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Pacific Northwest National Laboratory
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Summary of Radiological Monitoring of Columbia and Snake River Sediment, 1988 Through 2004

G. W. Patton
R. L. Dirkes

October 2007

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

Operation of the single-pass reactors at the Hanford Site resulted in the deposition of radionuclides, primarily short half-life activation products, to sediment accumulation areas on the Columbia River. Operation of the single-pass reactors ended in 1971, and a number of studies were conducted that documented the rapid decline in the radionuclide inventory in the sediment from the decay of short-lived radionuclides and the deposition of fresh sediment material. For the period from 1975 through 1988, environmental monitoring of Columbia River sediment was limited.

From 1988 through 2004, samples of upper-layer sediments from the Columbia River and Snake River were collected under the Hanford Site Surface Environmental Surveillance Project to document concentrations and trends of radionuclides. Low concentrations of potassium-40, cesium-137, uranium isotopes, and plutonium isotopes were detected consistently in sediment samples over the entire sampling period. The concentrations of most radionuclides were similar to values measured upstream of the Hanford Site behind Priest Rapids Dam. For all locations, the concentrations of radionuclides in sediment samples from the Columbia and Snake rivers were below concentrations that would result in a 1-mrem effective dose equivalent to a hypothetical exposed individual using a shoreline exposure scenario (i.e., 500 hr/yr of external dose). The U.S. Department of Energy (DOE) limit for public exposure is 100 mrem/yr.

During the early period (1988 through 1997) covered in this report, cobalt-60 was detected at elevated concentration for McNary Dam sediment compared to levels detected at Priest Rapids Dam. However, in the late 1990s the concentrations of cobalt-60 at all locations were generally below the laboratory-reported detection limits. The decline in cobalt-60 concentrations was in agreement with the rate of radioactive decay for releases from the Hanford Site single-pass reactors.

From 1988 through 1996, europium isotopes were detected periodically in Columbia River sediment samples, with some indication of slightly elevated concentration for McNary Dam sediment compared to sediment at Priest Rapids Dam. However, from 1997 through 2004, all results for europium isotopes were reported as undetected from the contract analytical laboratory, which was consistent with europium radioactive decay rates for releases from the Hanford single-pass reactors.

Annual average concentrations of strontium-90 at McNary Dam from 1988 through 1992 typically were elevated compared to those at Priest Rapids Dam. For 1988 and 1989, the differences between annual average concentrations at Priest Rapids and McNary dams were statistically significant (paired t-test, $P < 0.05$). Annual average values at McNary Dam generally decreased from 1988 until 1999, and values for subsequent years were below the detection limits for all samples.

Discerning changes in concentration trends for uranium isotopes in sediment was complicated by the use of different methods for analyzing for the presence of uranium. During the period covered by this report, uranium concentrations had been measured using both low-energy photon spectroscopy (U-LEPS) and alpha energy analysis (U-AEA). The U-LEPS method did not report values for uranium-234 and had higher detection limits for uranium-235, with most uranium-235 results reported as below the detection limit. For analyses done during 1998 through 2004, the U-AEA method was used. Results from this period revealed relatively constant concentrations over time, with little difference between concentrations for all uranium isotopes for sediments from McNary, Ice Harbor, and Priest Rapids dams. Concentrations

of uranium isotopes for Hanford Reach sediment were lower than those from sediments collected upstream of the dams and likely reflect the larger sediment grain size found at the locations in the Hanford Reach.

Annual average concentrations of plutonium-238 for sediment at McNary Dam were elevated compared to those for sediments from Priest Rapids Dam and the Hanford Reach for 1988 through 1991, 1994, 2000, and 2003. Concentrations of plutonium-238 were generally slightly lower for sediment from the Hanford Reach compared to the other locations and likely reflect the larger sediment grain size found at the locations in the Hanford Reach.

Plutonium-239/240 was detected in all sediment samples collected during the reporting period. For 1988 through 2004, the range of annual average concentrations for plutonium-239/240 was similar for sediment collected upstream from Priest Rapids, McNary, and Ice Harbor dams. The one exception was the values of concentrations from sampling in 1988 and 1989 at McNary Dam, which were elevated compared to Priest Rapids Dam. The differences in plutonium-239/240 levels between McNary and Priest Rapids dams in 1988 and 1989 were the result of low concentrations at Priest Rapids Dam compared to overall trend data from 1988 through 2004. Concentrations of plutonium-239/240 were lower for sediment from the Hanford Reach compared to the other locations and likely reflect the larger sediment grain size found at the locations in the Hanford Reach.

Radionuclide concentrations in sediment collected from riverbank spring discharges along the Hanford Site shoreline were similar to levels in Columbia River sediment, with one exception—the 300 Area, where the average uranium concentrations were usually two to three times the concentrations measured at Priest Rapids. For all locations, the concentrations of radionuclides in riverbank spring sediment samples were below concentrations that would result in a 1-mrem effective dose equivalent to the hypothetical maximally exposed individual using a shoreline exposure scenario (i.e., 500 hr/yr of external dose), which is below the DOE public exposure limit of 100 mrem/yr.

Acknowledgments

Dana Ward, U.S. Department of Energy Richland Operations Office, recognized the benefit of documenting historical Columbia River sediment monitoring results and provided support. The authors acknowledge Lynn Bisping for providing the detailed data set from the Hanford Environmental Information Database. Andrea Currie edited both draft and final versions of the report; text processing and layout were provided by Lila Andor, publications designer. Ted Poston and Tom Cooper provided peer review comments. Ernie Antonio provided a review of the surface sediment exposure scenario used in DOE/RL-91-50 (Hanford Site Environmental Monitoring Plan).

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1.0 Introduction

Environmental surveillance of the U.S. Department of Energy (DOE) Hanford Site and the surrounding region is conducted to demonstrate compliance with environmental regulations, confirm adherence to DOE Orders and environmental policies, support DOE environmental management decisions, and provide information to the public. The Hanford Site Surface Environmental Surveillance Project is an environmental monitoring effort to measure the concentrations of radionuclides and chemicals in multiple environmental media and assess the potential impacts of these materials on the environment and the public. As part of this project, water and sediment on the Columbia and Snake rivers are monitored to provide a historical record of radionuclide contributions to the river environment from natural causes, worldwide fallout from nuclear weapons testing, and operations at the Hanford Site.

Columbia River monitoring includes sampling of river water, river sediment, riverbank spring water entering the river, and riverbank spring sediment. Sediment samples are taken periodically in the Snake River to help understand the contribution of the Snake River to the sediment in McNary Pool. Results of the sediment sampling conducted under the Surface Environmental Surveillance Project are reported annually through the Hanford Site environmental report series and as topical reports. This report provides information on the long-term trends of radionuclides in river sediment and enhances the evaluation of potential Hanford Site impacts by evaluating information over a longer period than the 6-year window (current year compared to the 5 previous years) typically discussed in the annual reports.

This report also provides background information about the hydrological characteristics of the Columbia and Snake rivers, reviews former operations at the Hanford Site, including releases likely to affect sediment quality, and presents a history of sediment monitoring activities. The report describes the sediment sampling portion of the overall river monitoring program during the years 1988 through 2004 and summarizes the radiological results from that period. Additional related studies performed by the Surface Environmental Surveillance Project and other organizations during this period also are discussed, as appropriate.

2.0 Background

This section provides background information on the Columbia and Snake rivers, Hanford Site, and sediment surveillance around the Site.

2.1 Columbia River and Selected Tributaries

The Columbia River is one of the largest rivers in the continental United States in terms of total flow and is the dominant water body on the Hanford Site. The abundant water supply offered by the Columbia River was an important factor in the original selection of the Hanford Site for a plutonium production area. The river is a source of drinking water for onsite facilities and communities downstream of the Hanford Site. Water from the river downstream of the Site is used for crop irrigation. In addition, the Hanford Reach of the Columbia River is used for a variety of recreational activities, including hunting, fishing, boating, water skiing, and swimming.

Originating in the mountain snowpack of eastern British Columbia, Canada, the Columbia River drains an area of 670,000 km^2. The flow of the river is regulated by 3 dams in Canada and 11 dams in the United States. Of those 14 dams, 10 are upstream and 4 are downstream of the Hanford Site. Priest Rapids Dam is the nearest upstream dam; McNary Dam is the nearest dam downstream from the Site. The Hanford Reach is the stretch of the river below Priest Rapids Dam and extending downstream to the head of Lake Wallula (created by McNary Dam) near Richland, Washington. The Hanford Reach is the last stretch of the Columbia River in the United States (above Bonneville Dam) that remains unimpounded. The Yakima, Snake, and Walla Walla rivers join the Columbia River to form Lake Wallula behind McNary Dam. The Snake River is the primary contributor of sediment from tributaries to the Columbia River, although the Yakima and Walla Walla rivers also are significant sources of sediment (Whetten et al. 1969). Figure 2.1 shows the geographic relationships among all these features.

Flows through the Hanford Reach fluctuate significantly and are controlled primarily by operations at upstream dams. Annual average flows of the Columbia River below Priest Rapids Dam are nearly 3,400 m^3/sec (Wiggins et al. 1995). Daily average flow rates are highly variable; for example, daily average flow rates for 1999 ranged from 1,480 to 6,370 m^3/sec (Poston et al. 2000). As a result of fluctuations in discharges, the depth of the river varies significantly over time. River stage may change along the Hanford Reach by up to 3 m within a few hours. Seasonal changes of approximately the same magnitude also are observed. River-stage fluctuations measured at the 300 Area (near Richland, Washington) are approximately one-half the magnitude of those measured near the 100 Areas because of the effect of the pool behind McNary Dam and the relative distance of each area from Priest Rapids Dam (Campbell et al. 1993).

The Snake River, which originates in Yellowstone National Park, western Wyoming, is the largest tributary to the Columbia River. According to data from the U.S. Army Corps of Engineers (USACE), the Snake River comprises approximately 42% (282,000 km^2) of the total drainage of the Columbia River and accounts for about 18% (1,400 m^3/sec) of the annual flow of the Columbia River (USACE 1999). The highest water flows are in the spring (typically 4,200 m^3/sec); the lowest flows are in the late summer (typically 710 m^3/sec) (USACE 1999). There are four dams on the Snake River in Washington State.

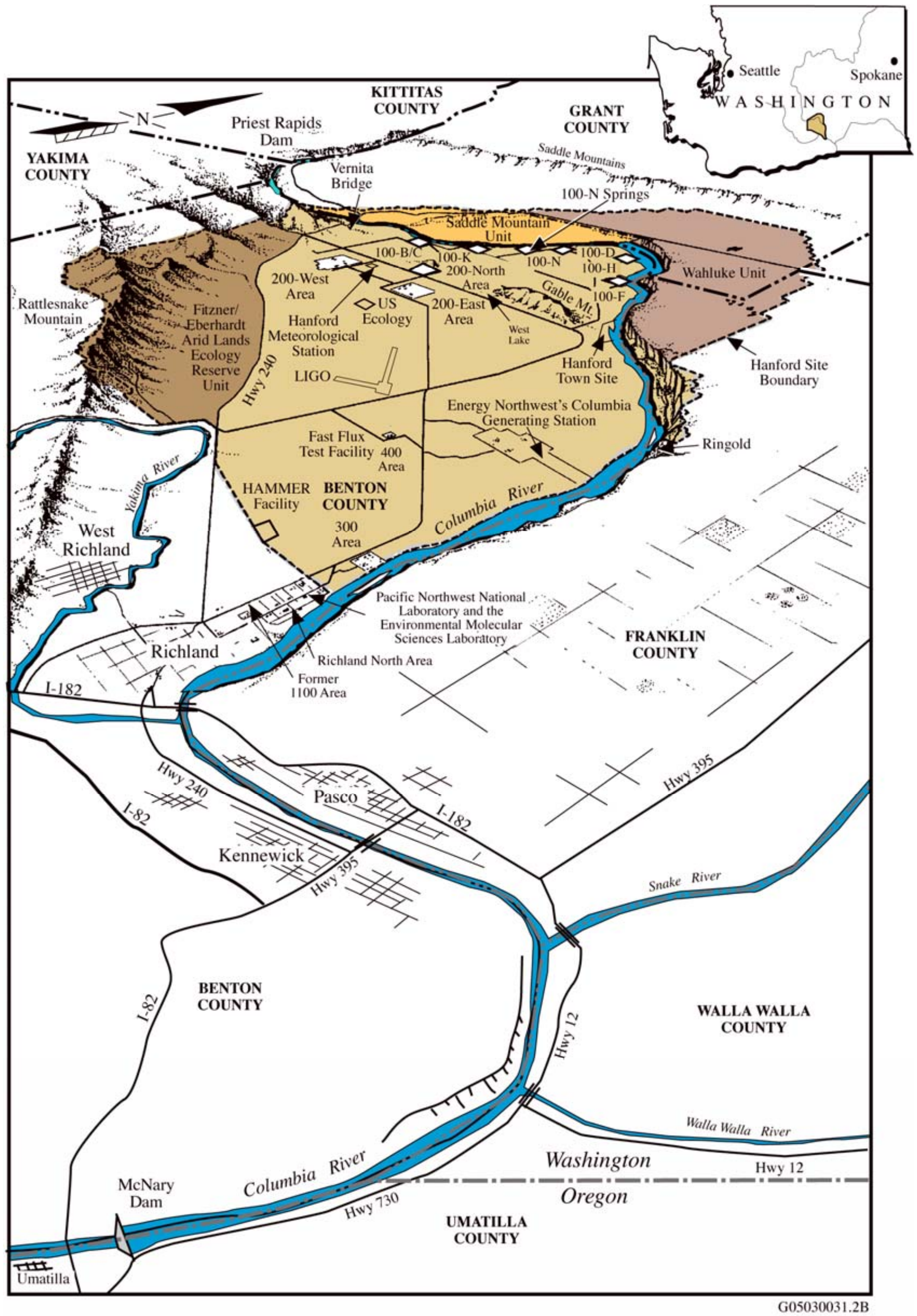

Figure 2.1. The Hanford Site and Surrounding Area. Columbia River flow is from the top of the map toward the bottom, and McNary Dam is approximately 56 river kilometers downstream from the Highway 395 bridge.

