sample studies collected at Priest Rapids Dam, both located upstream of the Hanford Site reactors (Dirkes and Hanf 1998).

3.2 Riverbank Spring Samples

On September 9, 1997, a riverbank spring with a low discharge rate was found along the 100-N Area shoreline near Site 3, in the vicinity of groundwater well 199-N-46. No other springs were visible in the sampling area at that time. On November 3, 1997 the SESP sampled the riverbank spring near Site 3 and at another riverbank spring located between Sites 4 and 5. Neither spring was visible during the 1998 sampling periods. All riverbank spring samples (unfiltered water) were collected in plastic bottles using either a ladle or small hand pump.

3.3 Sediment Samples

Historically, sediment is difficult to collect at the 100-N Area shoreline because the near-shore area is mostly cobble. However, three sediment samples were collected from depressions under large rocks at Sites 1, 3, and 5. The rocks were located on the shoreline in an area that would be underwater during

Table 3.1. Columbia River Flow at Priest Rapids Dam During Sample Collection Periods[a] (sample collection dates are in bold)

Date	Daily Average Flow (ft^3/sec)	Type of Water Sample
19-Aug-97	159000	
20-Aug-97	179000	
21-Aug-97	182000	
22-Aug-97	**164000**	SESP Routine Transect (100-N and Vernita Bridge)
05-Sep-97	109000	
06-Sep-97	103000	
07-Sep-97	69200	
08-Sep-97	**103000**	WDOH/SESP 100-N Near-Shore Water and Spring Sample (all stations)
26-Oct-97	94000	
27-Oct-97	94600	
28-Oct-97	100000	
29-Oct-97	**106000**	WDOH/SESP 100-N Near-Shore Water at Station 3a
31-Oct-97	82500	
01-Nov-97	80600	
02-Nov-97	87400	
03-Nov-97	**105000**	SESP Routine Spring Samples at Station 3a and Between Stations 4 and 5
27-Mar-98	144000	
28-Mar-98	121000	
29-Mar-98	101000	
30-Mar-98	**135000**	WDOH/SESP 100-N Near-Shore Water at Station 3a
08-Jun-98	218000	
09-Jun-98	208000	
10-Jun-98	176000	
11-Jun-98	**197000**	WDOH 100-N Near-Shore Water at Station 3a
17-Jul-98	168000	
18-Jul-98	137000	
19-Jul-98	122000	
20-Jul-98	**137000**	WDOH 100-N Near-Shore Water at Station 3a

(a) 1997 flow data are from Bisping 1998 and 1998 flow data are from Columbia River DART (Data Access in Real Time) http://www.cqs.washington.edn/dart/dart.html.

periods of high water, but were exposed during low water. No sediment was found at either Site 2 or Site 4. Sediment samples were placed into doubled plastic bags using stainless steel or nylon scoops.

3.4 Biota Samples

Fish were collected in the 100-N Area near shore vicinity on September 11, 1998 using a boat-mounted electroshocker. Sculpin were collected and liver samples were taken for metals analysis (Dirkes and Hanf 1998), and whole body samples (minus the livers) were analyzed for radionuclides. Sculpin have a reduced home range relative to larger species such as bass or carp. Sculpin are an ideal monitoring species because they are more likely to be exposed for greater periods of time in a given area of concern. Because sculpin are small, numerous sculpin must be combined to provide sufficient material for analysis.

Clam shells and milfoil (Sites 1 and 5) and adult caddisfly (Sites 3 and 5) samples were collected at two of the sampling sites, as well as at a background site upstream of Vernita Bridge. Clam shells were collected because live clams were not found on the exposed bottom. These biota were not available at the other 100-N Area stations. The clam shells were typically found between zero and 1 m depth of water. It is not known if these shells permanently resided in the 100-N Area shoreline vicinity or if they were deposited in the area by the river current. Milfoil was collected by hand from the river several meters from shore and placed into plastic bags. Adult caddisfly were collected at night with a light trap located on the shoreline. The insects fall into an isopropyl alcohol solution placed in a glass jar at the bottom of the light trap.

Periphyton and reed canary grass were collected from Sites 1, 3, and 5 and at a background site near Vernita Bridge. Reed canary grass was abundant on land above the high-water line. Reed canary grass was pulled by hand or cut with a knife and placed into plastic bags. Periphyton was found growing on submerged rocks located on the river bottom in about 1.5 to 2 m depth of water. There was no periphyton found on rocks in shallower water. Periphyton was scraped from cobble into doubled plastic bags.

3.5 External Radiation Measurement

External radiation exposure measurements were taken along the 100-N Area shoreline using an RSS-112 Rueter Stokes pressurized ionization chamber (PIC). The PIC was placed on a tripod and secured on the back of a jet boat with the detector approximately 1-2 m above the water's surface. The PIC logged exposure data every 5 seconds.

A Trimble Pro-XL geographic positioning system (GPS) was connected to the PIC. The GPS logged boat positions at 1-second intervals with an accuracy of 0.5 m. Data from the PIC were transferred in real time and logged with the GPS datalogger. Data from the PIC and GPS were synchronized using the time tags supplied by both units.

The jet boat was driven at slow speeds (to allow for the 5-second PIC integration period) around the study area. Positional and exposure data were plotted onto a basemap of the near-shore river in the vicinity of the 100-N Area. Color plots indicating various exposure intensity were produced.

3.6 Quality Assurance/Quality Control

Samples were collected according to the SESP Procedures Manual (PNL MA-580). All samples were issued unique sample numbers and chain of custody was documented on field record forms. Field notes were documented in permanently bound notebooks, and photocopies of notebook pages were placed into the SESP project files.

Analysis of the samples was divided between the WDOH and the SESP. At some locations, WDOH and the SESP separately collected and analyzed the same media for quality assurance purposes (see Appendix A). The SESP radionuclide samples were analyzed by Quanterra Environmental Services, Richland, Washington. The WDOH samples were analyzed by the Washington State Public Health Laboratory in Seattle, Washington. Both the SESP and WDOH operate under rigorous quality assurance programs that include quality control elements to ensure analytical proficiency and accuracy. Both laboratories' quality control programs include analysis of samples distributed by the federal government's quality assurance programs; split samples distributed on a smaller scale between cooperating federal, state, and private laboratories; and internal procedures relating to the counting facilities and analytical techniques (Dirkes and Hanf 1998). The quality assurance programs ensure that sample collection, sample transport, data entry, and analyses were performed in accordance with documented procedures.

4.0 Sample Results

Radionuclide concentration results for near-shore river water, sediment, clam shells, milfoil, periphyton, caddisfly, and reed canary grass are shown graphically in Figures 4.1-4.5 as a function of sampling site. External radiation exposure rates are shown in Figure 4.6. In Figures 4.1-4.5, the solid squares represent samples analyzed by WDOH, and the open triangles represent samples analyzed by the SESP. The sampling locations are shown in Figure 3.2. Where samples from the same location were analyzed by both the SESP and WDOH, the data in the graphs are shown slightly offset from each other. Fish and riverbank spring water results are not shown graphically because there are only a few samples. All results are tabulated in Appendix A.

Data are shown in the figures along with the two-standard deviation total propagated uncertainty, resulting from statistical counting uncertainty and estimated systematic uncertainty. In some cases, the uncertainty is smaller than the size of the graphical data point, and is thus not shown. When data are discussed in the text, uncertainties are not stated, but their values can be found in Appendix A.

4.1 Water

4.1.1 Routine SESP Columbia River Transects

To compare contaminant concentrations in bulk Columbia River water with near-shore water from the vicinity of the 100-N Area, the August 1997 SESP transect sampling results for the 100-N Area and the Vernita Bridge locations (Dirkes and Hanf 1998) are discussed here. The August 22, 1997 transect water samples from the vicinity of the 100-N Area and the Vernita Bridge background location had detectable concentrations of ^{3}H and ^{90}Sr in all samples. Average ^{3}H concentrations near the 100-N Area (30 pCi/L) were statistically higher than samples collected near Vernita Bridge (25 pCi/L). At the 100-N Area sampling location there was a slight concentration gradient for ^{3}H, and the near-shore sample was elevated by approximately 10% compared to mid-river samples. Average ^{90}Sr concentrations were not statistically different between 100-N Area and Vernita Bridge sampling areas, with mean concentrations of approximately 0.1 pCi/L at both locations. However, a concentration gradient for ^{90}Sr was observed at the 100-N Area location with the near-shore sample (0.16 pCi/L) elevated compared to the mid-river sample result (0.092 pCi/L).

4.1.2 Near-Shore Columbia River Water

The results for radionuclide concentrations found in 100-N Area near-shore Columbia River water are shown in Figure 4.1. Radionuclide concentrations for ^{137}Cs and ^{60}Co were at less-than-detectable levels at the near-shore vicinity of the 100-N Area and the SESP background location (labeled as site 'bg') near Priest Rapids Dam (Dirkes and Hanf 1998). Moreover, these radionuclides were not detected in groundwater monitoring well 199-N-46, near Site 3 when it was sampled in September 1997 (Hartman and Dresel 1998). Groundwater samples from wells 199-N-92A, 199-N-99A, and 199-N-96A are not