Ice Harbor Dam is the first dam upstream from the confluence of the Snake and Columbia rivers. By comparison, the annual average water discharges of the Yakima and Walla Walla rivers are 70 m^3/sec and 15 m^3/sec; respectively.

Pollutants, both radiological and nonradiological, are known to enter the Columbia River through the Hanford Reach. In addition to permitted direct discharges of liquid effluents from Hanford facilities, contaminants in groundwater from previous discharges to the ground are known to seep into the river (McCormack and Carlile 1984; Dirkes 1990; Peterson 1992; DOE/RL-92-12). Effluents from each direct discharge point were routinely monitored and reported by the responsible operating contractor and were summarized in Hanford Site environmental reports (e.g., Poston et al. 2005). Direct discharges are identified and regulated for nonradiological constituents under the National Pollutant Discharge Elimination System in compliance with the Clean Water Act of 1997. The discharges from the Hanford Site permitted by the National Pollutant Discharge Elimination System are summarized in the Hanford Site environmental reports (e.g., Poston et al. 2004).

As of 1997, Washington State classified the designated uses and water quality criteria for the stretch of the Columbia River from Grand Coulee Dam to the Washington-Oregon border, which includes the Hanford Reach, as *Class A, Excellent* (Washington Administrative Code [WAC] 173-201A). Waters in this classification are suitable for almost all uses, including raw drinking water, recreation, and wildlife habitat.

In 2003, the Washington State Department of Ecology revised the standards for surface water quality. Under the revised standards, the criterion for uses designated as *Class A, Excellent* was replaced with separate use designations for aquatic life, recreation, water supply, and miscellaneous purposes. For the Columbia River downstream from Grand Coulee Dam, the aquatic life designation is “salmonid spawning, rearing, and migration,” which provides for the protection of spawning, rearing, and migration of salmon and trout as well as protection of other associated aquatic life. The recreational uses designation for the Columbia River downstream from Grand Coulee Dam is “primary contact recreation,” which provides for activities that may involve complete submersion by the participant. The entire Columbia River is designated as suitable for all water supply and miscellaneous uses by the state of Washington.

2.2 Hanford Site

The Hanford Site occupies an area of approximately 1,500 km^2. The site is approximately 270 km southeast of Seattle, Washington; 200 km southwest of Spokane, Washington; and 320 km northeast of Portland, Oregon. The Hanford Site is described in detail in *Hanford Site National Environmental Policy Act (NEPA) Characterization* (Neitzel 2004); summary descriptions are provided in the annual Hanford Site environmental reports. The Hanford Site was established in 1943 to design, build, and operate nuclear reactors and chemical separation facilities for the production of special nuclear materials, primarily weapons-grade plutonium, for national defense (Gosling 1994). Past operations at the Hanford Site are discussed in detail in *Final Environmental Statement, Waste Management Operations, Hanford Reservation, Richland, Washington* (ERDA 1975).

As a result of Hanford Site operations, large quantities of radioactive materials were discharged to the Columbia River. Nine reactors producing special nuclear material were operated along the bank of the Columbia River after the Site was established. Eight of these reactors used once-through cooling systems, which resulted in the release of heated water, corrosion-inhibiting chemicals, and radionuclides directly into the river. These radionuclides were principally activation products, although some fission products, fuel components, and traces of transuranium radionuclides (e.g., plutonium and americium isotopes) were released from ruptured fuel elements. The ninth reactor, 100-N Area reactor, used a closed-loop cooling system that virtually eliminated direct releases of radionuclides and chemicals to the river but still discharged a significant amount of heated water into the river. With the shutdown of the single-pass reactors, which took place from 1965 to 1971, direct discharges of contaminants to the Columbia River were nearly eliminated (Cushing et al. 1981; Becker 1990).

Upon release to the river, contaminants from Hanford operations were dispersed rapidly, sorbed onto inorganic particles and detritus, incorporated into aquatic biota, or deposited on the riverbed as sediment. For some radionuclides, several of these processes occurred. Fluctuations in the river stage from dam operations, spring freshets, and occasional floods resulted in resuspension, transport, and redeposition of the sediment material (Haushild et al. 1971; Glenn and Van Atta 1971; DOE/RL-91-50, Rev. 3). However, sedimentation was limited along the Hanford Reach because of the relatively high river velocity. In general, sediment deposition areas in the Hanford Reach occur in backwater sloughs and along riverbank beaches. River substrate in the Hanford Reach is composed largely of pebble-cobble gravel with fine to coarse sand filling the matrices between gravel clasts (Dauble et al. 2003).

Production of nuclear materials at the Hanford Site essentially ended with the shutdown of the 100-N reactor in 1987 and the PUREX chemical separation plant in 1990 (Patton and Cooper 1993). The Hanford Site's current mission is environmental cleanup with an eventual move to long-term stewardship and legacy management. Currently, there are few direct discharges to the Columbia River from Hanford operations (Poston et al. 2005). However, site groundwater contaminated from past operations continues to discharge into the river from riverbank springs and groundwater seeps (Poston et al. 2005; Dirkes 1990).

2.3 Sediment Surveillance

Sediments in the Columbia River contain low concentrations of radionuclides and metals of Hanford Site origin as well as radionuclides from nuclear weapons testing fallout originating outside the area and metals from upper Columbia River mining and refining activities (Fix 1976; Robertson and Fix 1977; Beasley et al. 1981; Beasley and Jennings 1984; Beasley 1987; Blanton et al. 1995; Johnson et al. 1994; Johnson 1999). Potential public exposures are well below the level at which routine surveillance of Columbia River sediments is required (Sula 1980; Wells 1994). However, periodic sampling is necessary to confirm the low levels and to ensure that no significant changes have occurred for this pathway. The accumulation of radioactive materials in sediment can lead to human exposure by ingestion of aquatic species, sediment resuspension into drinking water supplies, or by irradiation during fishing, wading, sunbathing, or participating in other recreational activities associated with the river or shoreline (DOE/EH-0173T).

Since the shutdown of the original single-pass reactors in the early 1970s, the contaminant burden in the surface sediments has been decreasing as a result of radioactive decay and the subsequent deposition of uncontaminated material (Fix 1976; Robertson and Fix 1977). Many of the radionuclides dominant during operations of the single-pass reactors had relatively short half-lives. For a given radionuclide, after 10 half-lives have passed, only 1/1024 (0.098%) of the original radionuclide remains. Thus many radionuclides that were large contributors during single-pass reactor operations (e.g., chromium-51, zinc-65, scandium-46, manganese-54, and antimony-124) have decayed to diminutive levels. Currently, the Hanford Site discharges some pollutants to the Columbia River via contaminated groundwater seepage and some minor inputs via permit-regulated liquid effluent discharges (Poston et al. 2004).

Robertson and Fix (1977) studied the change in radionuclide concentrations in Columbia River sediment as the Hanford Site shut down the single-pass cooled nuclear reactors. Their work investigated how concentrations of radionuclides changed in surface and deep sediment from 1971 to 1976 by obtained samples from sediment cores from the McNary Dam pool (that appeared to penetrate to the deepest layer of sediment), conducted seismic surveys of the sediment bed, and estimated the inventory of radionuclides in the sediment behind McNary Dam. Major findings from their study included the following:

- Most short- and intermediate-lived radionuclides (half-life <1 yr) had decayed to insignificant levels.

- Only trace concentrations of a few non-natural radionuclides (manganese-54, iron-55, cobalt-60, cesium-137, europium isotopes, plutonium isotopes, and americium-241) were present in the sediment.

- Approximately 40–80 cm of new uncontaminated sediment had accumulated from 1971 to 1976.

- The concentrations of cesium-137, plutonium isotopes, and americium-241 in McNary Dam sediment were similar to levels at Priest Rapids Dam, upstream of the Hanford Site.

- Sediment from the deepest cores at McNary Dam (~1953 to 1960) contained ultra-low levels of Hanford-origin radionuclides, indicating that while releases from reactor operations were significant during the peak production years at Hanford, the sediment bed did not retain high concentrations of radionuclides.

- An estimate of the radionuclide inventory in McNary Dam sediment was produced using the depth-specific radionuclide concentration data and the seismic survey of the sediment bed.

Figure 2.2 shows the estimated radionuclide inventory for McNary Dam sediment reported by Robertson and Fix for 1976 conditions. In addition, Figure 2.2 provides an estimate of the remaining radionuclide inventory for the 1976 sediment by correcting for radioactive decay to 2004. In 1976, iron-55 was the highest contributor to the estimated inventory, but naturally occurring potassium-40 was the highest contributor in 2004. As expected, from 1976 to 2004, the inventory of manganese-54, iron-55, and cobalt-60 decreased dramatically, with inventories of europium-152, europium-154, cesium-137, and plutonium-238 decreasing slightly commensurate with their respective half-lives. In 1976, the inventory of thorium-228 was 63 curies; this isotope is a naturally occurring daughter product from thorium-232 (with a half-life of 1.4×10^{10} years). Excluding naturally occurring potassium-40 and thorium-228, the estimated total radionuclide inventory in 1976 was 5,798 curies, which had decayed to less than 600 curies by 2004. The sediment layers sampled by Robertson and Fix in 1976 are now buried by a layer of newer sediment. This “newer” sediment should have considerably lower radionuclide concentrations than the deeper sediment because of closures of the Hanford single-pass reactors and a reduced atmospheric source of radionuclides from nuclear weapons testing associated with the Limited Test Ban Treaty (LTBT 1963).

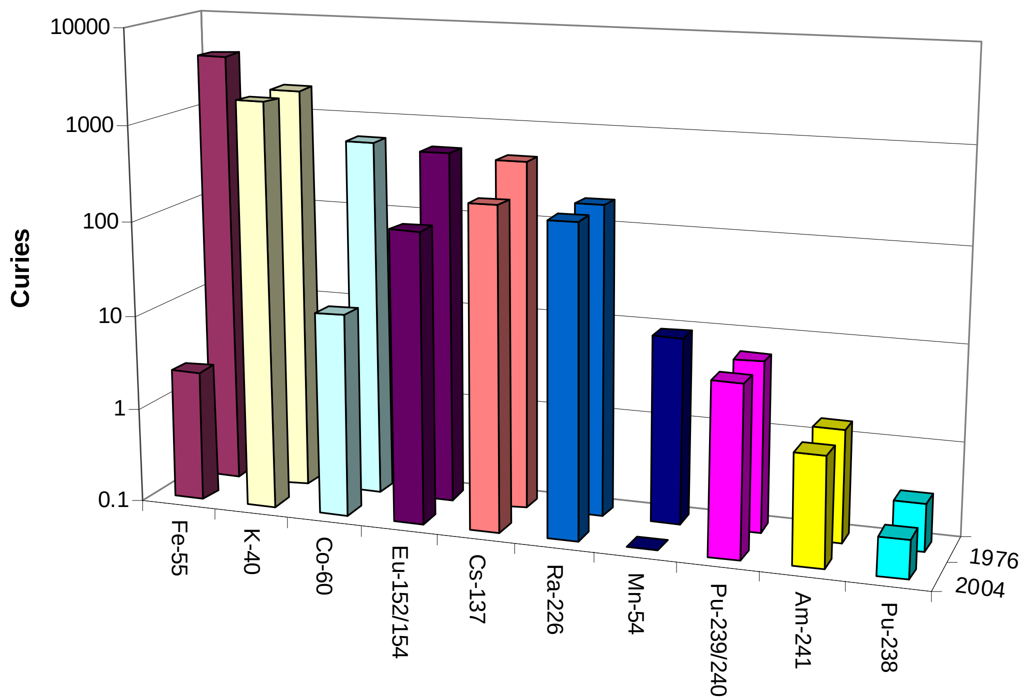

Figure 2.2. Estimated Radionuclide Inventory for McNary Dam Sediment for 1976 (Robertson and Fix 1977) and 1976 Inventory Decay-Corrected to 2004

Beasley and Jennings (1984) reported inventories of cobalt-60, cesium-137, plutonium-239/240, and americium-141 in Columbia River sediment samples obtained from gravity cores collected in 1977 from the Hanford Reach to the Columbia River estuary. They estimated the total radionuclide inventory in McNary Dam sediment as 197 Ci for cobalt-60, 172 Ci for cesium-137, 2.3 Ci for plutonium-239/240, and 0.67 for americium-241, which were similar to the values reported by Robertson and Fix (1976). They estimated that the majority of cobalt-60 was of Hanford origin, whereas 20–25% of the plutonium-239/240 and 34-48% of the cesium-137 was of Hanford origin. Beasley and Jennings (1984) concluded that, despite the substantial additions of artificial radionuclides to the Columbia River from Hanford operations, the 1977 inventory of residual Hanford-origin radionuclides in Columbia River sediment was "vanishingly small" and an order of magnitude below the level of natural radionuclides.