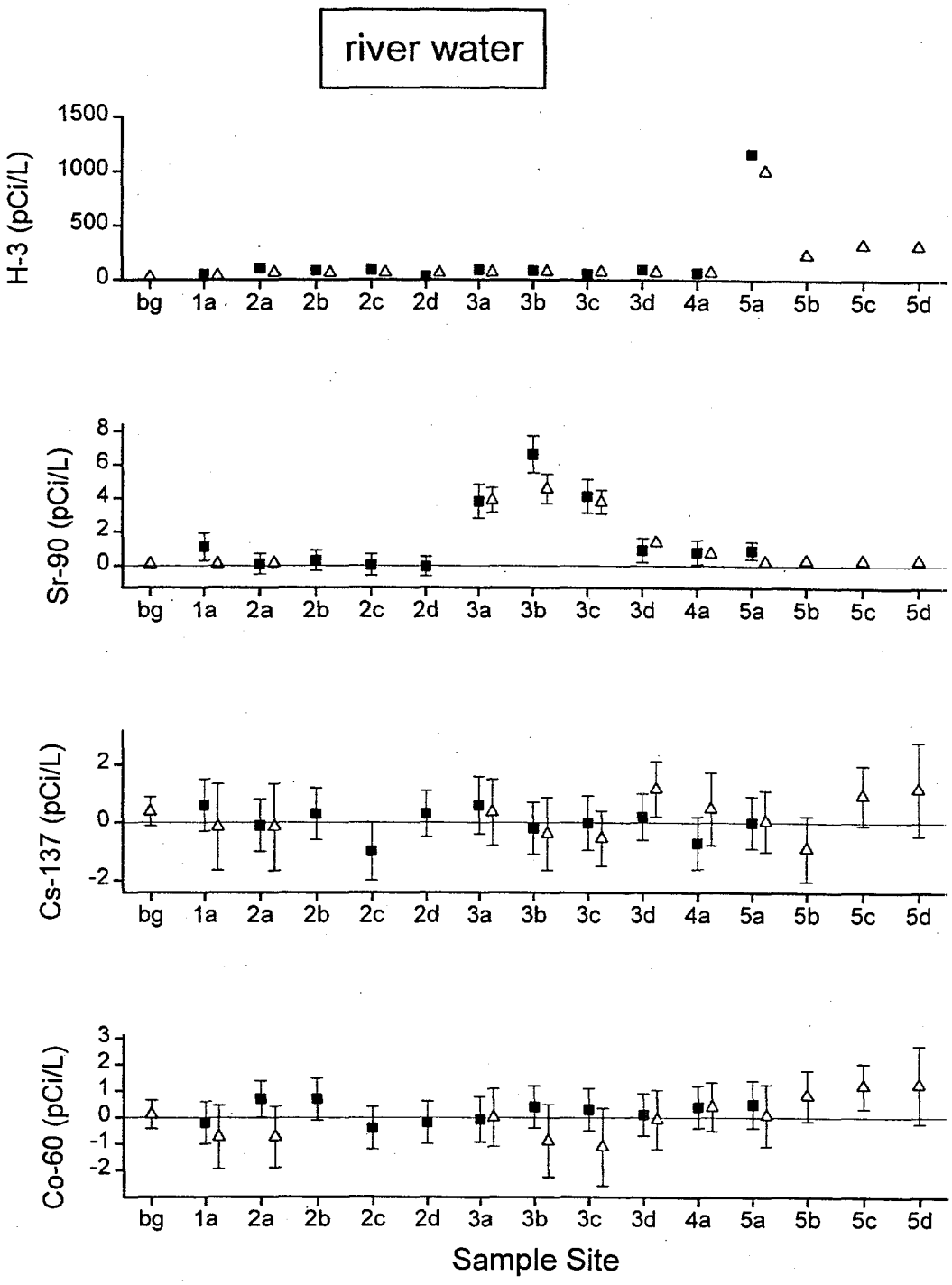

Figure 4.1. Tritium (^{3}H), ^{90}Sr, ^{137}Cs, and ^{60}Co Concentrations in Columbia River Water Collected from the Near-Shore Environment in the Vicinity of the 100-N Area on September 8, 1997. Solid symbols represent samples taken by WDOH; open symbols show samples taken by the SESP. (The sampling site locations are defined in Section 3.1 and shown in Figure 3.2.)

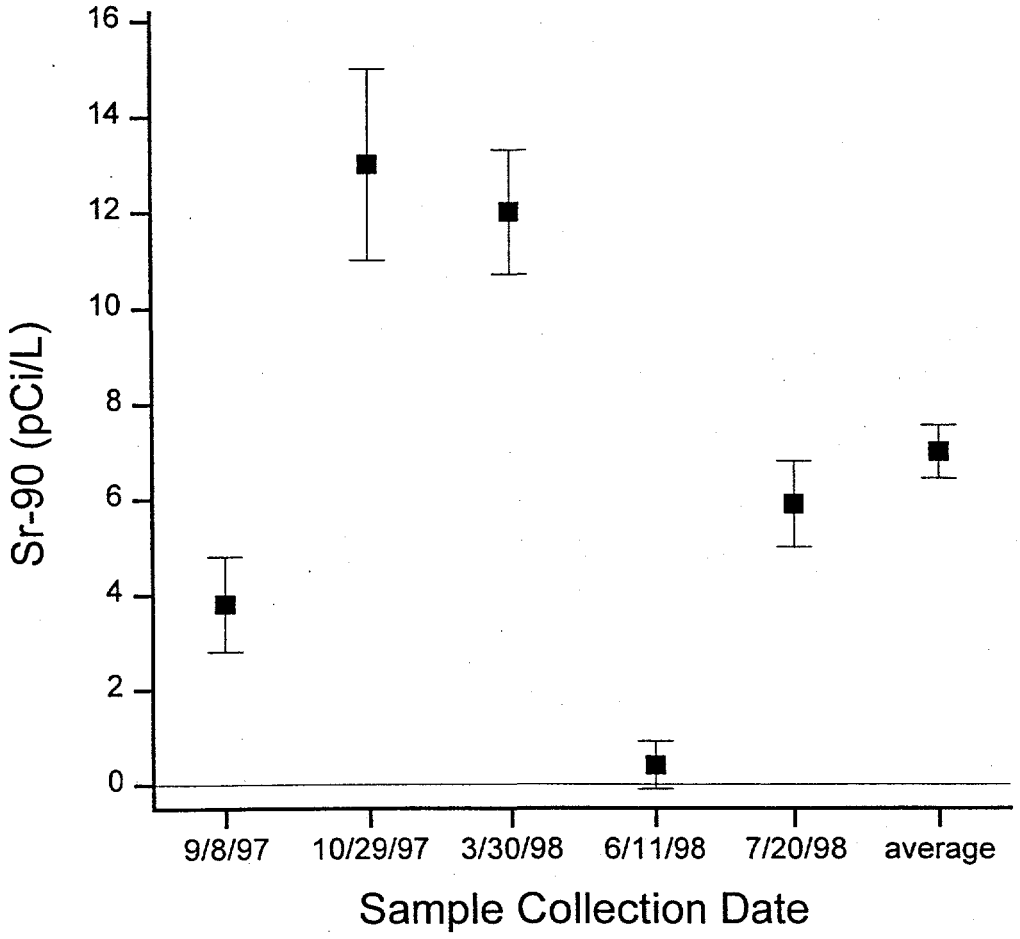

Figure 4.2. Strontium-90 Concentrations in Columbia River Water Collected at Sampling Site 3a from September 1997 to July 1998. The average of these results is also shown. Average daily river flows corresponding to the sample collection dates are shown in Table 3.1.

routinely analyzed for gamma emitters because historical results do not show their presence. Apparently, gamma-emitting contaminants are not entering the Columbia River in detectable quantities from the 100-N Area.

Tritium results at most 100-N Area near-shore sampling locations were elevated compared to the August 22, 1997 average background concentration at Vernita Bridge (25 pCi/L). Most near-shore results

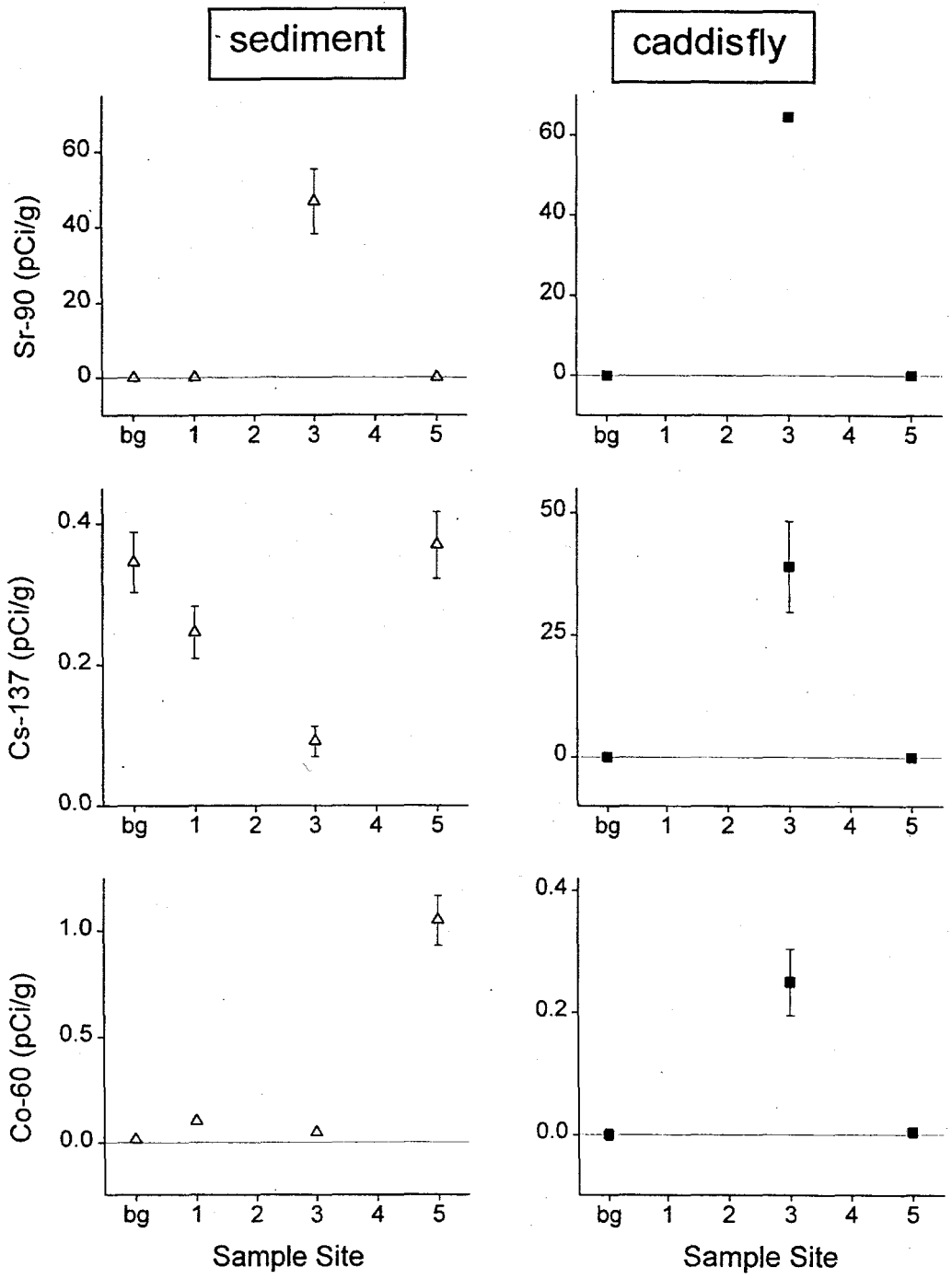

Figure 4.3. Strontium-90, ^{137}Cs, and ^{60}Co Concentrations in Sediment and Caddisfly Samples. Site bg is the background sample site located near Vernita Bridge. (Solid symbols represent samples taken by WDOH; open symbols show samples taken by the SESP.)