3.0 Columbia and Snake River Sediment Monitoring Program, 1988 Through 2004

This section describes the monitoring effort conducted by the Hanford Site Surface Environmental Surveillance Project on Columbia and Snake river sediments from 1988 through 2004 (Sections 3.1 through 3.4). All samples were taken from the upper surface of the sediment deposit (i.e., sediment at the river water/sediment interface) and should represent the most recently deposited sediment at a given location. A list of the annual environmental reports and data reports produced during this period is included in Section 3.5.1. Other recent studies of sediment quality for the Columbia River also are summarized.

3.1 Objectives

The objectives of sediment surveillance are to 1) assess radiological doses caused by Hanford Site operations through this pathway, by means of periodic river system evaluation, sampling, and analysis; 2) provide an indication of changes in environmental conditions with potential for increases in public and biological exposures; and 3) provide public assurance that the radiological conditions and potential exposure pathways are understood and receive appropriate attention.

The DOE public dose limit for all routine DOE activities is 100 mrem/yr (effective dose equivalent); the dose evaluation reflects realistic exposure conditions (DOE Order 5400.5). Because of variations in the bioavailability of contaminants in various sediments, no radionuclide-specific federal or state freshwater sediment criteria were available to directly assess the sediment quality of the Columbia River. However, radionuclide concentrations in sediment that might lead to a dose of 1-millirem (mrem) effective dose equivalent to the maximally exposed individual if sustained for one year (referred to as reporting level) are given in Table 3.1 for selected radionuclides (DOE/RL-91-50). The specific scenario for public exposure to surface sediments along the shoreline assumes 500 hr/yr of external exposure to

Table 3.1. Radionuclide Concentrations That Result in a 1-mrem Effective Dose Equivalent to a Hypothetical Exposed Individual (DOE/RL-91-50). These values assume a shoreline exposure scenario of 500 hr/yr of external exposure to 1,250 m^2 of surface sediment.

Radionuclide	pCi/g (dry wt.) for Effective Dose Equivalent 1-mrem Level
Cobalt-60	1.4
Strontium-90	30,000
Cesium-137	6
Europium-154	2.6
Uranium-234	50
Uranium-235	50
Uranium-238	50
Plutonium-239/240	81,000

1,250 m^2 of sediment, with no ingestion or inhalation pathways. These reporting levels provide an early indication of conditions that might require reporting to DOE Headquarters as specified by DOE Order 5400.5.

3.2 Sediment Sampling Locations

3.2.1 Columbia River and Snake River

From 1988 through 2004, annual samples of Columbia River surface sediments were collected from the pool upstream from Priest Rapids Dam, the Hanford Reach,[1] and the pool upstream from McNary Dam. In 1998, 1999, 2001, and 2004, sediment samples were collected from the pool upstream from Ice Harbor Dam on the Snake River. Samples from upstream of Hanford Site facilities provide reference data from locations unaffected by Hanford Site releases to the Columbia River. Samples were collected downstream of the Hanford Site above McNary Dam (the nearest downstream impoundment) to identify any increase in contaminant concentrations. Note that any increases in contaminant concentrations found in sediment above McNary Dam relative to that found above Priest Rapids Dam do not necessarily reflect a Hanford Site source. The confluences of the Columbia River with the Yakima, Snake, and Walla Walla rivers lie between the Hanford Site and McNary Dam, and all three of these rivers are significant sediment sources to the reservoir above McNary Dam. Several towns, irrigation water returns, and factories in these drainages also may contribute to the contaminant load found in McNary Dam sediment. Sediments were taken at Ice Harbor Dam to assess Snake River inputs. Sediment samples from the Hanford Reach of the Columbia River provide data from areas close to contaminant discharges (e.g., riverbank springs), from slack-water areas where fine-grained material is known to deposit (e.g., the White Bluffs, 100 F Area, Hanford Sloughs), and from the publicly accessible Richland shoreline.

3.2.2 Priest Rapids Dam

Seven locations were sampled at Priest Rapids Dam (PRD) during the period covered by this report. From 1988 to 1999, annual samples were collected at four stations spaced equidistant (approximately) on a transect line crossing the Columbia River. The transect was downstream from the private boat launch owned by the Desert Aire Owners Association (Desert Aire, Washington) and upstream from the island immediately upriver from the dam. The transect line is at a small railroad trestle on the Yakima County shoreline. The names of the stations (beginning on the Grant County shore and moving to the Yakima County shore) are PRD-Grant County Shore, PRD-1/3 Grant County Shore, PRD-2/3 Grant County Shore, and PRD-Yakima County Shore.

Beginning in 1998, additional Priest Rapids Dam sampling stations were established closer to the dam. These sampling stations are downstream of the island (immediately upstream from the dam) and approximately 100 m upriver from the boat exclusion buoys at the dam. These stations are named PRD-Grant County Near Dam, PRD-Mid River Near Dam, and PRD-Yakima County Near Dam. This move occurred because sediments from the early transect sites were composed primarily of medium and fine sand, while samples collected from the stations near the dam were more similar to those at McNary Dam locations (Blanton et al. 1995; Patton and Crecelius 2001). The sediments of the downstream stations are composed primarily of silt/clay, very fine sand, and fine sand. This change improved the comparability

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[1] Portion of the river downriver from Priest Rapids Dam to the start of the pool upstream from McNary Dam, just upstream from Richland.

of the annual monitoring data between Priest Rapids Dam and McNary Dam because the sediment at both stations is primarily silt/clay and very fine sand (Patton and Crecelius 2001).

3.2.3 Hanford Reach

Four sites were sampled in the Hanford Reach, along the Benton County shoreline, beginning in 1989 and continuing through 2004. Samples were collected from White Bluffs Slough, 100-F Slough, Hanford Town Site Slough, and the publicly accessible Richland shoreline (approximately 100 m downriver from the Snyder Street boat ramp, Richland, Washington). The Hanford Reach sloughs are slack-water areas where fine-grained sediment can accumulate. Sediments from these locations are typically composed primarily of fine sand and medium sand, with only minor contributions of very fine sand and silt/clay (Blanton et al. 1995; Patton and Crecelius 2001).

3.2.4 McNary Dam

Altogether six stations were sampled at McNary Dam during the period covered by this report. From 1988 through 1999, annual samples were collected at the first four stations spaced equidistant (approximately) on a transect line crossing the Columbia River. This transect is roughly 1.6 km upstream from the U.S. Army Corps of Engineers boat launch on the Oregon shore at McNary Dam. The names of the stations (beginning on the Oregon shore and moving to the Washington shore) are McNary OR Shore, McNary 1/3 OR Shore, McNary 2/3 OR Shore, and McNary WA Shore.

Beginning in 1998, two additional McNary Dam sampling stations were established closer to the dam. These two sampling stations are approximately 100 m upriver from the boat exclusion buoys at the dam. These stations are named McNary-Oregon Near Dam and McNary-Washington Near Dam. This move occurred because sediment from the transect sites (although composed primarily of silt/clay and very fine sand) revealed a gradient in sediment grain size with a higher fraction of fine sand occurring near the Washington shore (Blanton et al. 1995; Patton and Crecelius 2001). Samples collected from the sampling sites near the dam were composed primarily of silt/clay and very fine sand (Patton and Crecelius 2001). This change was undertaken to improve the comparability of the data between the Priest Rapids and McNary dam sampling sites because of more similar sediment size fractions.

3.2.5 Ice Harbor Dam

Three stations were sampled at Ice Harbor Dam on the Snake River during the period covered by this report. Samples were collected in 1998, 1999, 2001, and 2004 at three stations equidistant (approximately) on a transect line crossing the Snake River. The transect is approximately 250 m downstream from the boat launch at the U.S. Army Corps of Engineers Levy Landing Park in Franklin County. The names of the stations are Franklin County Shore, Mid-River, and Walla Walla County Shore. Sediments are composed primarily of silt/clay and very fine sand for the Walla Walla Shore and Mid-River stations and are medium sand for the Franklin County Shore station (Patton and Crecelius 2001). The change in sediment size distributions between sampling stations provides an indication of different river flows and sediment deposition patterns at the Ice Harbor Dam site.

3.2.6 Hanford Reach Riverbank Springs

Sampling of sediment associated with Hanford Reach riverbank springs began during 1993 at the Hanford town site and 300 Area. Sampling of riverbank springs in the 100-B, 100-K, and 100-F Areas began during 1995. Substrates at the dominant riverbank springs at the other major Hanford Site operation areas (100-N, 100-D, and 100-H Areas) consist predominantly of large cobble and are usually unsuitable for sediment collection.

3.3 Sample Collection

River-bottom surface sediment samples were collected using either a standard Ponar or petite Ponar dredge. The standard Ponar dredge has a 522-cm^2 opening and collects sediment to a maximum depth of 8.9 cm, with a maximum volume of 8.2 L. The petite Ponar dredge has a 232-cm^2 opening and collects sediment to a maximum depth of 7.0 cm with a maximum volume of 2.4 L. Both Ponar dredge types have a pair of weighted jaws held open during descent to the sediment surface by tension from the retrieval cable to a catch bar. Upon contact with the sediment, the tension on the cable is released, the catch bar releases, and the overlapping jaws close. Upon retrieval, the tension on the cable keeps the jaws closed. A mesh screen with rubber flaps covers the upper portion of the dredge. The rubber flaps allow water to flow through the dredge during descent but close to minimize sediment losses during retrieval. Both Ponar dredges types are suitable for most sediment types except hard clays (Mudroch and Azcue 1995). For most years, field records did not indicate which type of Ponar dredge was used for sampling. For 2000 through 2004, the petite Ponar dredge was used exclusively.

Surface sediment collected by a Ponar dredge captured several years of integrated deposits. Gibbons (2000) estimated average sediment deposition rates of 0.723 cm/yr for Priest Rapids Dam and 2.25 cm/yr for McNary Dam. Applying these deposition rates and assuming the maximum sediment sampling depth of the dredges, individual samples could integrate up to 9.7 years at Priest Rapids Dam and up to 3.1 years at McNary Dam using the petite Ponar and up to 12 years at Priest Rapids Dam and 4 years at McNary Dam using the standard Ponar. Sediment deposition rates were not estimated for Snake River and Hanford Reach sampling sites.

The major priority of the sediment sampling efforts was to estimate potential human exposure to radionuclides in the surface sediments; both types of Ponar dredges were effective in meeting this goal. However, caution should be used in making direct year-to-year comparisons of radionuclide concentration data between sediment sampling sites because of different sedimentation rates, different maximum sampling depths, and the wide variety of sediment grain size, which affects the sampling depth of the dredges. Because of the integrating nature of sediment samples collected with Ponar dredges, analysis of a long-term time series of annual samples can be considered a moving average (i.e., current year plus most previous years), with the weighting factors for the previous years dependent upon sediment deposition rate and specific dredge penetration depths at that location.

Samples of riverbank springs sediment were collected using a nylon ladle or spoon, immediately following the collection of riverbank springs water samples. Sediment samples were collected to evaluate any potential accumulation of Hanford groundwater contaminants into the sediment beds associated with riverbank springs. Sampling methods are discussed in detail in DOE/RL-91-50, Rev. 3 (2000) and Hanf and Poston (2000).

3.4 Sample Analysis and Quality Assurance

Sample analyses of Columbia River sediments were selected based on findings of previous Columbia River sediment investigations, reviews of past and present effluents discharged from Site facilities, and reviews of contaminant concentrations observed in near-shore groundwater monitoring wells.

Routine sediment samples were pretreated by weighing, screening (≤2 mm), drying, and ball milling to a constant particle size of 300 µm or less. Sediment samples were typically analyzed for gamma emitters (including beryllium-7, potassium-40, cobalt-60, zinc-65, zinc niobium-95, ruthenium-106, antimony-125, cerium praseodymium-144, cesium-134, cesium-137, europium-152, europium-154, and europium-155, thorium-232 (1988 only), strontium-90, uranium isotopes, and plutonium isotopes (DOE/RL-91-50, Rev. 3, 2000). Samples analyzed for gamma-emitting radionuclides were placed into Marinelli beakers and counted directly. During the reporting period, gamma-emitting radionuclides were counted on either a germanium/lithium (Ge[Li]) or high-purity germanium (HPGE) detector with a multichannel pulse-height analyzer after the sample had been placed into a Marinelli beaker.

Plutonium and strontium concentrations in sediment were measured after pretreatment (screening, drying, and ball milling) and acid leaching of the sediment sample. Strontium was precipitated from the leachate as strontium oxalate. The sample was then converted and precipitated as a carbonate, transferred to a planchet, and counted with a low-background gas-flow proportional counter. After the strontium was removed from the leachate, the plutonium was precipitated with calcium oxalate, dissolved, and loaded onto an ion-exchange column. The plutonium was eluted from the resin column with nitric and hydrofluoric acids, deposited onto a stainless steel or platinum disk, and counted with an alpha spectrometer.

Uranium levels in sediment were measured after pretreatment (screening, drying, and ball milling) of the sediment sample. Different contract analytical laboratories and analytical methods were used to determine the isotopic concentrations of uranium in sediment samples during the period covered by this report. Two distinctly different analytical methods were used. One was a nondestructive test that involved a direct gamma count of dried and sieved sediment using a low-energy photon detection system (U-LEPS). The U-LEPS provides isotopic uranium concentrations for uranium-235 and uranium-238 (no uranium-234) and has a higher detection limit (less sensitive), particularly for uranium-235, which has low natural abundance. The other analytical method (U-AEA) was a destructive test in which the sediment samples were leached with strong acid. The extracts then were pretreated using an ion-exchange column, plated onto a stainless steel planchet, and counted using alpha energy analysis (alpha spectroscopy). The U-AEA method has lower detection limits, particularly for the low-abundance uranium-234 and uranium-235 isotopes.