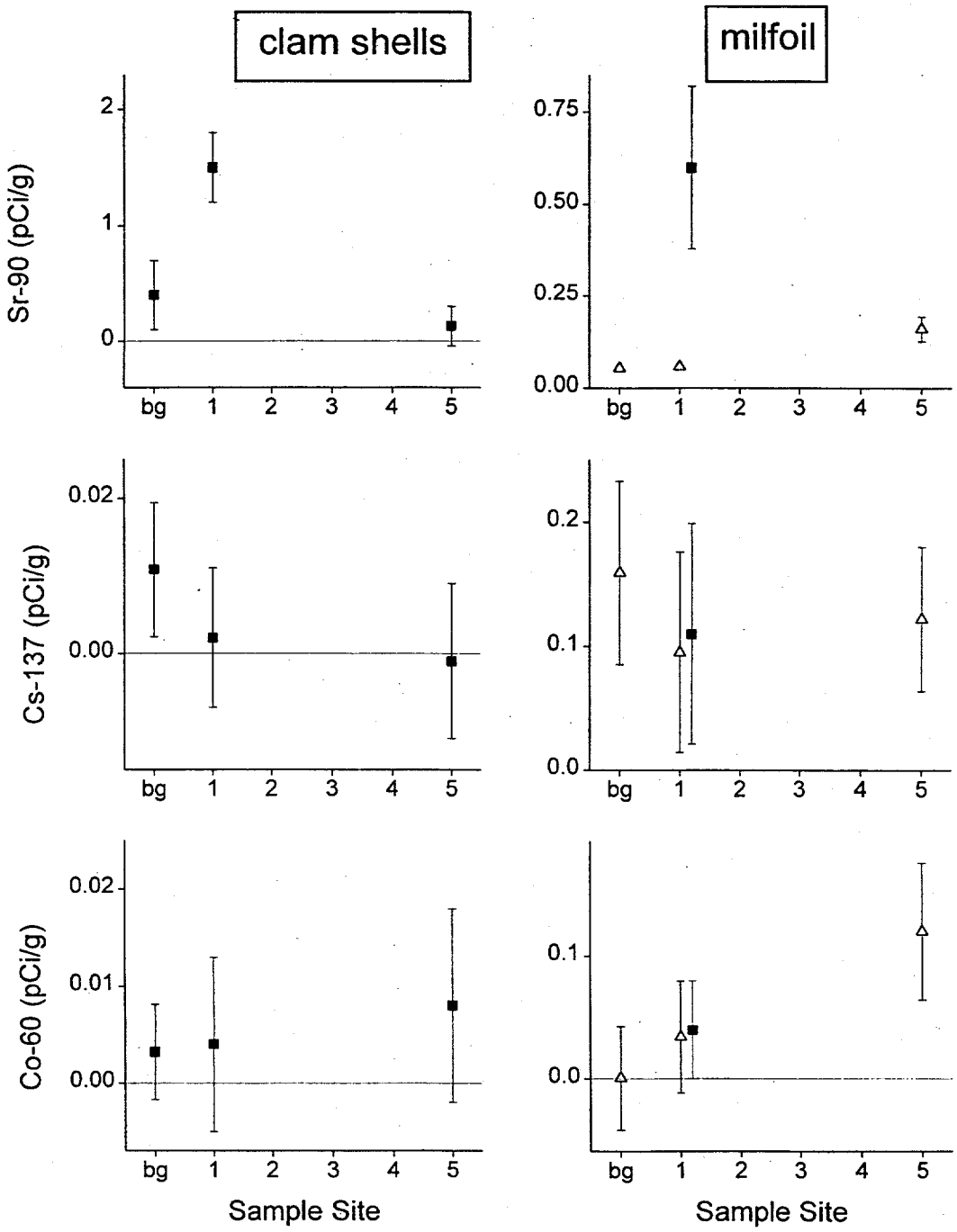

Figure 4.4. Strontium-90, ^{137}Cs, and ^{60}Co Concentrations in Clam Shell and Milfoil Samples. Site bg is the background sample site located near Vernita Bridge. (Solid symbols represent samples taken by WDOH; open symbols show samples taken by the SESP.)

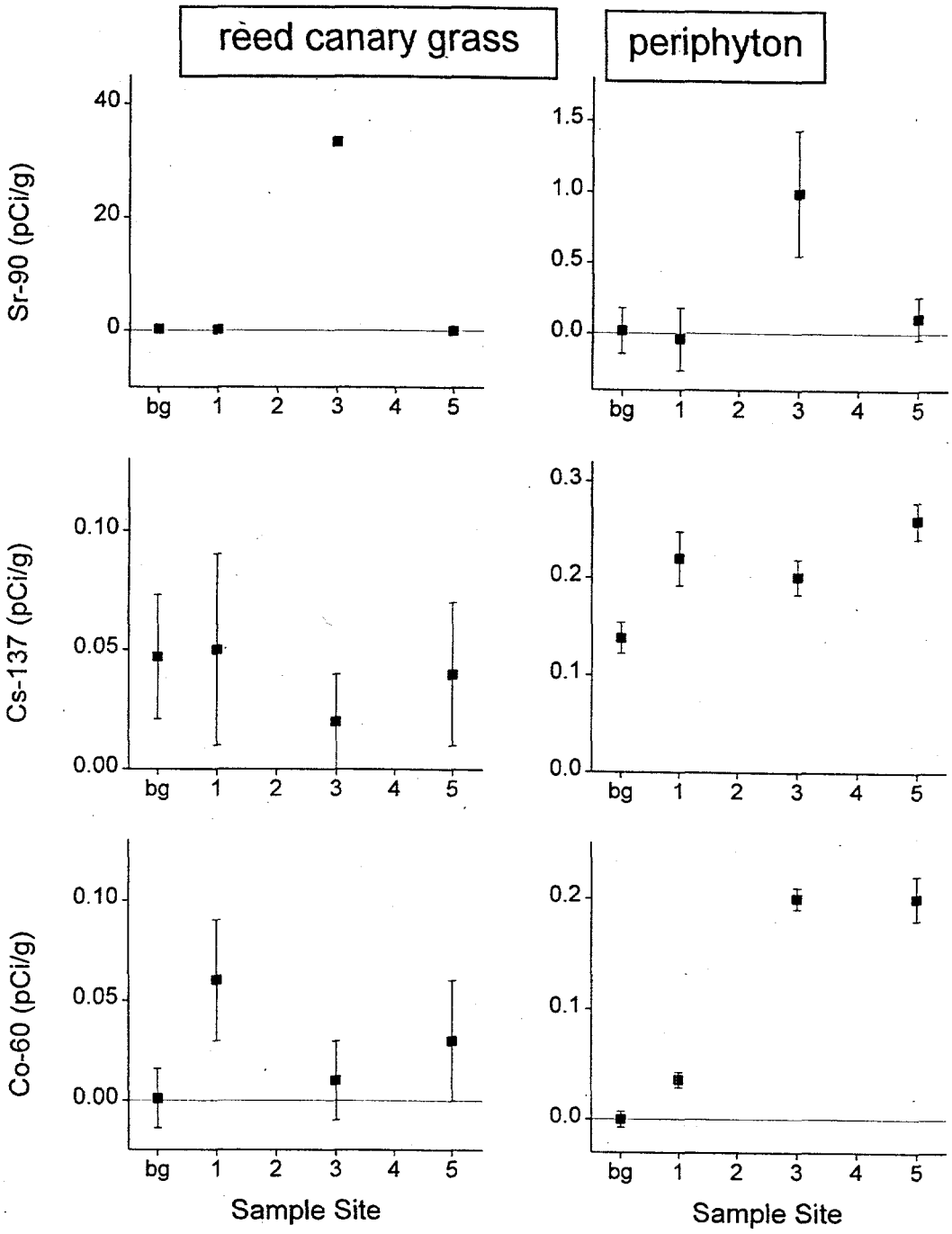

Figure 4.5. Strontium-90, ^{137}Cs, and ^{60}Co Concentrations in Reed Canary Grass and Periphyton Samples. Site bg is the background sample site located near Vernita Bridge.

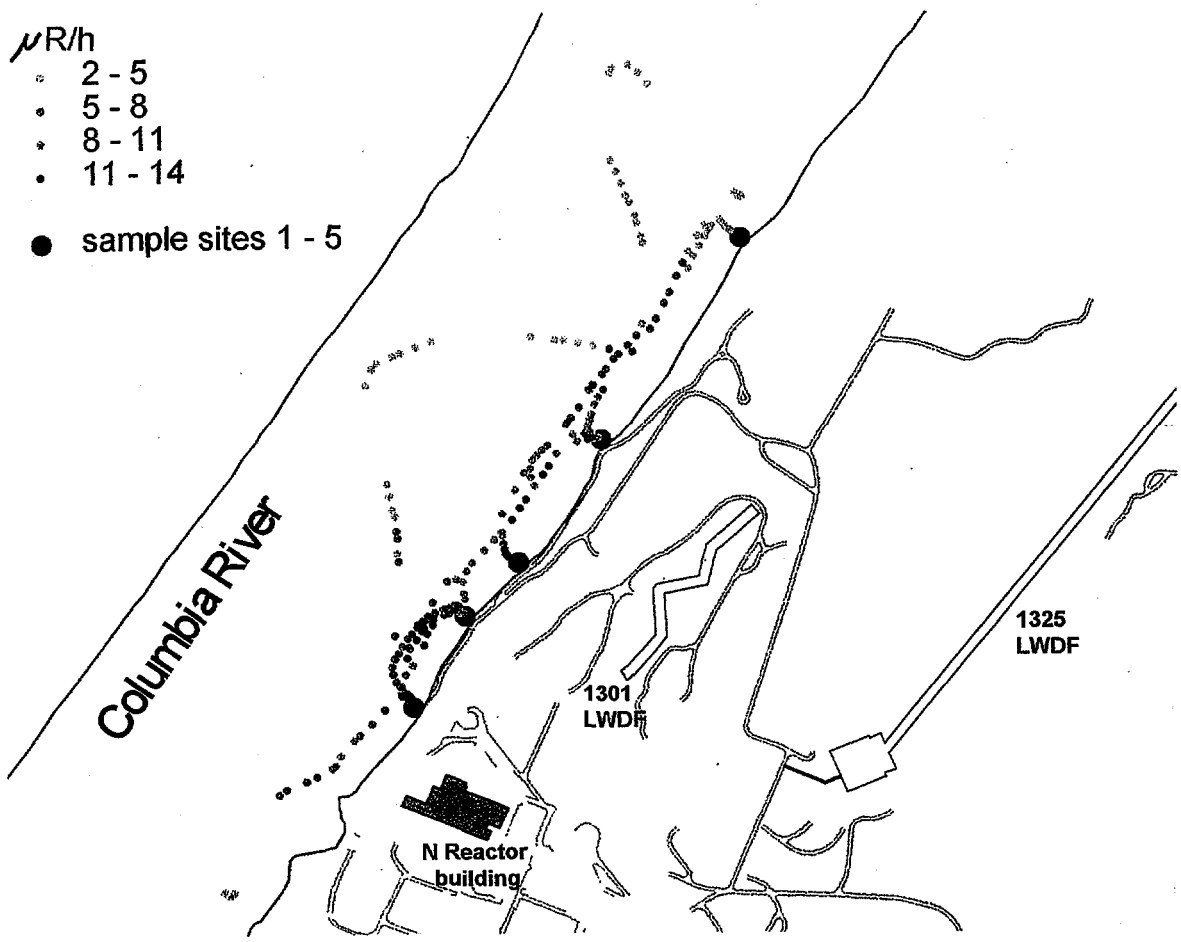

Figure 4.6. External Gamma Radiation Exposure Rates in the Vicinity of the 100-N Area Shoreline. Exposure intensities are indicated by the varying color scheme from green (less) to red (more). Also shown are the locations of the five primary sampling sites along the shoreline.

were also elevated compared to the August 22, 1997 average routine river transect concentration at the 100-N Area (30 pCi/L). The highest concentration of ^{3}H was 1,000 pCi/L, or 40 times background, found near the shoreline at Site 5.

Detection of the highest ^{3}H concentration in the river at Site 5 is consistent with September 1997 results from nearby groundwater monitoring well 199-N-92A (Hartman and Dresel 1998), which

measured groundwater ^{3}H concentrations of 19,000 pCi/L, the highest result of all the near-shoreline wells. Site 5 is just downstream of a small spit of land extending into the river, thus creating an eddy in this region. Therefore, the dilution in the river is probably not as great at this site. Tritium was not highly elevated in the river at Site 3, where nearby groundwater monitoring well 199-N-46 measured ^{3}H concentrations of 15,800 pCi/L during the same period (Hartman and Dresel 1998).

Strontium-90 results for near-shore water at Sites 1 and 2 were consistent with the August 22, 1997 average background level at Vernita Bridge (0.094 pCi/L). Strontium-90 concentrations at Site 3 (Figures 4.1 and 4.2) ranged from below detectable levels to 130 times background. This site is adjacent to shoreline groundwater well 199-N-46, which typically measures ^{90}Sr concentrations near 10,000 pCi/L. In September 1997, this well measured a ^{90}Sr concentration of 11,300 pCi/L (Hartman and Dresel 1998). Near-shore river water concentrations ranged from below detectable levels to 13 pCi/L at Site 3. These data indicate that contaminated groundwater is diluted by 3 orders of magnitude upon entering the river. Strontium-90 concentrations in near-shore water were approximately 3 to 9 times higher than background levels at Sites 4 and 5.

It would be expected that ^{90}Sr concentrations at Site 4 would be close to the levels measured at Site 3 because both locations are within the estimated 1,000 pCi/L contour of the groundwater plume. Well 199-N-99A, which is near Site 4, was not sampled during the fall of 1997. The ^{90}Sr concentrations at Sites 1, 2, and 5 were within the expected range since nearby groundwater concentrations of ^{90}Sr, measured in September 1997, were below detection limits for well 199-N-92A and only 8.6 pCi/L in well 199-N-96A (Hartman and Dresel 1998).

The highest ^{90}Sr concentration measured in near-shore water during the September 8, 1997 sampling was 6 pCi/L (solid square at station 3b in Figure 4.1). However, the concentration of ^{90}Sr in the sample collected several weeks later at station 3a was 13 pCi/L, which is more than two times the earlier value. This is a clear indication that extended periods of low river stage can result in higher concentrations of contaminated groundwater and riverbank spring water flowing into the Columbia River.

Although the ^{90}Sr plume in river water extends out to station 3c, the river bottom is very steep in this region of the shoreline so station 3c is only 3-4 m into the river from the water line. Within another few meters from shore, at station 3d, ^{90}Sr concentrations decreased by a factor of approximately 5. The data indicate that the ^{90}Sr-contaminated water entering the river is quickly diluted. This rapid dilution is also seen in the routine August 22, 1997 river transect data that did not show a statistically significant difference for ^{90}Sr concentrations between the Vernita Bridge and 100-N Area river water transect samples. The ^{3}H and ^{90}Sr plumes entering the river do not spatially coincide, which is consistent with higher concentrations of ^{3}H found in groundwater monitoring wells farther downstream.

The ^{90}Sr concentrations measured at Site 3a for the multiple sampling periods are shown in Figure 4.2. The average concentration for the five sampling periods is 7.0 ± 0.56 pCi/L. From the river flow data shown in Table 3.1, a high-river flow results in a ^{90}Sr concentration below the detection limit (approximately 0.5 pCi/L). For daily average flow rates within 20% of the long-term average flow rate (120,000 ft^3/sec), there is no correlation between ^{90}Sr concentrations and flow rate on the day of sample

collection. The relationship between ^{90}Sr concentration in near-shore river water and Columbia River flow rates is complex and not completely understood.

In 1988, while the LWDFs were still in operation, a single near-shore river water sample collected near well 199-N-46 was found to have a ^{90}Sr concentration of 6,740 pCi/L (Dirkes 1990). This result was similar to the nearby groundwater and likely the result of higher discharges of contaminated groundwater to the river during LWDF operation. In 1991, a ^{90}Sr concentration of 8.1 pCi/L was found in near-shore river water in the same area (DOE 1992). In four other river water samples collected downstream of well 199-N-46, ^{90}Sr concentrations were consistent with background. This finding is similar to that in the present study.

4.1.3 Riverbank Spring Water

The riverbank spring water collected on September 9, 1997, near Site 3 in the vicinity of well 199-N-46, was found to have ^{90}Sr and ^{3}H concentrations of 6,100 pCi/L and 14,000 pCi/L, respectively. Concentrations of ^{60}Co and ^{137}Cs were below detection limits, as expected since these radionuclides are typically not detected in 100-N Area groundwater. The SESP sampled the Site 3 riverbank spring on November 3, 1997; ^{90}Sr and ^{3}H concentrations were 9,900 pCi/L and 14,000 pCi/L, respectively (Dirkes and Hanf 1998). A riverbank spring located between Site 4 and Site 5 was sampled on November 3, 1997; ^{90}Sr and ^{3}H concentrations were 0.59 and 19,000 pCi/L, respectively (Dirkes and Hanf 1998). All other radionuclides were below detection limits for the November samples.

4.1.4 Summary of Water Results

Qualitatively, the river water, riverbank springs, and groundwater monitoring results are all consistent with respect to the spatial distribution of elevated contaminant concentrations. The highest ^{90}Sr concentrations for groundwater monitoring wells and riverbank springs were found at Site 3. The corresponding near-shore river water at Site 3 was also elevated compared to all other river water samples. In the vicinity of Sites 4 and 5, ^{90}Sr concentrations for groundwater, riverbank springs, and river water were relatively low; either below detection limits or slightly above river water background concentrations. The highest ^{3}H concentrations for river water, riverbank springs, and groundwater were all found in the vicinity of Sites 4 and 5. In the vicinity of Sites 1 and 2, ^{90}Sr and ^{3}H concentrations for river water, riverbank springs, and groundwater were all relatively low.

4.2 Sediment

Sediment samples collected near the 100-N Area had detectable concentrations of ^{60}Co, ^{90}Sr, and ^{137}Cs, as shown in Figure 4.3. Cobalt-60 and ^{90}Sr were the only radionuclides with elevated concentrations near the 100-N Area compared to background samples collected above Priest Rapids Dam by the SESP routine surveillance (Dirkes and Hanf 1998). Cobalt-60 concentrations at Sites 1, 3, and 5 were 0.10, 0.049, and 1.0 pCi/g, respectively. Cobalt-60 concentrations in sediment from the Priest Rapids Dam background location were all below a nominal detection limit of 0.01 pCi/g.

Strontium-90 concentrations at Sites 1, 3, and 5 were 0.085, 47, and 0.014 pCi/g, respectively. The ^{90}Sr concentration at Site 5 was similar to the range of concentrations reported for the Priest Rapids Dam background location (from 0.0081 to 0.015 pCi/g). The ^{90}Sr concentration at Site 3 was considerably larger than the background samples while the ^{90}Sr concentration at Site 1 was slightly elevated compared to the background samples.

4.3 Biota

4.3.1 Periphyton

Periphyton results from this study were compared to earlier studies on radiological concentrations in periphyton in the 100-N Area (Cushing et al. 1981; Cushing 1993). Before closure of the plutonium production reactors, concentrations of ^{60}Co measured in periphyton were approximately 240 pCi/g. Shortly after closure of the first reactors these values dropped to approximately 22 pCi/g, and following closure of all reactors fell to approximately 2 pCi/g (all reported on a dry-weight basis). The 1993 work was a special aquatic study performed at the 100-HR-3 and 100-NR-1 operable units to assess existing levels of inorganic chemical and radionuclide contamination in water, periphyton, and caddisfly larvae (Cushing 1993). Of the 93 periphyton samples analyzed by Cushing (1993), only five resulted in measurable values for radionuclides. Of these five samples, only three contained ^{90}Sr, all from the 100-H Area, ranging from 0.23 - 0.69 pCi/g. One measurable value was reported for ^{137}Cs (1.1 pCi/g) at the 100-H Area, and one sample had a ^{60}Co concentration of 2.2 pCi/g at the 100-N Area. Strontium-90 was below the detection limits for all periphyton samples collected at the 100-N Area during the 1993 study (Cushing 1993).