Procedures for sample collections (including sample handling and chain of custody) met the requirements for the *Surface Environmental Surveillance Procedures Manual* (Hanf and Poston 2000) and project quality assurance plans.

3.5 Sediment Studies 1988–2004

This section provides a list of annual Hanford Site environmental reports and annual surveillance data reports from 1988 through 2004. Other studies of Columbia River sediment quality conducted during this period also are listed and a brief summary is included. This section is intended for informational purposes only; specific details of these studies should be obtained from the individual reports.

3.5.1 Hanford Site Annual Environmental Reports (Routine SESP Sediment Monitoring)

Results of the routine surveillance program on Columbia and Snake river sediment are documented in the annual Hanford Site environmental reports (HSERs) and Hanford Site environmental surveillance data reports (HESDRs) for 1988 through 2004 as listed below. For these reports, sediment results for the current year were evaluated compared to samples collected at Priest Rapids Dam, upstream from Hanford operations. For calendar years 1991 through 1994, results from the current year were also evaluated compared to the preceding 2–4 years. For calendar years 1995–2004, the current year's results were compared to the results from the previous 5 years.

- HSER Calendar Year 1988 (Jaquish and Bryce, eds. 1989) PNL-6825
- HESDR Calendar Year 1988 (Bisping 1989) PNL-6914

- HSER Calendar Year 1989 (Woodruff and Hanf, eds. 1990) PNL-7346
- HESDR Calendar Year 1989 (Bisping 1990) PNL-7360

- HSER Calendar Year 1990 (Woodruff and Hanf, eds. 1991) PNL-7930
- HESDR Calendar Year 1990 (Bisping 1991) PNL-7929

- HSER Calendar Year 1991 (Woodruff and Hanf, eds. 1992) PNL-8148
- HESDR Calendar Year 1991 (Bisping 1992) PNL-8149

- HSER Calendar Year 1992 (Woodruff and Hanf, eds. 1993) PNL-8682
- HESDR Calendar Year 1992 (Bisping 1993) PNL-8683

- HSER Calendar Year 1993 (Dirkes, Hanf, and Woodruff, eds. 1994) PNL-9823
- HESDR Calendar Year 1993 (Bisping 1994) PNL-9824

- HSER Calendar Year 1994 (Dirkes and Hanf, eds. 1995) PNL-10574
- HESDR Calendar Year 1994 (Bisping 1995) PNL-10575

- HSER Calendar Year 1995 (Dirkes and Hanf, eds. 1996) PNNL-11139
- HESDR Calendar Year 1995 (Bisping 1996) PNNL-11140

- HSER Calendar Year 1996 (Dirkes and Hanf, eds. 1997) PNNL-11472
- HESDR Calendar Year 1996 (Bisping 1997) PNNL-11473

- HSER Calendar Year 1997 (Dirkes and Hanf, eds. 1998) PNNL-11795
- HESDR Calendar Year 1997 (Bisping 1998) PNNL-11796

- HSER Calendar Year 1998 (Dirkes, Hanf, and Poston, eds. 1999) PNNL-12088
- HESDR Calendar Year 1998 (Bisping 1999) PNNL-12088, Appendix 1

- HSER Calendar Year 1999 (Poston, Hanf, and Dirkes ,eds. 2000) PNNL-13230
- HESDR Calendar Year 1999 (Bisping 2000) PNNL-13230, Appendix 1

- HSER Calendar Year 2000 (Poston, Hanf, and Dirkes, eds. 2001) PNNL-13487
- HESDR Calendar Year 2000 (Bisping 2001) PNNL-13487, Appendix 1

- HSER Calendar Year 2001 (Poston, Hanf, and Dirkes, eds., 2002) PNNL-13910
- HESDR Calendar Year 2001 (Bisping 2002) PNNL-13910, Appendix 1

- HSER Calendar Year 2002 (Poston, Hanf, and Dirkes, eds. 2003) PNNL-14292
- HESDR Calendar Year 2002 (Bisping 2003) PNNL-14292, Appendix 1

- HSER Calendar Year 2003 (Poston, Hanf, and Dirkes, eds. 2004) PNNL-14687
- HESDR Calendar Year 2003 (Bisping 2004) PNNL-14687, Appendix 1

- HSER Calendar Year 2004 (Poston, Hanf, and Dirkes, eds. 2005) PNNL-15222
- HESDR Calendar Year 2004 (Bisping 2005) PNNL-15222, Appendix 1

3.5.2 Hanford Site Surface Environmental Surveillance Project Sediment Studies

Blanton et al. (1995). *Environmental Monitoring of Columbia River Sediments: Grain-Size Distributions and Contaminant Association*.

The Hanford Site Surface Environmental Surveillance Project conducted a study in 1994 to investigate the differences in sediment grain-size composition and total organic carbon content at routine monitoring sites (Blanton et al. 1995). Physicochemical sediment characteristics were found to be highly variable among monitoring sites along the Columbia River. Samples containing the highest percentage of silts, clays, and total organic carbon were collected above McNary Dam and from White Bluffs Slough. All other samples consisted primarily of sand. Higher contaminant burdens of metals generally were associated with sediments containing higher total organic carbon and finer grain-size distributions. Consistent with the routine sediment monitoring (Section 3.5.1), this study found that the majority of radionuclide concentrations except uranium isotopes and cesium-137 were below detection limits.

Van Verst et al. (1998). *Survey of Radiological Contaminants in the Near-Shore Environment at the Hanford Site 100-N Reactor Area*.

The Washington State Department of Health and the Hanford Site Surface Environmental Surveillance Project surveyed radiological contaminants in the near-shore environment adjacent to the 100-N Area during 1997 to 1998 (Van Verst et al. 1998). The near-shore sampling sites bracketed the location where the maximum groundwater contours for strontium-90 had been reported. River water, sediment, riverbank spring water, periphyton, milfoil, flying insects, clamshells, and reed canary grass from the 100-N Area near-shore environment were collected and selectively analyzed for tritium, strontium, and gamma-emitting radionuclides. Van Verst et al. (1998) acknowledged that collecting sediment was difficult along the 100-N Area shoreline because of the absence of sediment; however, sediment samples were obtained at three of five sampling sites by collecting material from depressions under large rocks. Cobalt-60 and strontium-90 were the only radionuclides with elevated concentrations near the 100-N Area compared to samples from the Priest Rapids Dam pool (Dirkes and Hanf 1998). The maximum strontium-90 concentration at the 100-N Area was 47 pCi/g (dry wt.), which was well above the reported background level at Priest Rapids Dam (0.0081 to 0.015 pCi/g, dry wt.).

Patton and 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*.

A three-year study of trace metals in Columbia River and lower Snake River sediments for the same locations described in Sections 3.2.1 through 3.2.6 was conducted from 1997 through 1999 (Patton and Crecelius 2001). Although the Patton and Crecelius report focuses on metals, it does provide sediment grain fraction information for 1998 and total organic carbon measurements, both of which are useful for evaluating radionuclide levels in sediment.

Patton et al. (2002). *Survey of Radiological and Chemical Contaminants in the Near-Shore Environment at the Hanford Site 300 Area*.

In 2001, the Washington State Department of Health and the Hanford Site Surface Environmental Surveillance Project conducted a survey of radiological and chemical contaminants in the near-shore environment at the Hanford Site 300 Area (Patton et al. 2002). Sediment samples from the 300 Area had elevated concentrations of strontium-90, cesium-137, and uranium compared to levels near the Vernita Bridge. The Vernita Bridge is approximately 13 km downstream from Priest Rapids Dam and 6 km upstream of the nearest Hanford operating site (100-B/C Area). The concentrations of total beta, technetium-99, and thorium isotopes were similar to those for the 300 Area near-shore and Vernita Bridge sediment samples.

Patton et al. (2005). *Survey of Potential Hanford Site Contaminants in the Upper Sediment for the Reservoirs at McNary, John Day, The Dalles, and Bonneville Dams, 2003.*

In 2003 and 2004, the Oregon Department of Energy (representing the Oregon Hanford Waste Board), Washington State Department of Health, Washington Department of Ecology, the U.S. Department of Energy, and Pacific Northwest National Laboratory conducted a multi-agency cooperative study of the four pools (McNary Dam, John Day Dam, The Dalles Lock and Dam, and Bonneville Dam) downriver from Hanford Site operations (Patton et al. 2005). Sediment samples and adjacent beach sediment (where available) were collected from each pool. In addition, river water samples were collected at McNary Dam. Results from this study were compared to values from sediment and water samples collected from the pool upstream of Priest Rapids Dam (upstream of the Hanford Site) by the Hanford Site Surface Environmental Surveillance Project (Poston et al. 2003). Samples were analyzed for radionuclides, chemicals, and physical parameters. In addition, bioassays of sediment porewater (i.e., the water associated with the sediments) were conducted. In 2003, initial sediment samples were collected in the impoundment upriver from McNary, John Day, The Dalles, and Bonneville dams and at beaches along the shores of the impoundments (where available). In 2004, a follow-on study collected sediment samples at Priest Rapids, McNary, and John Day dams on the Columbia River and at Ice Harbor Dam on the Snake River.

For 2003 samples, upper-layer sediment was readily available upriver from McNary, John Day, and The Dalles dams. Sediment was limited (as determined by unsuccessful attempts to collect samples) upriver of Bonneville Dam and was collected successfully only in proximity to the dam structure. Beach sediment sampling locations were limited to above McNary Dam and at the mouth of Eagle Creek on the Oregon side of the Bonneville Dam impoundment. In general, the river sediment samples were composed primarily of very fine sand, silt, and clay, whereas the beach sediment was composed primarily of coarse and medium sand. At McNary and The Dalles dams, there was a trend toward coarse-grained sediment on the Washington side of the river. Total organic content of the river sediment was fairly consistent, with most locations having concentrations above 10,000 mg/kg; the locations with higher organic content generally had finer-grained sediment. Samples from the Washington side of the McNary and The Dalles dams had lower total organic content.

Sediment samples collected in 2003 had detectable levels of potassium-40, cobalt-60, strontium-90, cesium-137, europium-152, isotopic uranium, and isotopic plutonium (Patton et al. 2005). In general, the values were similar to previously reported concentrations at Priest Rapids Dam (Wells 1994; OHD 1994; Poston et al. 2003). Cesium-137 and europium-152 concentrations were somewhat elevated at the lower Columbia River pools compared to sediment from the Priest Rapids pool. Although this provides an indication of a potential Hanford source, additional sampling and evaluation would be required to confirm this information. A separate report on the analytical results for sediment samples collected in 2004 has not been published at this time; however, results for the samples collected by Pacific Northwest National Laboratory are available in the HESDR for calendar year 2004 (Poston et al. 2005).

3.5.3 Other Sediment Studies

This section provides a listing and brief summary of additional studies of Columbia River sediment quality conducted during 1988 through 2004 that were not directly part of the Hanford Site Surface Environmental Surveillance Project. This section is intended for informational purposes only; specific details of these studies should be obtained from the individual reports.

Peterson and Johnson (1992). *Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site*.

Peterson and Johnson (1992) reported the concentrations of radionuclides and chemicals in riverbank spring water and sediment samples from the 100 Area shoreline of the Hanford Site. The 100 Area consists of the individual reactor areas at 100-B, 100-K, 100-N, 100-D, 100-H, and 100-F. Elevated concentrations of strontium-90 and gross beta were reported for riverbank spring sediment samples taken at the 100-N Area. Trace levels of cobalt-60 and europium isotopes also were reported and attributed to residual material from the former operations of the Hanford Site single-pass cooling nuclear reactors.

Pinza et al. (1992). *Snake and Columbia River Sediment Sampling Project*.

Pinza et al. (1992) collected sediment cores from the lower Snake River and the Columbia River near Kennewick, Washington. Samples were analyzed for sediment grain size, total organic carbon, total volatile solids, ammonia, phosphorus, sulfides, oil and grease, total petroleum hydrocarbons, metals, and persistent semi volatile organic compounds. Radionuclides were not included in the analysis suite, but the information on grain size and total organic carbon can be useful for evaluating radionuclides in sediment.

Friant and Hulstrom (1993). *Sampling and Analysis of the 300-FF-5 Operable Unit Springs and Near Shore Sediments and River Water*.

Friant and Hulstrom (1993) collected water and riverbank spring sediment samples for radiological and chemical analysis from the near-shore environment at the 300 Area. Trace levels of gross alpha, gross beta, uranium, potassium-40, cesium-137, radium-226, and thorium isotopes were observed. They concluded that riverbank spring sediments were composed primarily of coarse material (i.e., not fines), which were not expected to retain contaminants coming from the riverbank springs.

Wells (1994). *Radioactivity in Columbia River Sediments and Their Health Effects*.

In March 1994, the Washington State Department of Health issued a special report that evaluated radioactivity in Columbia River sediments and their associated health effects (Wells 1994). In that report, dose estimates were made for the maximally exposed individual using maximum measured concentrations of artificial radioactivity in surface (i.e., upper-layer) sediments of the Columbia River. The report presented calculated doses from both surface and buried sediments in addition to other scenarios. In the report, the maximally exposed individual dose was reported to be 0.13 mrem/yr for surface sediments, which is less than 1% of the natural background exposure dose. From this dose assessment study, the Washington State Department of Health concluded "calculated doses and attendant risks (to humans) from exposure to artificial radioactivity in Columbia River sediments are small for every section of the river."

Wu (1994). *Determination of Effective Doses from Radionuclides in the Columbia River Sediments*.