For the present study, ^{90}Sr concentrations in periphyton (Figure 4.5) were below the detection limits (approximately 0.2 pCi/g) at 100-N Area Site 1, Site 5, and at the background location near Vernita Bridge. The ^{90}Sr concentration at Site 3 was 0.99 pCi/g. The concentration found at Site 3 was elevated compared to the other locations. The Site 3 result was also elevated compared to the results from Cushing (1993).

The ^{137}Cs concentration in periphyton at the Vernita Bridge background site was 0.14 pCi/g. Cesium-137 concentrations in periphyton at the 100-N Area locations were not appreciably different from one another and all were approximately 0.2 pCi/g. The concentrations of ^{137}Cs at the 100-N Area were slightly higher than those found at the background site. Cesium-137 was not detected in periphyton at the 100-N area in the 1993 aquatic survey (Cushing 1993).

Cobalt-60 concentrations in periphyton collected at the Vernita Bridge background site were below the detection limit (approximately 0.01 pCi/g). Concentrations of ^{60}Co at all three 100-N sampling sites were higher than background. Concentrations at Site 1, Site 3, and Site 5 were 0.036, 0.20, and 0.2 pCi/g, respectively. The concentrations of ^{60}Co found in this study are substantially lower than those measured in the 1993 study (2.2 pCi/g) (Cushing 1993).

4.3.2 Caddisfly

Previous radionuclide studies of caddisfly at the 100-N Area focused on larvae, thus no caddisfly adult concentrations are available for comparison. Cushing (1993) reported a ^{90}Sr concentration of 0.57 pCi/g in larval caddisfly collected from the 100-N Area; however, no other data are available for ^{90}Sr. Cushing et al. (1981) reported ^{60}Co values of 66 pCi/g for caddisfly larvae collected before closure of the single-pass plutonium production reactors. These values decreased to approximately 12 pCi/g (dry weight) following closure of all reactors.

For the current study, the background concentrations of ^{90}Sr, ^{137}Cs, and ^{60}Co in adult caddisfly were below detection limits (approximately 0.05 pCi/g) (Figure 4.3). Two adult caddisfly samples were taken at the 100-N Area near Site 3 and Site 5. Concentrations from Site 5 were also below detection limits. However, concentrations at Site 3 were substantially higher; ^{90}Sr was 65 pCi/g, ^{137}Cs was 39 pCi/g, and ^{60}Co was 0.25 pCi/g. It is not clear why the results for Site 3 were different from those at Site 5 because the home range of the caddisfly at these locations should overlap. It was not possible to collect any additional adult caddisfly samples in 1997 to confirm these elevated results because by the time the sample results were received in the late fall the caddisfly were no longer available.

4.3.3 Sculpin

To our knowledge, sculpin collected in the Hanford Reach have never been analyzed for radionuclides. This species is not a sportfish but was chosen because of its assumed limited mobility and small home range, which would maximize the potential exposure to river water contaminated with water from shoreline springs and groundwater seeps in the vicinity of the 100-N Area. Larger fish species such as bass or carp tend to be more mobile and have a larger home range. For example, fish tagged in the Hanford Reach have been recaptured in the Yakima River (Denham et al. 1993). Thus, uncertainties regarding residence time and exposure may be reduced by targeting less mobile fish species such as sculpin (Gibbons et al. 1997). The sculpin data should provide a worst-case exposure scenario for fish that can be used to estimate exposure for fish-eating biota. Sculpin were analyzed whole-body, minus livers (livers were analyzed separately for trace metals [Dirkes and Hanf 1998]). Therefore, the values obtained are not comparable to fish fillet analysis typically performed for food fish/human health risk evaluation.

A background composite sample of 15 individual sculpin (minus livers) was collected near the vicinity of the Vernita Bridge area. In addition, a composite sample of 21 sculpin was collected from the vicinity of the 100-N Area shoreline. Gamma emitters (nominal detection limit of 0.05 pCi/g) were not detected in composited sculpin samples from either the 100-N Area or the Vernita Bridge sites. Strontium-90 was detected at 0.75 pCi/g at the 100-N Area, compared to the upstream background concentration of 0.015 pCi/g.

Cobalt-60, ^{137}Cs, and ^{90}Sr were rarely detected in fillets from other fish species collected from the Hanford Reach during routine environmental surveillance (Dirkes and Hanf 1998). However, ^{90}Sr was routinely detected in offal samples (skin and fish body less fillets and soft tissue). The highest concentration since 1983 was 0.52 pCi/g in bass offal from the 100-F slough observed in 1986 (Poston 1994).

The mean concentration of ^{90}Sr in 19 carp samples collected from the 100-N Area from 1990 to 1996 was 0.077 pCi/g (wet weight) (Woodruff et al. 1991; Dirkes and Hanf 1997). The maximum value observed for carp collected in the vicinity of the 100-N Area was 0.42 pCi/g for a carp offal sample in 1990 (Poston 1994). The maximum concentration of ^{90}Sr in a whitefish offal sample (0.49 pCi/g) was collected from between the 100-N to 100-D Areas in 1995 (Bisping 1996). A study of white sturgeon from the Hanford Reach conducted from 1989 to 1990 found that the maximum concentration of radionuclides were less than 0.01 pCi/g and that there was little to no human dose from consumption of these sturgeon (Dauble et al. 1993).

4.3.4 Clam Shells

The concentrations of ^{137}Cs and ^{60}Co in clam shells were near to or below the detection limit (approximately 0.01 pCi/g) near the 100-N Area at Site 1 and Site 5 and at the background site above Vernita Bridge (Figure 4.4). Strontium-90 concentrations were near to or below the detection limit (approximately 0.3 pCi/g) at Site 5 and the background site, while the concentration at Site 1 was slightly elevated at 1.5 pCi/g. Clam shells were not observed at Site 3. Woodruff and Hanf (1992) reported that concentrations of ^{137}Cs and ^{60}Co in clam shells collected from the 100-N Area were below detection limits (0.2 and 0.4 pCi/g, respectively). However, the ^{90}Sr concentration in clam shells from the 100-N Area was 270 pCi/g (Woodruff and Hanf 1992), which is substantially higher than the concentrations found in this study.

4.3.5 Milfoil

The concentrations of ^{90}Sr and ^{137}Cs in milfoil (Figure 4.4) collected at the background location were 0.053 and 0.16 pCi/g, respectively; while the ^{60}Co concentration was below the detection limit of 0.05 pCi/g. Cesium-137 concentrations in milfoil collected at Site 1 and Site 5 were not different from background concentrations. Strontium-90 and ^{60}Co concentrations at Site 5 were slightly elevated at 0.16 and 0.12 pCi/g, respectively. The milfoil sample collected and analyzed by WDOH at Site 1 had a ^{90}Sr concentration of 0.6 pCi/g, which is approximately 10 times the background concentration. The sample collected nearby at Site 1 by the SESP was consistent with the background concentration. Milfoil was not available at 100-N Area Site 3. In comparison, Antonio et al. (1993) reported the concentration of ^{90}Sr in milfoil from the 100-N Area and the Vernita Bridge locations were 0.12 and 0.096 pCi/g (dry weight), respectively. In 1994, the SESP collected milfoil at the shorelines between the 100-N and 100-D Areas and at Vernita Bridge; the average ^{90}Sr concentrations were 0.13 and 0.078 pCi/g (dry weight), respectively.

4.3.6 Reed Canary Grass

The concentrations of ^{90}Sr and ^{137}Cs in reed canary grass collected at the background location were 0.24 and 0.047 pCi/g, respectively, while the background concentrations of ^{3}H and ^{60}Co were below the detection limit of approximately 200 pCi/L and 0.04 pCi/g, respectively. The concentrations of radionuclides in reed canary grass collected at 100-N Area sampling Sites 1, 3, and 5 were similar to the background location (Figure 4.5) with the exception of ^{90}Sr at Site 3, where an elevated concentration of 33 pCi/g was found, and ^{3}H at all three sites, with concentrations of approximately 500 pCi/L of water

distilled from the plants. In comparison, Antonio et al. (1993) reported concentrations of ^{90}Sr in reed canary grass of 0.017 pCi/g (dry weight) for the 100-N Area and 0.005 pCi/g (dry weight) for the Yakima River. Rickard and Price (1990) reported that ^{90}Sr concentrations in reed canary grass collected at the 100-N Area approached 50 pCi/g (dry weight) and decreased for samples collected downstream of the 100-N Area.

4.3.7 Summary of Biota Results

The biota results tracked well with river water and sediment results. Typically, the lowest concentrations of radionuclides are found at Vernita Bridge (background site). For ^{90}Sr, a contaminant profile is identifiable at the five sampling locations along the 100-N Area. Concentrations at the farthest upstream locations (Sites 1 and 2) are similar to background biota concentrations. However, at Site 3 a contaminant source is evident because the contaminant concentrations in biota samples were substantially higher than background. The spatial extent of this contaminant source is limited, as is demonstrated by concentrations observed at Sites 4 and 5, which are generally less than Site 3 and often return to background levels.

4.4 External Radiation Results

External radiation exposure rates along the shoreline in the vicinity of the 100-N Area are shown in Figure 4.6. Exposure rates ranged from 2 to 14 μR/h, with the highest rates found along the shoreline vicinity nearest to the 1301-N and 1325-N LWDFs. Upstream of sampling Site 1 and downstream of Site 4, radiation exposure rates were reduced by a factor of two, to approximately 5 μR/h. Exposure rates from mid-river to near the opposite shoreline range from 2 to 6 μR/h.

Background external radiation exposure rates on the Columbia River near the 100-N Area are approximately 4 μR/h (Cooper and Woodruff 1993; Thatcher 1995). Thus, external radiation rates in the nearshore vicinity of the 100-N Area range from two to three times background. These rates are similar to those measured in 1992 (Cooper and Woodruff 1993) but are slightly lower than those measured in 1994 (Thatcher 1995). Exposure rates approach background just upstream and downstream of the 100-N Area and from mid-river to the opposite shoreline.

5.0 Human Dose Assessment

The radiological impact to offsite individuals from 100-N Area near-shore contaminants was estimated using data collected in this study. A discussion of the methodology to assess current health impacts is presented in Section 5.1. Radiation dose for several current-use activities typical of this area are discussed in Section 5.2. Also discussed in Section 5.2 is the application of the data from this study to future site-use dose assessments.

5.1 Methodology for Assessment of Current Human Health Impacts

Currently, the most common uses of the stretch of river adjacent to the 100-N Area are recreational boating and fishing. This report therefore assesses radiation exposures to a person pursuing recreational boating and fishing activities near the 100-N Area shoreline. Human exposure pathways include ingestion of contaminated river water, ingestion of contaminated fish, and exposure to external radiation. Ingestion of riverbank spring water is also considered, although exposure to this source should be limited since access to the shoreline is restricted. Immersion of the body in contaminated river water and immersion of the hands in contaminated riverbank spring water were also considered, but the doses were found to be negligible, and are not discussed further.

Dose assessments commonly report results as an annual dose and are highly dependent on the scenario chosen to describe an individual's activities throughout the year. A single or small number of exposure scenarios are rarely able to encompass the activities and lifestyles of all population groups. To help eliminate the subjective nature of choosing a particular current site-use scenario, this study reports doses resulting from unit-time exposures to external radiation and unit intakes of contaminated media. These doses are referred to as unit doses.

The unit dose concept provides a common basis for interpretation of the reported contaminant concentrations, and the doses can be used as the basis for specific population group current-use exposure scenarios (Section 5.2). Unit doses are based on a 1-hour exposure to external radiation, reported in mrem/h, and ingestion of 1 L of riverbank spring water and 1 L of river water, both reported in mrem/L ingested.

The external radiation exposure rates for much of the river at the 100-N Area, shown in Figure 4.6, are near the background rate of 4μR/h. However, in determining the 1-hour unit dose, it is assumed that exposure is received from the vicinity with the maximum exposure rate of 14μR/h on the river near sampling Site 3a. The excess exposure rate, the total rate minus the background rate, is 10 μR/h. To convert exposure rate measured in R (Roentgen) to effective dose rate measured in rem, the exposure rate is first multiplied by a factor of 0.87 (Shleien 1998) to convert to absorbed dose rate in air (units of rad). This result is multiplied by a factor of 0.7 to convert absorbed dose rate in air to effective dose rate in

humans (UNSCEAR 1988; Saito et al. 1998). Combining the two conversion factors and converting μR to mR, the excess exposure rate of 10 μR/h leads to a unit dose rate of 0.006 mrem/h (effective dose), as shown in Table 5.1.

The unit dose from ingesting 1 L of river water, contaminated with both ^{90}Sr and ^{3}H, is 0.001 mrem/L (effective dose), as listed in Table 5.1. Dose conversion factors for adults from the International Commission Radiological Protection Publication 72 (IRCP 1996) were used to calculate doses from ingestion. This unit dose corresponds to ingesting river water with contaminant concentrations equal to those found at Site 3a on October 29, 1998: 13 pCi/L for ^{90}Sr and 153 pCi/L for ^{3}H. The unit dose from ingesting 1 L of riverbank spring water is 1 mrem/L (effective dose), also listed in Table 5.1. This unit dose corresponds to ingesting riverbank spring water with contaminant concentrations equal to those found near Site 3 on November 3, 1998: 9,900 pCi/L for ^{90}Sr and 14,000 pCi/L for ^{3}H. For both unit doses, the contribution to dose from ^{3}H is negligible compared to that of ^{90}Sr. Background water concentrations for ^{90}Sr and ^{3}H are small compared to the concentrations used to calculate unit dose, and therefore, excess dose and total dose are nearly identical.

Ingesting fish caught from the 100-N Area was also considered for its contribution to dose. Sculpin were collected in this study, and although they are excellent environmental indicators (Sections 3.4 and 4.3), they are not a primary human food source. The sculpin results are therefore applied to the ecological risk assessment (Section 6.0) but are not included as part of the human dose assessment.

Most fishing in the Hanford Reach is for adult salmon or steelhead (WDW 1983). Migrating adult salmon and steelhead do not feed during their upstream migration or during spawning life (Healey 1991; Mahler and Larkin 1954). Therefore, the body burdens of radionuclides from fish caught near the 100-N Area likely represent what they were exposed to as they matured in the ocean. In addition, any body burden of radionuclides in steelhead or salmon associated with feeding from the Hanford Reach is probably due to background contaminants since the fish spend little time in the vicinity of contaminated shorelines. Therefore, dose from consumption of anadromous fish is likely not correlated with contaminants from the 100-N Area and is not considered further.

5.2 Application to Specific Exposure Scenarios

A goal of this study was to report data that may be used by others to assess current radiological impacts to various population groups. The contaminant concentrations, external radiation exposure rates,

Table 5.1. Dose from Unit Exposure to Various 100-N Area Contaminants

Sample Type	Type of Exposure	Unit of Exposure	Unit Dose (mrem)
External radiation	external	1 hour at max exposure rate	0.006
River water	ingestion	1 liter at max concentration	0.001
Spring water	ingestion	1 liter at max concentration	1

and calculated unit doses reported here may be used to assess doses from specific activities and lifestyles associated with specific population groups. Numerous exposure scenarios are possible. Three examples, as well as additional information for developing exposure scenarios, are given below.

As an example of a current-use exposure scenario, consider the dose for a fisherman who spends 2 hours per day, 2 days per week near the 100-N Area shoreline during the fishing season, which is approximately 18 weeks. The fisherman brings his own drinking water supply, and since the shoreline is restricted, does not go ashore. Therefore, excess dose, or dose above background, is from external radiation only. The maximum excess annual exposure can be estimated by multiplying the 72-hour total exposure time by the unit dose of 0.006 mrem/h. This results in an annual excess dose of 0.43 mrem for this specific scenario.

Another example considers the exposure to excess external radiation resulting from fishing boats drifting with river current. The stretch of river with elevated external radiation rates is approximately 1 km long. Assuming a drift speed of 10 km/h results in an exposure period of 0.1 hours. Multiplying by the unit dose for external exposure leads to a dose of 0.0006 mrem per drift. This dose is 5 orders of magnitude smaller than the 100 mrem/year dose limit to offsite individuals from exposure to DOE facilities (DOE Order 5400.5).

As a final example, consider a kayaker who is curious about the industrial complex on the bluff and explores close to the shoreline. The kayaker spends 30 minutes in the area and fills a 1-L water bottle from the river. Using this information with the unit doses in Table 5.1, the kayaker will receive an upper bound dose of 0.003 mrem from external radiation and an upper bound dose of 0.001 mrem from ingestion of contaminated water, leading to a total dose of 0.004 mrem. The doses from these three specific scenarios are significantly smaller than the 100 mrem/year dose limit to offsite individuals from exposure to DOE facilities (DOE Order 5400.5).

Any scenario that includes ingestion of contaminated river water will result in upper bound doses because the unit dose was generated from the maximum measured ^{90}Sr concentrations in river water. In addition, the maximum measured river water concentrations were from samples collected at a time of prolonged low river stage, when maximum contaminant concentrations were expected to be found. Further, boaters are likely to bring their own drinking water supply since water from rivers, lakes, and even pristine mountain streams typically need to be treated before consumption.

Current-use exposure scenarios involving the ingestion of riverbank spring water, although possible, are highly unlikely. Access to the Hanford Site shoreline upstream of the wooden tower powerline crossing at the Old Hanford Townsite is prohibited, and this includes the 100-N Area shoreline. In addition, the shoreline is a riprap of large boulders and rocks, making it difficult for an intruder to dock a boat and walk in this area (Figure 5.1). Site 3, the location with the highest ^{90}Sr concentrations in river and riverbank spring water, has the steepest bank, the largest boulders, and the swiftest river current, making it the most difficult location to come ashore in the 100-N Area. From a visual inspection, the riverbank along the 100-N Area in the vicinity of the ^{90}Sr plume is among the most inhospitable of the entire Hanford Reach.

Figure 5.1. The 100-N Area Shoreline Showing the Large Boulders at Sample Site 3a

In addition, most of the shoreline near the ^{90}Sr plume is posted as a radiation zone, with numerous radiation warning signs visible. It is only possible to intrude on the shore during a low river stage when land is exposed between the radiation zone and the river. Further, the area above the bluff consists of a visible industrial area, namely the 100-N Area reactor complex. All these considerations result in a relatively undesirable stretch of shoreline for bringing a boat ashore. Finally, field observations indicate riverbank springs are only exposed approximately 15% of the year. For the remainder of the year, they are not available for human contact since they are either not flowing or are underwater.

It is common in risk assessment to estimate dose to future users of a site. At the 100-N Area, this might include, for example, exposure from contaminated river water used as a drinking water source or used to irrigate crops. However, the data presented in this study are of limited value for conducting future-use dose assessments. First, it is difficult to predict future near-shore contaminant concentrations. Contaminant concentrations have changed dramatically over the last two decades (Dirkes 1990; DOE 1992), primarily due to shutdown of the reactor. Since that time, contaminant concentration measurements have not been adequate to determine trends and predict future concentrations. The

groundwater/river interface is a highly dynamic system that results in highly variable near-shore river water concentrations. Second, if the land is released in the future for less restricted use, it is likely the land will have been remediated or the radioactive contaminants will have partially decayed; thus future contaminant concentrations will be significantly different than those measured today.

The river and riverbank spring water concentrations reported in this study were taken at a few selected points in time, and they do not represent annual average water concentrations. However, many regulatory quantities, for example U.S. EPA drinking water Maximum Contaminant Levels (MCL), are reported as annual average concentration limits (USEPA 1976). Therefore, additional work may be needed to determine annual average near-shore river water concentrations.

This study provides data that may be used to estimate doses to individuals involved in specific current-use activities at the 100-N Area shoreline vicinity. The examples demonstrate that typical current-use doses are significantly smaller than the 100 mrem/year dose limit to individuals offsite from a DOE facility. Numerous other exposure scenarios are possible, and the data provided here should prove useful in evaluating exposures based on other activities or lifestyles.