Wu (1994) used previously reported sediment concentrations of 15 radionuclides in sediment from the Oregon shore of the McNary reservoir to estimate maximum and average effective doses for the population around the lower Columbia River. The exposure pathways considered in this study were ingestion of water, fish and shellfish, and external exposure. The total effective dose (including naturally occurring radionuclides) for the maximally exposed individual was 10 mrem/yr and 2.1 mrem/yr for the average exposed individual. Europium-152 was the primary dose contributor to the total effective dose, excluding naturally occurring radionuclides. The most significant internal exposure came from the shellfish ingestion pathway with cobalt-60, strontium-90, europium-152, radium-226, uranium-238, and plutonium-239/240 as the main dose contributors. The estimated effective doses from Hanford-derived radionuclides were 3.7 mrem/yr for the maximally exposed individual and 0.7 mrem/yr for the average exposed individual; these exposures were less than 4% of the annual dose limit for the public (ICRP 1977).

DOE/RL-96-16 (1998). *Screening Assessment and Requirements for a Comprehensive Assessment. Columbia River Comprehensive Impact Assessment*.

In 1998, the U.S. Department of Energy, U.S. Environmental Protection Agency, and Washington State Department of Ecology initiated a study to evaluate the impact to the Columbia River from Hanford Site contaminants. This study was referred to as the Columbia River Comprehensive Impact Assessment (CRCIA); it comprised a screening assessment of Columbia River human health and ecosystem impacts and developed recommendations for a more detailed assessment (DOE/RL-96-16). Radionuclides identified as contaminants of potential interest related to human health and ecological risk included neptunium-237, strontium-90, cesium-137, and cobalt-60.

Gibbons (2000). *An Investigation of the Origin of ^{152}Eu in Columbia River Sediments*.

Gibbons (2000) conducted a study of deep sediment cores from the reservoirs behind Priest Rapids, Ice Harbor, and McNary dams to determine the origin of europium-152 previously reported in these sediments. The Gibbons study provides evidence that the europium-152 was produced by neutron activation of natural stable europium in Columbia River water used as coolant for the single-pass production reactors. This study also documents concentrations of selected radionuclides in the only deep sediment cores collected for radionuclide analysis from these sediment reservoirs since the mid 1970s.

Johnson et al. (2005). *Heavy Metal Transport and Behavior in the Lower Columbia River, USA*.

Johnson et al. (2005) analyzed samples from the Gibbons (2000) deep sediment cores for heavy metals. This study found that zinc, cadmium, and lead concentrations for 1999 had declined approximately two-fold from their depth profile maximums. This decline was in response to a reduced metal loading to the river from upriver refining and mining activities.

4.0 Results and Discussion

The Hanford Site Surface Environmental Surveillance Project efforts to monitor sediment from the Columbia and Snake rivers for radionuclides are summarized in Table 4.1. A search was conducted of the Hanford Environmental Information System database for sediment samples collected from 1988 through 2004 by the Hanford Site Surface Environmental Surveillance Project and analyzed for radionuclides. This search included samples collected for both the annual surveillance samples and other sediment studies. Table 4.1 provides the sampling locations, sample types, and the year in which samples were collected at each location. These specific locations were described in Sections 3.2.1 through 3.2.6 in this report.

A summary of the overall concentrations of radionuclides in river sediment is provided in Table 4.2. Results for samples of sediments from riverbank springs are discussed in Section 4.5. Because of the large number of analytes and locations, this section is organized by radionuclide; differences between locations are discussed for each individual radionuclide. Average concentrations are reported as the mean ± 1 standard deviation of the mean.

4.1 Gamma-Emitting Radionuclides in Columbia and Snake River Sediments

For sediment samples collected from 1988 through 2004 by the Hanford Site Surface Environmental Surveillance Project, a total of 16 gamma-emitting radionuclides were reported for Columbia and Snake river sediment samples. More than 2,000 individual results were reported (not including U-LEPS results, which are given in Section 4.3). The analytical contract laboratories were required to report all detected gamma-emitting radionuclides and to report all results, including results below the detection limits, for beryllium-7, potassium-40, cobalt-60, ruthenium-106, antimony-125, cesium-134, cesium-137, europium-152 (required beginning in 2003), europium-154, and europium-155.

Beryllium-7 is a naturally occurring radionuclide with a 53-day half-life. It is produced in the upper atmosphere by the interaction of cosmic rays with atmospheric nuclei. Beryllium-7 could be incorporated into the upper layer of river sediment from atmospheric deposition processes. However, because of the short half-life, beryllium-7 would not accumulate in sediment. Beryllium-7 was detected for 28 of 197 reported results. For samples with beryllium-7 above the detection limit, there was no difference between the average values at Priest Rapids Dam (0.31 ± 0.17 pCi/g) and McNary Dam (0.37 ± 0.29 pCi/g). There was no indication of any Hanford source of beryllium-7 for river sediment.

Potassium-40 is a naturally occurring primordial nuclide with an extremely long half-life of 1.28×10^9 years and would be found in river sediment from natural geological processes. Potassium-40 was reported above the detection limit for all samples, as expected. There were slight difference between the average values at Priest Rapids Dam (13 ± 1.4 pCi/g) compared to McNary Dam (15 ± 1.3 pCi/g) and Ice Harbor Dam (15 ± 1.4 pCi/g). Differences in potassium-40 concentrations at these locations are likely related to differences in sediment grain sizes.

Table 4.1. Sediment Sampling Locations and Analytes

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Priest Rapids Dam																	
Grant Co. Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	No Sample	No Sample	No Sample	No Sample
1/3 Grant Co. Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	No Sample	No Sample	No Sample	No Sample
2/3 Grant Co. Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	No Sample	No Sample	No Sample	No Sample
Yakima Co. Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	No Sample	No Sample	No Sample	No Sample
Grant Co. Near Dam	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
Mid River Near Dam	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu
Yakima Co. Near Dam	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
Hanford Reach																	
White Bluffs Slough	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
100-F Slough	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu, Th	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U
Hanford Town Site Slough	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
Richland Shoreline	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U
McNary Dam																	
Oregon Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	Sr-90	Pu
1/3 Oregon Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	No Sample	No Sample
2/3 Oregon Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
Washington Shore	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	No Sample	Pu
Oregon Near Dam	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
Washington Near Dam	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu
Ice Harbor Dam																	
Franklin Co. Shore	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	No Sample	Pu
Mid River	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	No Sample	Gamma, Sr-90, U
Walla Walla Co. Shore	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U, Pu	Gamma, Sr-90, U, Pu	No Sample	Gamma, Sr-90, U, Pu	No Sample	No Sample	Pu
Riverbank Springs																	
100-B Area	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U
100-K Area	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90	No Sample	Gamma, Sr-90	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U	No Sample	Gamma, Sr-90, U
100-H Area	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U
100-F Area	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U
Hanford Town Site	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90	Gamma, Sr-90, U, Pu	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90	No Sample	Gamma, Sr-90, U	Gamma, Sr-90, U	No Sample	Gamma, Sr-90, U	No Sample	Gamma, Sr-90, U
300 Area	No Sample	No Sample	No Sample	No Sample	No Sample	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90	Gamma, Sr-90	No Sample	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U	Gamma, Sr-90, U

Key for Analytes

(hatched)	**= No Sample**
Sr-90	
Pu	
Gamma, Sr-90	
Gamma, Sr-90, U	
Gamma, Sr-90, U, Pu	
Gamma, Sr-90, U, Pu, Th	

Table 4.2. Summary Data for Radionuclides in Columbia and Snake River Sediment, 1988 Through 2004

Location	Det/Total	Max	Min	Mean	Std Dev
Beryllium-7					
Priest Rapids	6/58	18	–1.2	0.47	2.5
Hanford Reach	8/63	0.37	–12	–0.47	2.4
McNary Dam	13/66	13	–8.8	0.051	2.1
Ice Harbor	2/10	0.59	–0.15	0.15	0.20
Cesium-137					
Priest Rapids	66/66	1.0	0.16	0.41	0.16
Hanford Reach	64/67	1.5	0.0071	0.36	0.27
McNary Dam	73/73	1.2	0.11	0.48	0.22
Ice Harbor	10/10	0.36	0.031	0.21	0.11
Europium-155					
Priest Rapids	20/62	0.11	–0.073	0.047	0.030
Hanford Reach	24/67	0.16	0.0036	0.052	0.026
McNary Dam	23/69	0.15	–0.028	0.069	0.035
Ice Harbor	0/10	0.12	0.016	0.061	0.032
Plutonium-238					
Priest Rapids	45/66	0.0018	0.000015	0.00040	0.00035
Hanford Reach	31/61	0.0018	–0.000091	0.00028	0.00034
McNary Dam	54/74	0.0038	–0.000016	0.00062	0.00069
Ice Harbor	6/11	0.00039	0.000015	0.00019	0.00013
Radium-228					
Priest Rapids	9/9	0.96	0.85	0.90	0.044
Hanford Reach	8/8	1.2	0.51	0.93	0.22
McNary Dam	10/10	1.3	0.80	1.0	0.12
Ice Harbor	3/3	1.3	1.0	1.1	0.15

Location	Det/Total	Max	Min	Mean	Std Dev
Cobalt-60					
Priest Rapids	3/66	0.042	–0.032	0.0047	0.014
Hanford Reach	37/67	0.32	–0.0092	0.049	0.059
McNary Dam	38/73	0.44	–0.0034	0.10	0.11
Ice Harbor	0/10	0.014	–0.019	–0.0032	0.011
Europium-152					
Priest Rapids	0/5	0.026	–0.034	0.00035	0.027
Hanford Reach	9/16	0.64	0.0076	0.21	0.20
McNary Dam	13/20	1.1	–0.0058	0.47	0.36
Ice Harbor	0/1	–0.0099	–0.0099	–0.0099	NA
Potassium-40					
Priest Rapids	66/66	17	10	14	1.5
Hanford Reach	67/67	25	9.9	16	2.4
McNary Dam	73/73	17	10	15	1.2
Ice Harbor	10/10	17	13	15	1.4
Plutonium-239/240					
Priest Rapids	68/68	0.018	0.0014	0.0083	0.0037
Hanford Reach	65/65	0.010	0.00040	0.0029	0.0021
McNary Dam	76/76	0.032	0.00047	0.0091	0.0040
Ice Harbor	11/11	0.011	0.00077	0.0064	0.0034
Ruthenium-106					
Priest Rapids	3/62	0.51	–0.35	–0.0017	0.12
Hanford Reach	3/63	0.23	–0.12	0.020	0.070
McNary Dam	3/69	0.26	–0.34	0.0063	0.091
Ice Harbor	0/10	0.11	–0.11	0.015	0.062

Location	Det/Total	Max	Min	Mean	Std Dev
Cesium-134					
Priest Rapids	1/65	0.060	–0.62	–0.050	0.11
Hanford Reach	2/67	0.066	–0.26	–0.020	0.072
McNary Dam	6/72	0.41	–0.39	–0.0087	0.11
Ice Harbor	2/10	0.37	–0.28	0.064	0.19
Europium-154					
Priest Rapids	0/62	0.19	–0.12	0.0020	0.046
Hanford Reach	10/67	0.089	–0.060	0.013	0.034
McNary Dam	13/69	0.26	–0.19	0.026	0.069
Ice Harbor	0/10	0.10	–0.082	–0.013	0.052
Manganese-54					
Priest Rapids	1/1	0.022	0.022	0.022	NA
Hanford Reach	1/1	0.021	0.021	0.021	NA
McNary Dam	0/0	NA	NA	NA	NA
Ice Harbor	0/0	NA	NA	NA	NA
Radium-226					
Priest Rapids	13/13	0.97	0.57	0.74	0.14
Hanford Reach	8/8	0.78	0.43	0.65	0.11
McNary Dam	14/14	0.95	0.68	0.82	0.091
Ice Harbor	3/3	0.85	0.63	0.72	0.12
Antimony-125					
Priest Rapids	0/54	0.060	–0.048	0.00033	0.026
Hanford Reach	2/59	0.048	–0.028	0.0038	0.017
McNary Dam	2/61	0.072	–0.12	0.0046	0.032
Ice Harbor	0/10	0.083	–0.025	0.0072	0.031

Table 4.2. (contd)

Location	Det/Total	Max	Min	Mean	Std Dev	Det/Total	Max	Min	Mean	Std Dev	Det/Total	Max	Min	Mean	Std Dev
	Strontium-90					**Thorium-228**					**Thorium-230**				
Priest Rapids	55/66	0.072	–0.00094	0.012	0.0010	0/0	NA	NA	NA	NA	0/0	NA	NA	NA	NA
Hanford Reach	32/67	0.020	–0.025	0.0033	0.0072	1/1(a)	0.37	0.37	0.37	NA	1/1(a)	0.16	0.16	0.16	NA
McNary Dam	57/75	0.064	–0.010	0.024	0.015	0/0	NA	NA	NA	NA	0/0	NA	NA	NA	NA
Ice Harbor	6/10	0.024	–0.030	0.0074	0.016	0/0	NA	NA	NA	NA	0/0	NA	NA	NA	NA
	Thorium-232					**Uranium-234**					**Uranium-235**				
Priest Rapids	4/4	0.98	0.82	0.93	0.076	31/31	1.1	0.15	0.67	0.22	37/66	0.32	–0.038	0.050	0.059
Hanford Reach	1/1(a)	0.24	0.24	0.24	NA	44/44	2.6	0.11	0.56	0.62	39/70	0.24	–0.011	0.039	0.054
McNary Dam	4/4	1.1	0.98	1.0	0.057	37/37	1.3	0.44	0.85	0.21	48/73	0.22	–0.087	0.046	0.061
Ice Harbor	0/0	NA	NA	NA	NA	10/10	1.9	0.30	0.92	0.43	10/10	0.056	0.014	0.026	0.015
	Uranium-238					**Zinc-65**					**Zirconium/Niobium-95**				
Priest Rapids	65/66	2.2	0.15	0.81	0.36	0/24	0.21	–0.64	–0.20	0.19	1/28	1.8	–1.8	0.068	0.63
Hanford Reach	69/70	2.4	0.10	0.77	0.64	0/23	0.010	–0.66	–0.20	0.19	3/27	2.0	–0.77	–0.011	0.47
McNary Dam	71/73	2.3	0.35	0.98	0.49	1/24	0.12	–0.94	–0.25	0.24	5/28	3.0	–0.19	0.21	0.73
Ice Harbor	10/10	1.2	0.23	0.64	0.26	0/0	NA	NA	NA	NA	0/0	NA	NA	NA	NA

Hanford Reach = White Bluffs Slough, 100-F Slough, Hanford Slough, and Richland Beach.
NA = Not Applicable.
Results for cerium/praseodymium-144 are not shown; all values were reported as undetected.
(a) Thorium analysis by chemical separation and alpha energy analysis (100-F Slough, August 2000).

Manganese-54 has a half-life of 312 days and is produced as an activation product in light water nuclear reactors and from weapons testing. Manganese-54 was readily observed in Columbia River sediment during the operation period of the Hanford single-pass reactors and was found to be associated largely with particles (Nelson et al. 1966; Perkins et al. 1966). Almost 20 half-lives passed from the time the last single-pass reactor shut down (1971) and this reporting period began; thus, there should be no observable Hanford-originated manganese-54 in Columbia River sediment. Manganese-54 was below the detection limits for all Columbia River sediment samples except for a 1992 sample from Priest Rapids Dam and a 1994 sample from 100-F Slough. However, both results were near the detection limits.

Cobalt-60 has a half-life of 5.27 years and is produced as an activation product in nuclear reactors and from weapons testing. Cobalt-60 was readily observed in Columbia River sediment during the operation period of the Hanford single-pass reactors and was found to be associated largely with particles (Nelson et al. 1966; Perkins et al. 1966). During the operational period of the single-pass reactors, the fraction of cobalt-60 associated with particles, compared with water concentrations, increased with increasing distance downstream (Perkins et al. 1966). Robertson and Fix (1977) reported typical concentrations for cobalt-60 in McNary Dam sediments of 27 pCi/g for 1971 and 1.2 pCi/g for 1976.

Approximately 3 half-lives passed (~12% of original material would remain) during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988. By the end of the reporting period in 2004, approximately 6 half-lives had passed and only approximately 1.6% of the original material would remain. A high percentage of detected values for cobalt-60 was observed for samples from the Hanford Reach and McNary Dam through the mid 1990s, with only a few samples having detected values after 1996 (Figure 4.1). The majority of sediment samples from Priest Rapids Dam were below the detection limits throughout the entire reporting period, confirming a Hanford source of cobalt-60 into the Columbia River.

The annual average concentrations of cobalt-60 at Priest Rapids Dam, the Hanford Reach, and McNary Dam are shown in Figure 4.2. Annual average concentrations at McNary Dam from 1988 to the 1990s ranged from 0.27 to 0.18 pCi/g. These values were elevated compared to those at Priest Rapids Dam, which were below the detection limits (approximately 0.025 pCi/g). For 1988 to 1996, the differences between annual average concentrations at Priest Rapids Dam and McNary Dam were statistically significant (t-test, $P < 0.001$). Annual average values at McNary Dam steadily decreased from 1988 until 1996, and values for subsequent years generally were below the detection limit. Annual average concentrations of cobalt-60 in Hanford Reach sediment were lower than those in McNary Dam sediment for the period 1989 to 1994 but were higher for 1995 and 1996. However, the differences were not statistically significant (t-test, $P = 0.14$). Statistical tests were not conducted for samples from 1997 through 2004 because most results were below the detection limit.

Figure 4.3 shows the trend for cobalt-60 in sediment from McNary Dam from 1971 to 2004 and the decay curve for the concentration reported in 1971 from Robertson and Fix (1977). Concentrations of cobalt-60 at McNary Dam decreased dramatically from 1971 to 1976 and reflect the shutdown of the single-pass reactors at the Hanford Site, which eliminated the direct source of cobalt-60 to the Columbia River. The measured decrease in the sediment at McNary Dam was larger than the rate of radioactive decay (using 1971 sediment concentrations) due to dilution with recently deposited uncontaminated sediment. From 1976 through 2004, the measured sediment concentrations of cobalt-60 decreased at a rate that was similar to the rate of radioactive decay, indicating that direct Hanford releases of cobalt-60 had been eliminated.

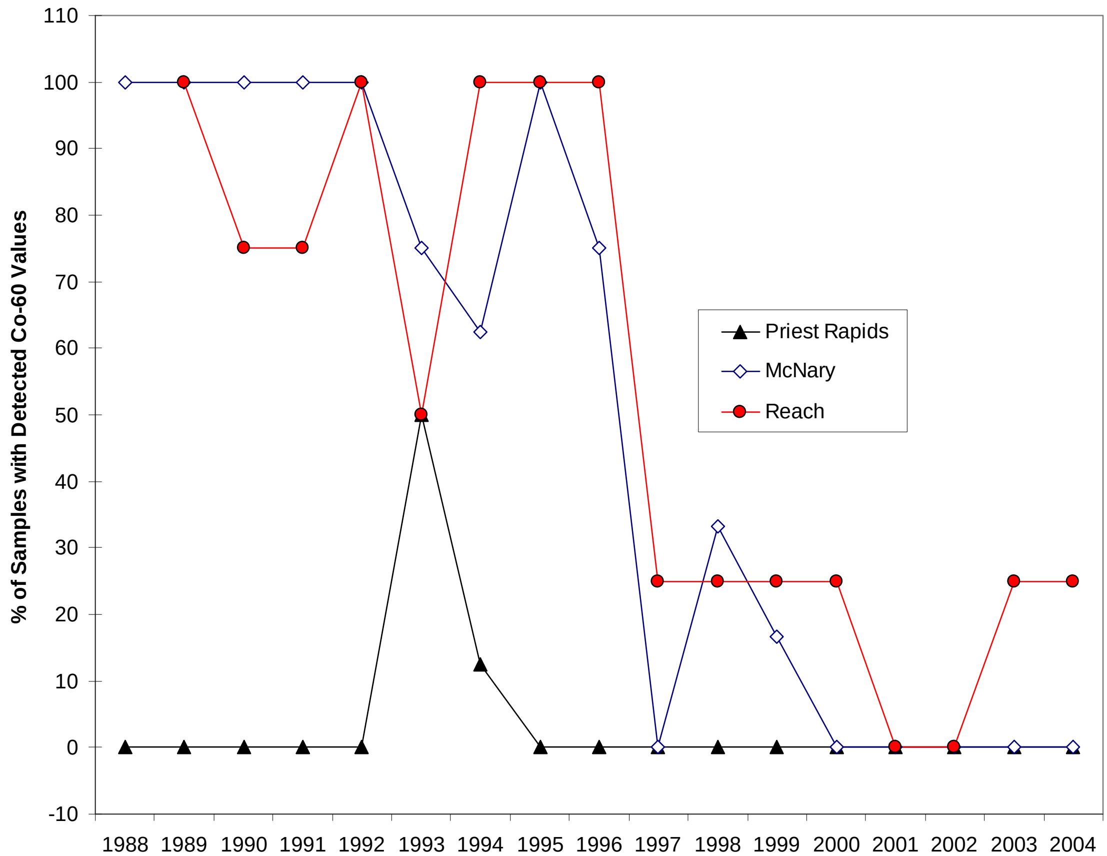

Figure 4.1. Percentage of Columbia River Sediment Samples for Cobalt-60 with Detected Values. All sediment samples from Ice Harbor Dam (10 samples, 1998 through 2004) were reported as undetected.

Zinc-65 has a half-life of 244 days and is produced as an activation product in nuclear reactors and from weapons testing. Zinc-65 was readily observed in Columbia River sediment during the operational period of the Hanford single-pass reactors and was found to be associated largely with particles (Nelson et al. 1966; Perkins et al. 1966). More than 25 half-lives passed during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988; thus, there should be no observable Hanford-originated zinc-65 in Columbia River sediment. Zinc-65 was below the detection limits for all Columbia River sediment samples except for one of four samples from McNary Dam in 1994.

Zirconium/Niobium-95 is a parent and daughter radionuclide pair produced as a fission product. The parent zirconium-95 has a 65-day half–life, and the daughter niobium-95 has a 35-day half-life. For sediment samples, the pair would be in secular equilibrium. More than 175 half-lives passed during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988; thus, there should be no observable Hanford-originated zirconium/niobium-95 in Columbia River sediment. Zirconium/niobium-95 was detected for 8 of 82 reported results for Columbia River sediment samples; however, all of these values were at or near the detection limit. Because of the short half-lives for this radionuclide pair and values at or near the detection limit, the detected values likely resulted from the random probability of counting statistics or possibly an artifact of the analytical process (e.g., difficulty in identifying specific gamma spectrum peaks near the detection limit).

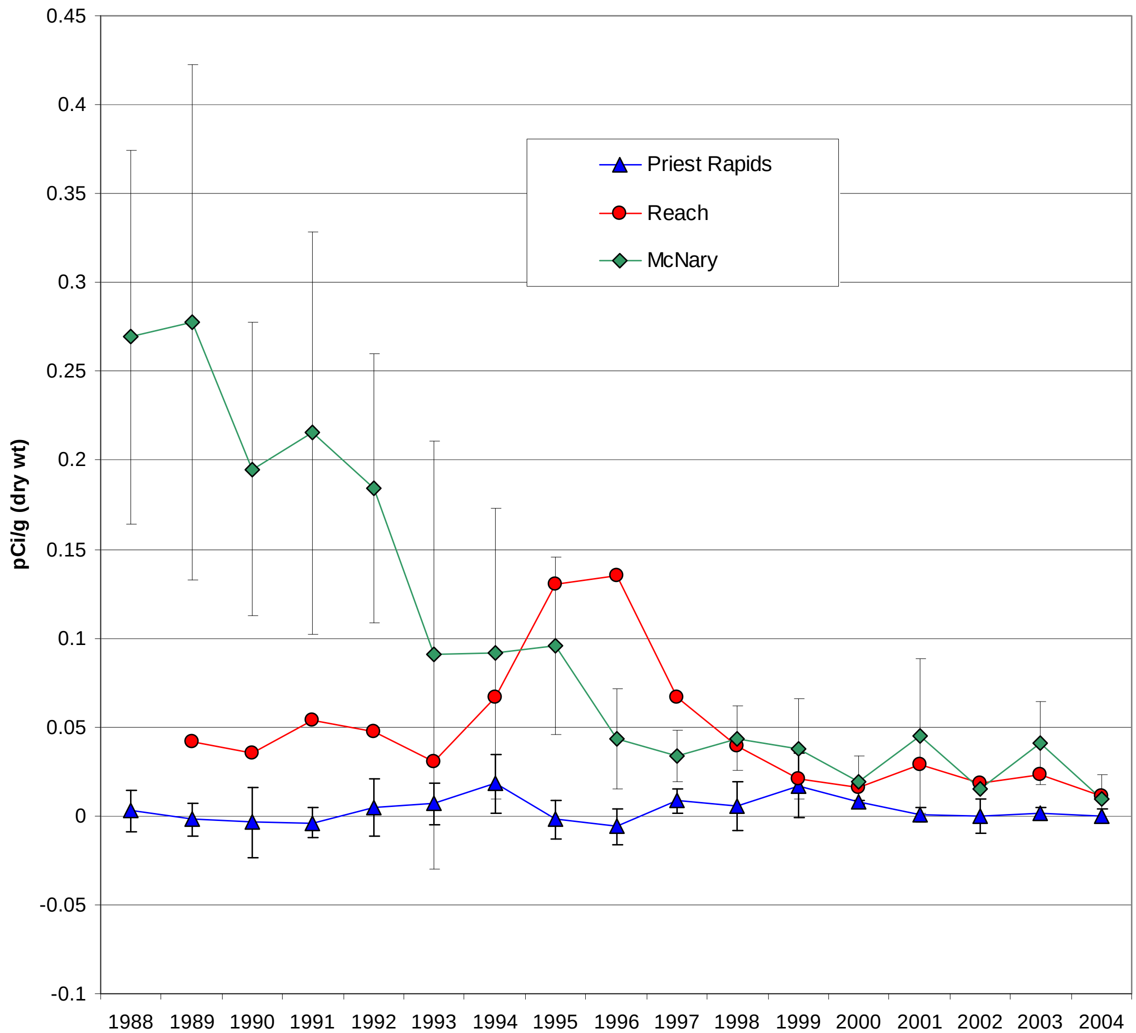

Figure 4.2. Average (±1 std dev) Concentrations of Cobalt-60 in Columbia River Sediment. Error bars were not shown for Hanford Reach values because they obscured differences between results for Priest Rapids Dam and McNary Dam. Note: Most values from Priest Rapids Dam and all values from Ice Harbor Dam (not shown) were reported as undetected values. Prior to 1996, most values from the Hanford Reach and McNary Dam were reported as detected, but most results for samples collected after 1996 were reported as undetected values.