6.0 Ecological Dose/Risk Assessment

This section provides a discussion of the radiation exposure levels and doses to aquatic organisms at the 100-N Area observed in this study. The degree to which exposure to radiation is considered safe or deleterious depends upon the duration and magnitude of exposure. A dose rate of less than 1 rad per day is considered by the International Atomic Energy Agency (IAEA) to be protective of the environment and unlikely to result in any significant deleterious effects to aquatic organism populations (IAEA 1976, 1992). An aquatic wildlife dose limit of 1 rad/day has been adopted by the U.S. Department of Energy (DOE Order 5400.5). The following section provides dose estimates for selected aquatic biota. Sections 6.1 and 6.2 summarizes the findings from this study and places the environmental dose and biota tissue concentrations into ecological context.

6.1 Aquatic Biota Dose Calculations

Radiological dose estimates were calculated for various aquatic organisms using the CRITRII computer model and the data collected from this study. The methods and scenario descriptions used by the CRITRII code are outlined in Baker and Soldat (1992). As discussed in Section 4.0, ^{3}H and ^{90}Sr were the major radiological contaminants detected above background concentrations at the 100-N Area. Most other radionuclides in environmental samples from the 100-N Area were either below detection limits or were similar to background concentrations. Based on the results from this study, the two radionuclides of primary interest for the aquatic dose assessment are ^{3}H and ^{90}Sr.

The whole-body concentration of ^{90}Sr for sculpin at the 100-N Area was 0.75 pCi/g (wet weight basis). The internal dose rate for sculpin from ^{90}Sr -^{90}Y was 0.000044 rad/day. Sediment burdens of ^{90}Sr were not expected to cause any effective external dose for bottom dwelling sculpin because of shielding afforded by the sediment matrix. In addition, because ^{90}Sr is a beta-emitter, no effective external dose from the water is expected.

Bioaccumulation factors (BAF) are based on several assumptions, one of which is that the tissue concentration is in equilibrium with the water concentration. This is likely true for the background sculpin samples where the whole body concentration of ^{90}Sr was 0.015 pCi/g wet weight, and the background water concentration of ^{90}Sr was 0.1 pCi/L. The BAF is 150 for whole body burdens. Bioaccumulation in soft tissue can be estimated more precisely by the following equation (Vanderploeg et al. 1975, Poston and Klopfer 1988).

$$BAF(muscle) = e^{[5.18-(1.21*\ln Ca(mg/L))]}$$

The concentration of calcium (Ca) in the Columbia River is about 17 mg/L on an annual basis (based on U.S. Geological Survey data in Bisping 1997). This results in an estimated BAF of 5.8 for ^{90}Sr in muscle. This estimate is a factor of 10 lower than the CRITRII default value of 50. For example, the estimated concentration of ^{90}Sr in soft tissue was 0.075 pCi/g wet weight for a maximum water concentration of

13 pCi/L (see Appendix A). The much higher body burden observed in the composite sample of sculpin indicates that most of the body burden is most likely associated with bone. This observation is consistent with surveillance monitoring data for fish fillets and offal (Poston 1994). The accumulation of ^{90}Sr by freshwater fish is influenced by the concentration of calcium in the water and the life history and physiology of the fish species. Poston and Klopfer (1986) reported a wide range (0.73 to 1,250) of BAF that were influenced by water chemistry and differences between fish species.

Sculpin from the 100-N Area were collected from about 2000 m of shoreline. Using the maximum observed ^{90}Sr concentration in water (13 pCi/L) at station 3 as representative of fish exposure overestimates the actual exposure of sculpin that made up the composite sample at the 100-N Area. The high water concentrations occurred in only a very small portion of the area sampled (see Figure 4.1). Because the sculpin sample was a composite sample of 21 fish, there is a strong likelihood that individual fish had a higher concentration of ^{90}Sr than that indicated by the composite sample. Nothing is known about the distribution of ^{90}Sr concentrations for individual fish, so maximum body burdens cannot be evaluated more precisely.

The riverbank spring samples collected from 100-N Area Site 3 had high concentrations of ^{3}H and ^{90}Sr (14,000 and 9,900 pCi/L, respectively). This is a small spring with a low discharge rate that is typically covered by river water; thus, no identifiable aquatic community lives in the direct spring discharge zone (i.e., no substantial community of aquatic organisms can exist in the undiluted spring water). Therefore, exposure to the radionuclides in the spring water does not occur until the spring water has been diluted with Columbia River water. For September 1997 samples collected at Site 3a, the concentration ratios of spring water to river water were 150 for ^{3}H and 1,600 for ^{90}Sr. A conservative assumption was made that a few aquatic animals might be exposed to the concentration of radionuclides measured in the spring water after a 20-fold dilution by the river (e.g., for a spring water concentration of 1.0 pCi/L, the exposure concentrations used would be 0.05 pCi/L.

To provide a conservative estimate of daily dose rates for aquatic organisms, the CRITTR code was used with a maximum water concentration of 1:20 spring water of 495 pCi/L (based on 9900 pCi/L spring water, see Appendix A). The dose to fish for ^{90}Sr (and ^{90}Y daughter decay) was 0.0014 rad/day based on the default BAF of 50 in CRITRII. This dose is considerably higher than the 0.000044 rad/day dose associated with the composite whole body tissue burden of 0.75 pCi/g. CRITRII was also used to conservatively estimate daily dose rates for other aquatic biota based on this 20-fold dilution of the maximum spring water concentration (Table 6.1). The conservatism of these dose estimates is apparent from the maximum near-shore water concentration of 13 pCi/L at station 3a.

All estimated doses to aquatic biota in Table 6.1 were below the U.S. DOE 1 rad/day limit. The plant-eating duck and muskrat scenarios, as modeled, approached the 1 rad/day limit. However, it should be emphasized that the CRITRII code is a tool used to aid in interpreting environmental radiological surveillance data. The exposure scenarios used for various biota have very specific assumptions and may not be representative for every site being investigated. In this case, it is assumed that the plant-eating duck resided only in the vicinity of the 100-N Area spring, was being exposed to 20-fold diluted spring water, and consumed only plants growing in this area (similar assumptions were used for muskrat). The estimated dose would decrease if the ^{90}Sr concentrations were estimated over a larger area because of dilution of the source. For example, the estimated dose rate for a water concentration of 13 pCi/L (the

Table 6.1. Dose Estimates for Near-Shore Biota (rad/d)

Analyte	Fish	Mollusk	Crawfish	Plant-Eating Duck	Fish-Eating Duck	Heron	Muskrat	Crawfish-Eating Raccoon	Fish-Eating Raccoon
^{90}Sr	1.4 E-3	2.9E-3	2.9E-3	9.0E-1	3.0E-2	2.0E-2	9.0E-1	2.7E-2	1.4E-2
^{3}H	2.0E-7	2.0E-7	2.0E-7	3.0E-7	6.0E-5	3.8E-7	3.0E-7	2.6E-7	2.6E-7
Total Internal Dose	1.4E-3	2.9E-3	2.9E-3	9.0E-1	3.0E-2	2.0E-2	0.90E+0	2.7E-2	1.4E-2

highest near-shore ^{90}Sr concentration observed at station 3a) using CRITRII and a BAF of 50 was 0.000037 rad/day in sculpin. The elevated concentrations at the 100-N Area were observed only over a small section of the shoreline. The results from CRITRII modeling indicate that the dose in this small area approaches the DOE guideline

6.2 Ecological Risk Potential to Aquatic Biota from 100-N Area Releases

This study was designed to document exposure pathways and estimate the potential magnitude of that exposure. From such data, the relative health of the system can be inferred and it can be determined whether additional detailed studies are warranted.

Because of the relatively small spatial extent of the contamination occurring at the 100-N Area, there should be no substantial risk to aquatic biota populations of the Hanford Reach of the Columbia River. The elevated ^{90}Sr concentration in adult caddisfly measured at Site 3 was unusual and may require additional sampling to determine if this concentration is realistic or an analytical/sampling artifact. Bottom-dwelling macroinvertebrate populations do not appear to be at risk. In general, invertebrates are more resistant to radiological dose than vertebrates. However, there is a small area where macroinvertebrates are exposed to elevated ^{90}Sr. Additional study of the macroinvertebrate and sculpin community residing near the 100-N Area may be warranted to further understand localized community-level and individual-level effects occurring at the 100-N Area, if any.

7.0 Conclusions

This study evaluated radiological contaminants in the 100-N Area near-shore environment. Near-shore river water, riverbank spring water, river sediment, periphyton, milfoil, reed canary grass, caddisfly, clam shells, and fish were collected and analyzed for ^{3}H, ^{90}Sr, and gamma emitters. This study also measured near- and off-shore external radiation levels. The data represent current radiological contaminant levels and can be used to evaluate current human health and ecological impacts.

Strontium-90 is the primary contaminant of concern for near-shore risk assessment. Groundwater contaminated from past 100-N Area reactor operations flows into the Columbia River through shoreline springs and upwelling areas on the river bottom. The five sampling locations selected along the 100-N Area shoreline bracket the ^{90}Sr groundwater plume entering the Columbia River. Strontium-90 was evident in all samples collected at Station 3, the location bordering the peak contour of the ^{90}Sr plume and adjacent to a visible spring. Strontium-90 was also present at lower concentrations in samples collected at the other 100-N Area sampling sites and the upriver background locations. Transect samples of near-shore river water show that ^{90}Sr was rapidly diluted by the Columbia River.

The biota samples show ^{90}Sr transfers throughout the local ecosystem. Strontium-90 was detected in primary food sources (periphyton and reed canary grass) and in primary consumers (clams, sculpin, and caddisfly). Strontium-90 also can be taken up by wildlife (e.g., deer or geese) feeding on the grass, or fish feeding on sculpin, clams, and pre-emergent caddisfly, although these animals are not full-time residents in this area and were not collected. Cobalt-60 concentrations in periphyton at all 100-N Area locations were elevated compared to the background samples; however, the current levels are below those observed during active operation of the LWDFs. The adult caddisfly sample collected at Site 3 had elevated concentrations of ^{60}Co, ^{90}Sr, and ^{137}Cs compared to both Site 5 and the background location. This result was unexpected because of the proximity of Site 3 and Site 5; additional caddisfly samples may be required to confirm this unusual finding. Contaminated soil from the 100-N Area contributes to the offsite external radiation levels on the Columbia River and adjacent shoreline. The highest exposure rates were along the shoreline Site 3a, which is nearest to the LWDFs. External radiation rates are one to two times higher than background rates at the near-shore and decrease to background levels at the shoreline beyond the study area and from mid-river to the opposite shore.