Antimony-125 has a half-life of 2.77 years and is produced as an activation product in nuclear reactors. More than 6 half-lives passed (<3% of original material would remain) during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988. By the end of the reporting period in 2004, 12 half-lives had passed; thus, there should be no observable Hanford-originated antimony-125 for this period. Antimony-125 was detected for 2 of 59 reported results from the Hanford Reach and 2 of 61 reported results from McNary Dam, with all values near the detection limits. All other values were reported as below the detection limits. Because of the short half-life and values at or near the detection limit, the detected values likely resulted from the random probability of counting statistics or possibly an artifact of the analytical process (e.g., difficulty in identifying specific gamma spectrum peaks near the detection limit).

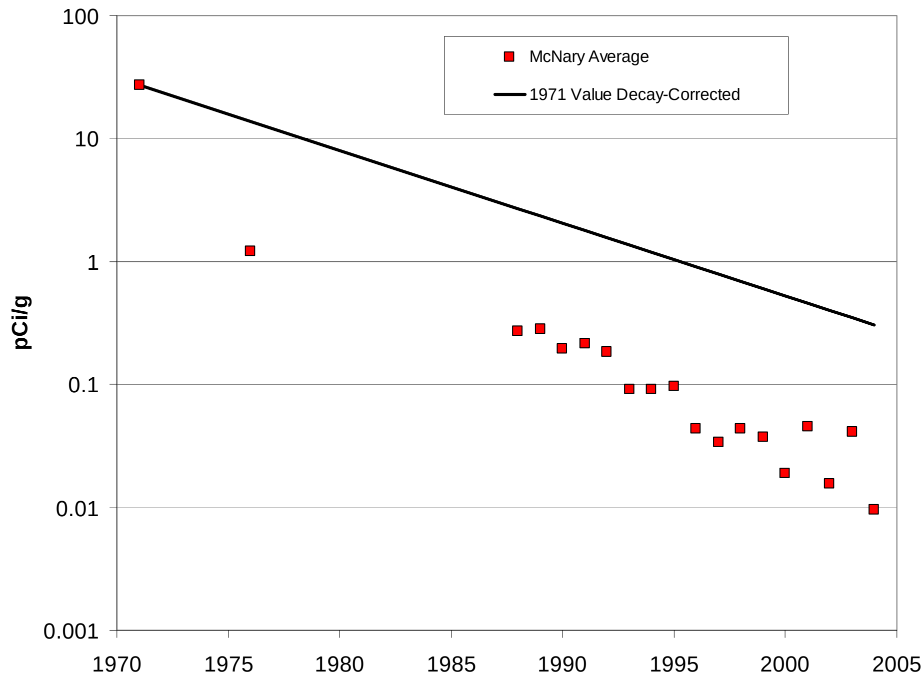

Figure 4.3. Annual Average Concentrations of Cobalt-60 in the Upper Sediment Layer at McNary Dam. The 1971 and 1976 results are from Robertson and Fix (1977).

Cesium-134 has a half-life of 2.06 years and is an activation product in nuclear reactors. More than 8 half-lives passed (<0.4% of original material would remain) during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988; thus, there should be no observable Hanford-originated cesium-134 in Columbia River sediment. Cesium-134 was detected for 1 of 65 reported results at Priest Rapids Dam, 1 of 66 reported results from the Hanford Reach, 3 of 69 reported results from McNary Dam, and 2 of 10 reported results from Ice Harbor Dam. All of these values were near the detection limits. Because of the short half-life and values at or near the detection limit, the detected values likely resulted from the random probability of counting statistics or possibly an artifact of the analytical process (e.g., difficulty in identifying specific gamma spectrum peaks near the detection limit).

Cesium-137 has a half-life of 30.2 years and is a fission product in nuclear reactors and nuclear weapons testing. As a fission product, cesium-137 would have been released to the river following rupture of the metal jackets (cladding) covering the fuel rods in the single-pass reactors. Gephart (2003) reviewed Hanford Site cladding failure events and their contribution to the Columbia River, which were typically small compared to the release of activation products. Beasley and Jennings (1984) estimated that 34 to 48% of the cesium-137 in McNary Dam sediment was of Hanford origin. For Hanford-originated material, approximately 0.56 half-life passed (~68% of original material would remain) during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988. By the end of the reporting period in 2004, approximately 1 half-life had passed (~50% of original material would remain). Cesium-137 is also an important radiological component of Hanford Site waste in the 200 Area vadose zone and waste storage/disposal locations; however, it is readily adsorbed to soil and sediment and is not highly mobile in the vadose zone or groundwater. No significant groundwater plumes are contaminated with cesium-137 at the Hanford Site. As such, transport through the groundwater to the Columbia River is not a viable pathway.

More than 98% of the samples from all locations reported detectable concentration of cesium-137 in river sediment. Annual average cesium-137 concentrations were elevated for McNary Dam sediment compared to sediment from Priest Rapids Dam during 1988 and 1989. However, from 1990 through 2004, there was no observed difference in annual average sediment concentrations from these locations (Figure 4.4). In addition, sediment concentrations for cesium-137 in the Hanford Reach were similar to or less than values from Priest Rapids Dam throughout the reporting period. It is not clear why elevated concentrations at McNary Dam for cesium-137 were reported for 1988 and 1989. The contract analytical laboratory was changed in 1990 (Woodruff et al. 1991, p. 63), and from 1990 to the end of the reporting period the large differences between these locations was not observed. Differences in sediment grain size may also have affected the 1988 and 1989 samples at Priest Rapids Dam. Sediment at the Priest Rapids sampling locations for the four cross-river stations discussed in Section 3.2 was composed primarily of medium and fine sand, while samples collected from the locations near the dam were more similar to those from downstream locations, which are composed primarily of silt/clay, very fine sand, and fine sand (Blanton et al. 1995; Patton and Crecelius 2001). The 1988 and 1989 annual average sediment concentrations at Priest Rapids Dam were similar to the annual average concentrations reported for Hanford Reach sediment collected in 1989; these locations likely had more similar sediment grain size distributions (Hanford Reach sediment was not collected in 1988).

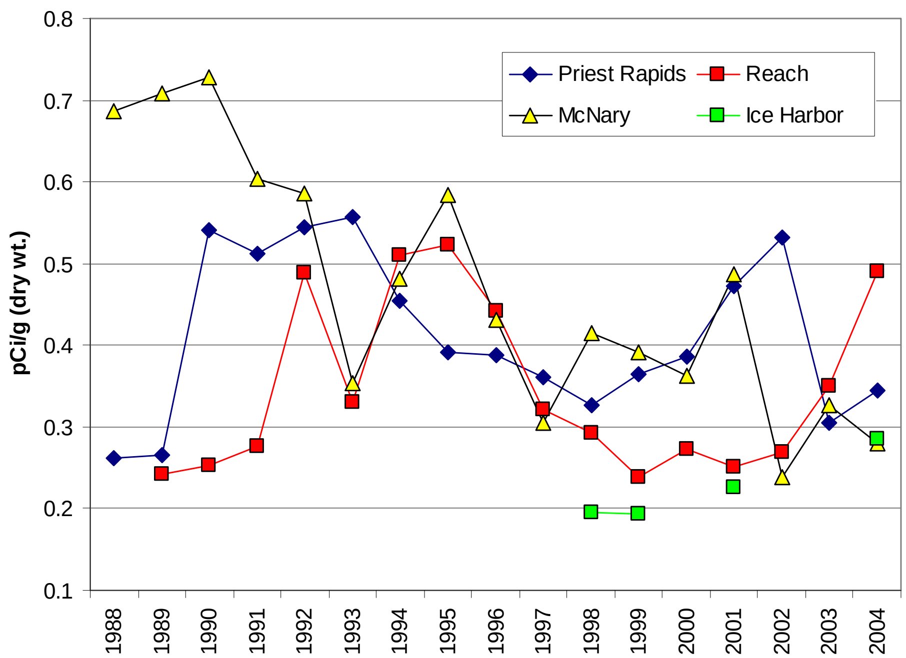

Figure 4.4. Average Concentrations of Cesium-137 in Columbia and Snake River Sediments

For most years, sediment samples from White Bluffs Slough had the highest cesium-137 concentration reported for Hanford Reach locations, most notably for 2004 (1.5 ± 0.18 pCi/g). Previous studies of soils from the White Bluffs Slough detected elevated concentrations of cesium-137, europium-152, and plutonium-239/240 (Sula 1980; Cooper and Woodruff 1993), which were associated with single-pass reactor operations.

Cerium/praseodymium-144 is a parent and daughter radionuclide pair produced as a fission product. The parent cerium-144 has a 285-day half–life, and the daughter praseodymium-144 has a 17-minute half-life. For sediment samples, the pair would be in secular equilibrium. More than 21 half-lives passed during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988; thus, there should be no observable Hanford-originated cerium/praseodymium-144 in Columbia River sediment. There were 71 results reported for cerium/praseodymium-144 in Columbia River sediment samples, and all values were below the detection limits.

Europium isotopes (europium-152, -154, -155) are activation products in nuclear reactors and have half-lives of 13.3, 8.8, and 5 years, respectively. For europium-152, -154, and -155, approximately 41%, 26%, and 9.5% of the original material would remain during the time since the last single-pass reactor shut down in 1971 and this reporting period began in 1988. Further, these values would have decreased to approximately 18%, 7.4%, and 1.0% by the end of the reporting period in 2004. During 1988 through 1997, europium isotopes were detected for some samples; however, from 1998 through 2004, only one sample (White Bluffs Slough, July 2004, 0.51 ± 0.099 pCi/g) was reported above the detectable concentrations by the analytical laboratory. Previous studies of soils from the White Bluffs Slough detected elevated europium-152 (Sula 1980; Cooper and Woodruff 1993), which was associated with single-pass reactor operations.

From 1988 until the early 1990s, europium-152, europium-154 (1988 only), and europium-155 annual average concentrations in sediment were elevated at McNary Dam compared to those samples from other locations (Figures 4.5, 4.6, and 4.7). For samples with detected concentrations at McNary Dam, europium-152 had the highest concentrations, with overall average values typically 5–7 times higher than europium-154 and europium-155.

The thorium isotopes (thorium-228, -230, -232) are naturally occurring radionuclides. Thorium-232 has a half life of 1.4×10^{10} years, with thorium-228 (1.9 year half-life) as a daughter product in the thorium decay series. Thorium-230 has an 80,000-year half-life and is a daughter product in the uranium-238 decay series. In 1988, thorium-232 was detected in sediment samples from both Priest Rapids Dam and McNary Dam, with similar concentrations at both locations. This was the only data available for thorium isotopes from assays for gamma-emitting radionuclides. In August 2000, a sediment sample collected from the 100-F Slough was analyzed using a chemical separation followed by alpha energy analysis with detected values reported for thorium-228, -230, and -232. The concentration of thorium-232 reported for 100-F Slough was lower than 1988 results at Priest Rapids Dam and McNary Dam.

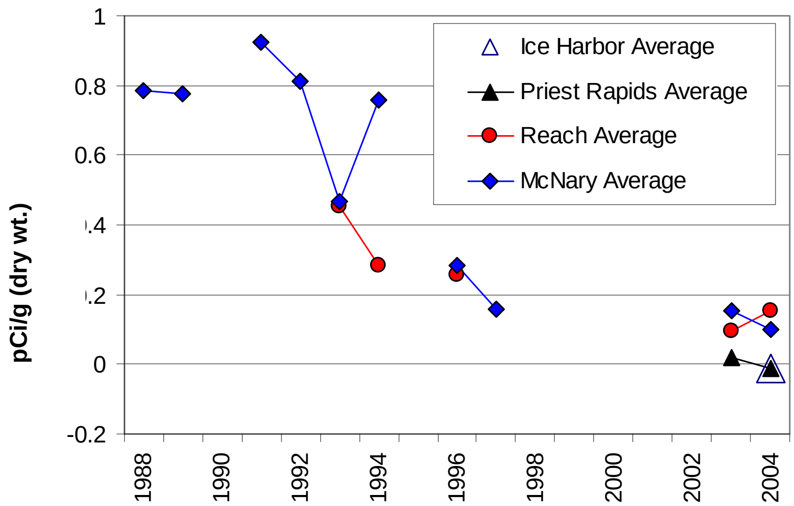

Figure 4.5. Average Concentrations of Europium-152 in Columbia and Snake River Sediments. From 1997 through 2004, only two results were reported above the detection limit (1997 McNary Dam Washington Shore, 0.16 ± 0.039 pCi/g; and 2004 White Bluffs Slough, 0.51 ± 0.099 pCi/g).