The contaminant levels and external radiation levels were evaluated for current human health impact. There are numerous current-use exposure scenarios to which the present contaminant concentrations, external radiation rates, and calculated unit doses may be applied. The river water and riverbank spring water results represent upper bound contaminant concentrations and doses since sampling was carried out during low-river stage, when the highest contaminant concentrations are expected and the riverbank springs are exposed. Site 3 is the location with the highest ^{90}Sr concentrations in river and riverbank spring water; however, this area has the steepest bank, the largest boulders, and the swiftest river current, making it the most difficult location to come ashore to at the 100-N Area. It is only possible to access the shore during a low river stage when the water line is below a posted radiation zone. Since 100-N Area river water and riverbank springs are not currently used as a drinking water source, the present water results were not used to calculate an annual drinking water dose.

The highest calculated dose results from drinking riverbank spring water near Site 3. However, the likelihood of a person drinking this water is extremely remote. Given the current access restrictions at the 100-N Area, the most likely current public activity along the Hanford shoreline is boating or fishing. Thus, the most likely route of exposure is from external radiation. The calculated dose to a person engaging in typical activities along the 100-N Area shoreline is far below levels for which there is a known health impact and below any limits set by federal regulations.

The radiological dose to aquatic organisms at the 100-N Area was estimated using the results from this study and a biological pathways model. The dose estimate is complicated because the area with elevated concentrations of contaminants is small compared to the normal home range of the biota. All estimated doses to aquatic biota were below the U.S. DOE 1 rad/day limit. The plant-eating duck and muskrat model scenarios approached the 1 rad/day limit; however, an actual exposure of this magnitude is highly unlikely.

The data presented here can be used to assess doses from many specific activities. The doses calculated from current-use exposure scenarios, fishing and boating, are low and not expected to be harmful to people engaged in these activities.

8.0 References

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Appendix A

Results of Radiochemical Analysis of N-Springs Shoreline Samples

Table A.1. Results of Radiochemical Analysis of N-Springs Shoreline Samples

Sample Location	Collection Date	Sr-90				H-3				Cs-137				Co-60			
		WDOH		SESP		WDOH		SESP		WDOH		SESP		WDOH		SESP	
		Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]
River Water (pCi/L)																	
Site 1a	9/8/97	1.1	0.8	0.10	0.036	53	38	37	9.6	0.6	0.9	-0.15	1.5	-0.2	0.8	-0.74	1.2
Site 2a	9/8/97	0.1	0.6	0.13	0.041	110	41	64	12	-0.1	0.9	-0.15	1.5	0.7	0.7	-0.74	1.2
Site 2b	9/8/97	0.3	0.6			84	39	61	11	0.3	0.9			0.7	0.8		
Site 2c	9/8/97	0.04	0.63			89	40	64	11	-1	1			-0.4	0.8		
Site 2d	9/8/97	-0.05	0.58			31	37	61	11	0.3	0.8			-0.2	0.8		
Site 3a	9/8/97	3.8	1	3.9	0.74	90	39	68	12	0.6	1	0.35	1.2	-0.07	0.85	0	1.1
Site 3b	9/8/97	6.6	1.1	4.6	0.87	84	39	73	12	-0.2	0.9	-0.39	1.2	0.4	0.8	-0.88	1.4
Site 3c	9/8/97	4.1	1	3.8	0.70	55	38	72	12	-0.02	0.94	-0.55	0.95	0.7	0.8	-1.1	1.5
Site 3d	9/8/97	0.9	0.7	1.4	0.26	93	39	66	12	0.2	0.8	1.2	0.96	0.1	0.8	-0.086	1.1
Site 4a	9/8/97	0.8	0.7	0.72	0.15	65	38	66	12	-0.7	0.9	0.48	1.26	0.4	0.8	0.41	0.92
Site 5a	9/8/97	0.9	0.5	0.23	0.060	1200	70	1000	90	0	0.9	0.046	1.1	0.5	0.9	0.074	1.2
Site 5b	9/8/97			0.30	0.070			230	25			-0.90	1.1			0.82	0.97
Site 5c	9/8/97			0.30	0.073			320	33			0.934	1.0			1.2	0.85
Site 5d	9/8/97			0.29	0.069			310	32			1.2	1.6			1.2	1.5
Site 3a	10/29/97	13	2			150	42			0	1			-0.1	0.9		
Site 3a	3/30/98	12	1.3			-62	33			0.1	0.9			0.8	0.7		
Site 3a	6/11/98	0.4	0.5			-15	31			1	1			0	1		
Site 3a	7/20/98	5.9	0.9							-0.3	0.9			0	1		
Background				0.094	0.037			25	8.0								
Riverbank Spring Water (pCi/L)																	
Site 3	9/9/97	6100	80			14000	300			-1	1			1	1		
Site 3	11/3/87			9900	1900			14000	1100			0.35	1.5			0.074	1.8
Site 4/5	11/3/97			0.59	0.13			19000	1500			0.72	0.85			2.2	1.6
Sediment (pCi/g dry)																	
Site 1	9/9/97			0.085	0.020							0.25	0.037			0.10	0.024
Site 3	9/9/97			47	8.5							0.091	0.022			0.049	0.019
Site 5	9/9/97			0.014	0.0055							0.37	0.047			1.1	0.12

Table A.1. Results of Radiochemical Analysis of N-Springs Shoreline Samples

Sample Location	Collection Date	Sr-90				H-3				Cs-137				Co-60			
		WDOH		SESP		WDOH		SESP		WDOH		SESP		WDOH		SESP	
		Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]	Result	Error[a]
Background	8/18/97			0.011	0.0055							0.36	0.047			0.0086	0.012
Sculpin (pCi/g wet)																	
Shoreline	9/11/97			0.75	0.15							0.013	0.025			0.023	0.023
Background	9/11/97			0.015	0.0090							0.009	0.048			0.034	0.050
Clam Shells (pCi/g)																	
Site 1	9/9/97	1.5	0.3							0.002	0.009			0.004	0.009		
Site 5	9/8/97	0.13	0.17							-0.001	0.01			0.008	0.01		
Background	9/11/97	0.4	0.3							0.011	0.009			0.003	0.005		
Caddisfly (pCi/g dry)																	
Site 3	9/11/97	65	1.2							39	9.3			0.25	0.055		
Site 5	9/8/97	0.007	0.035							-0.002	0.008			0.004	0.009		
Background	9/23/97	0.02	0.05							0.007	0.009			0	0.01		
Milfoil (pCi/g dry)																	
Site 1	9/9/97	0.60	0.22	0.058	0.015					0.11	0.089	0.095	0.081	0.04	0.04	0.034	0.046
Site 5	9/9/97			0.16	0.034							0.12	0.058			0.12	0.056
Background	9/11/97			0.053	0.015							0.16	0.074			0.0006	0.042
Reed Canary Grass (pCi/g dry; except H-3, pCi/L)																	
Site 1	9/9/97	0.18	0.04			470	170			0.05	0.04			0.06	0.03		
Site 3	9/9/97	33	0.4			470	190			0.02	0.02			0.01	0.02		
Site 5	9/8/97	0.035	0.029			530	170			0.04	0.03			0.03	0.03		
Background	9/11/97	0.24	0.04			140	190			0.047	0.026			0.001	0.015		
Periphyton (pCi/g dry)																	
Site 1	9/9/97	-0.04	0.22							0.22	0.028			0.036	0.007		
Site 3	9/8/97	0.99	0.44							0.20	0.018			0.20	0.01		
Site 5	9/9/97	0.11	0.15							0.26	0.019			0.2	0.02		
Background	9/9/97	0.02	0.16							0.14	0.016			0.0002	0.0073		

(a) Total propagated analytical uncertainty.

Appendix B

Location Names

Appendix B

Location Names

Some location names are different in this report than reported in Bisping 1998 and the Hanford Environmental Information System (HEIS) database. This report lists Site 1 as the farthest upriver with subsequent Site numbers increasing downriver. The Bisping 1998 report and the HEIS database listed the Site 5 as the farthest upriver with Site numbers decreasing downriver.

This Report	Bisping 1998/HEIS
Site 1	Site 5
Site 2	Site 4
Site 3	Site 3
Site 4	Site 2
Site 5	Site 1

These differences are for river water, sediment, and milfoil. The following is a list of corresponding names that are dissimilar or that might be confused.

Sample Type	This Report's Location Name	HEIS Sample Number	Bisping 1998 and HEIS Location Name
Sediment	100 N Site 5	S0LWD6	100 N Spring-1
Sediment	100 N Site 3	S0LWD7	100 N Spring-3
Sediment	100 N Site 1	S0LWD8	100 N Spring-5
Milfoil	100 N Site 5	S0LWF3	100 N Spring-1
Milfoil	100 N Site 3	S0LWF4	100 N Spring-3
Milfoil	100 N Site 1	S0LWF5	100 N Spring-5
River Water	100 N Site 5A	S0LW98	100 N Spring-1A
River Water	100 N Site 5B	S0LWB0	100 N Spring-1B
River Water	100 N Site 5C	S0LWB2	100 N Spring-1C
River Water	100 N Site 5D	B0LWB4	100 N Spring-1D
River Water	100 N Site 3A	B0LWB6	100 N Spring-3A
River Water	100 N Site 3B	S0LWB8	100 N Spring-3B
River Water	100 N Site 3C	B0LWC0	100 N Spring-3C

Sample Type	This Report's Location Name	HEIS Sample Number	Bisping 1998 and HEIS Location Name
River Water	100 N Site 3D	S0LWC2	100 N Spring-3D
River Water	100 N Site 2A	S0LWC4	100 N Spring-4A
River Water	100 N Site 2B	S0LWC6	100 N Spring-4B
River Water	100 N Site 2C	S0LWC8	100 N Spring-4C
River Water	100 N Site 2D	S0LWD0	100 N Spring-4D
River Water	100 N Site 4	S0LWD2	100 N Spring-2
River Water	100 N Site 1	S0LWD4	100 N Spring-5

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