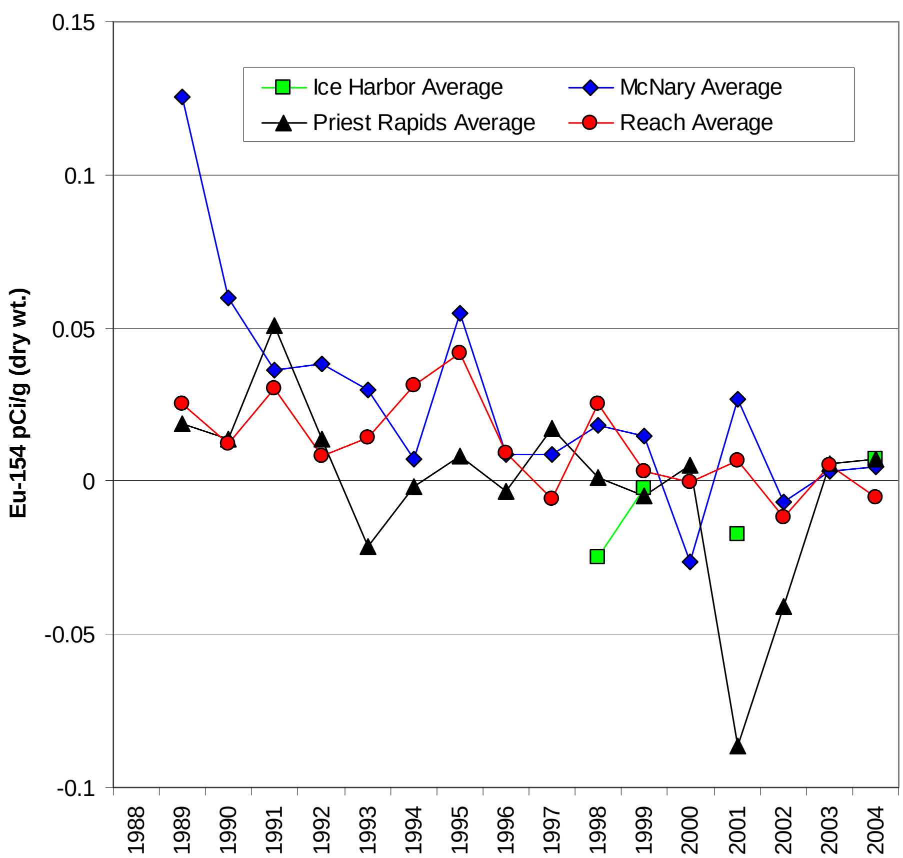

Figure 4.6. Average Concentrations of Europium-154 in Columbia and Snake River Sediments. From 1997 through 2004, all results were below the reported detection limits.

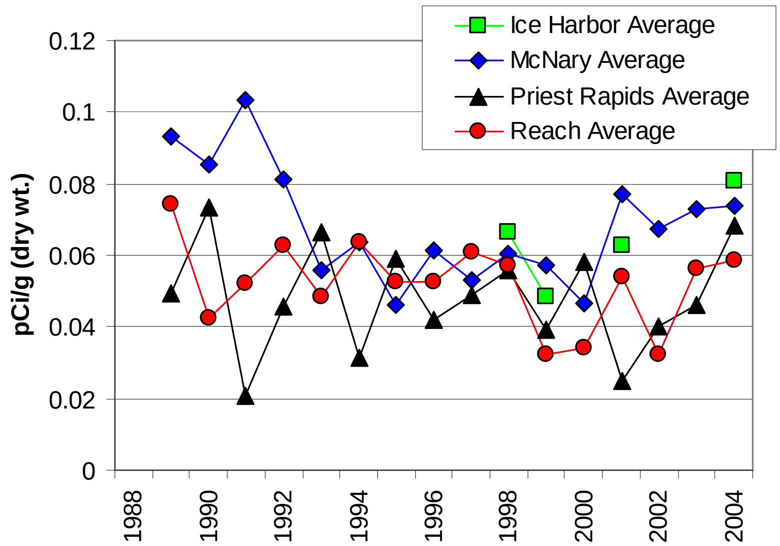

Figure 4.7. Average Concentrations of Europium-155 in Columbia and Snake River Sediments. From 1997 through 2004, all results were below the reported detection limits.

4.2 Strontium-90 in Columbia and Snake River Sediments

Strontium-90 has a half-life of 29.1 years and is produced as a fission product in nuclear reactors and from weapons testing. Strontium-90 typically was not analyzed in Columbia River sediment during the operational period of the single-pass reactors (Nelson et al. 1966; Perkins et al. 1966) or following the shutdown of the single-pass reactors (Robertson and Fix 1977; Beasley and Jennings 1984). These early studies focused on primarily on gamma emitting radionuclides (particularly activation products) associated with the releases from the single pass reactors; whereas, inputs of strontium-90 to the Columbia River during this period would have been dominated by atmospheric fallout (Jaquish 1993; Poston et al. 1998). In addition, the analytical method for strontium-90 was considerably more complex and costly compared to method for measuring gamma-emitting radionuclides.

Following the closure of the single-pass reactors, strontium-90 releases to the Columbia River were largely from the 100-N Area reactor and contaminated groundwater plumes near the single-pass reactors (Peterson and Poston 2000). The 100-N Area reactor was a heat-exchanged reactor that operated continuously from 1963 to 1987. Effluents from the primary coolant system from the reactor were discharged to cribs approximately 0.4 km from the river shore. Strontium-90 was a major component of the 100-N Area reactor effluent that was discharged to the cribs. Over time, strontium-90 migrated from the cribs, through the soil column, into the groundwater and eventually reached the Columbia River. Substantial amounts of strontium-90 (reported as liquid effluents by Site contractors) began to enter the Columbia River at the 100-N Area around 1977, peaked at roughly 8.5 Ci/yr by 1985, and had decreased to less than 1 Ci/yr by 1991 (Figure 4.8) which continued through 2004 (Poston et al. 2005). Strontium-90 discharged with groundwater at the 100-N Area would have been dispersed by the river; however, some of the material would have become associated with waterborne particles and deposited on the riverbed as sediment. The earliest data points for strontium-90 in Columbia River sediment from the Hanford Site Surface Environmental Surveillance Project are from 1988 and 1989.

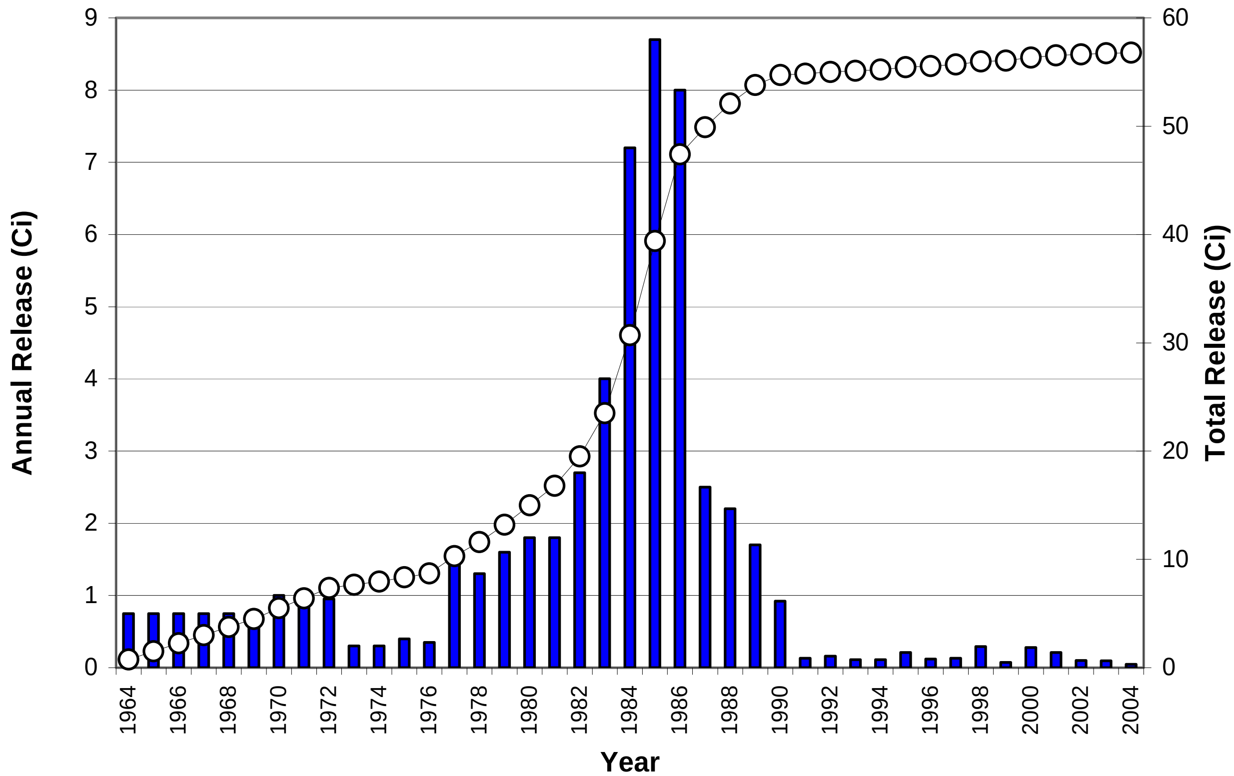

Figure 4.8. Estimated Releases of Strontium-90 to the Columbia River from 100-N Area Groundwater Sources, 1964 through 2004. The 1964 through 1991 values are from Jaquish (1993); 1992 through 2004 values are from the Hanford Site annual environmental reports (Section 3.5.1).

A discussion of the strontium-90 concentrations measured in unfiltered Columbia River water collected upriver and downriver from the Hanford Site provides some information on the potential for Hanford operations to influence downriver sediment concentration. For 1980 through 1989, the concentrations of strontium-90 in unfiltered Columbia River water samples at Priest Rapids Dam and the city of Richland water intake were similar and not statistically different at the 5% significance level (P-value = 0.0517); however, the difference was very close to being significant and may be indicative of a slight influence attributable to Hanford operations (Dirkes 1994). Hanford Site annual environmental reports for 1990 through 2004 reported similar water concentration for strontium-90 at Priest Rapids Dam and the city of Richland water intake, with no significant difference between locations on an annual basis (references in Section 3.5.1).

A high percentage of detected values for strontium-90 was observed at all sediment sampling locations from 1988 through 1999 (Figure 4.9). However, by the end of the reporting period (2000 through 2004), almost all values were reported as below the detection limits. Because the majority of results for 2000 through 2004 were below the detection limits and to allow for easier observation of trends for detected values, the annual average concentrations of strontium-90 in sediment at Priest Rapids Dam, the Hanford Reach, McNary Dam, and Ice Harbor Dam are shown for only 1988 through 1999

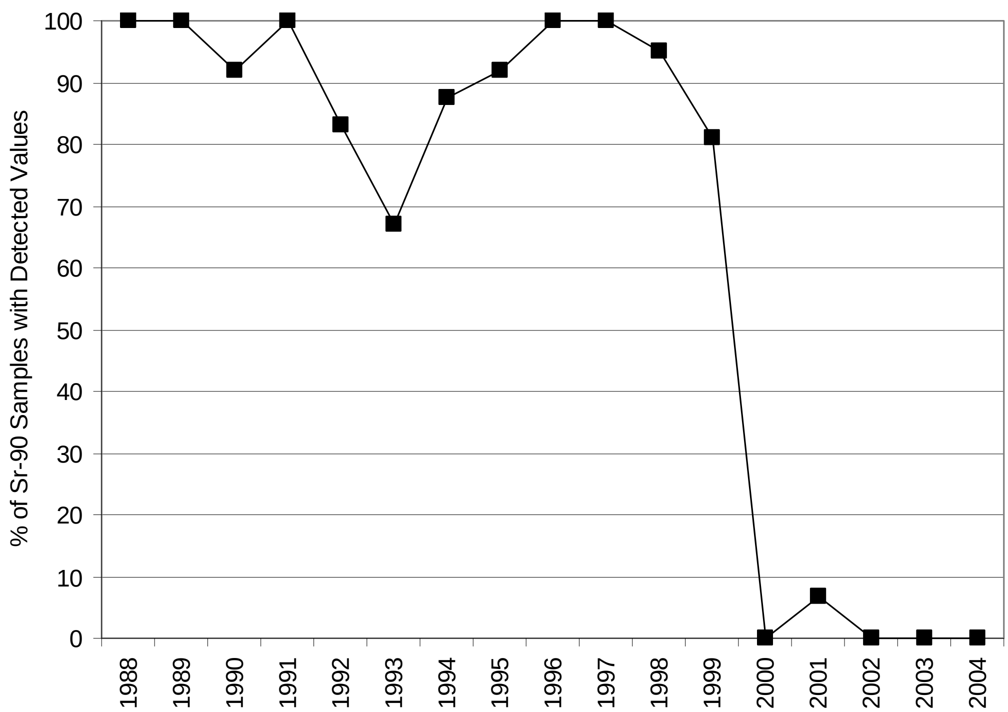

Figure 4.9. Percentage of Columbia River Sediment Samples for Strontium-90 with Detected Values, 1988 through 2004

(Figure 4.10). Annual average concentrations at McNary Dam from 1988 through 1992 typically were above 0.03 pCi/g, and these values were elevated compared to those at Priest Rapids Dam, which typically were less than 0.015 pCi/g. However, the maximum strontium-90 concentration was reported for a 1988 sediment sample collected from Priest Rapids Dam (0.072 ± 0.015 pCi/g, at Priest Rapids Dam - 1/3 Grant Shore). For 1988 to 1999, the differences between annual average concentrations at Priest Rapids Dam and McNary Dam were statistically significant (paired t-test, $P < 0.05$). Annual average values at McNary Dam generally decreased from 1988 until 1996, and values for subsequent years were mostly below the detection limit.

4.3 Uranium Isotopes (Uranium-234, -235, -238) in Columbia and Snake River Sediments

Uranium occurs naturally in the environment. Natural uranium is composed of uranium-234 (half-life of 2.5×10^5 yr), uranium-235 (half-life of 7.1×10^8 yr), and uranium-238 (half-life of 4.5×10^9 yr) with natural abundances of 0.005%, 0.72%, and 99.275%, respectively. The half-lives of these isotopes are extremely long, and essentially no radioactive decay would have occurred for any uranium released from operations at the Hanford Site. Natural uranium is interesting in that, on a chemical basis, almost all of the uranium is present as uranium-238. However, on a radiological basis, the activities of uranium-234 and uranium-238 are roughly equal, with uranium-235 contributing only a negligible portion of the total activity. For nuclear fuel or special nuclear material, the percentage of the fissile uranium-235 typically is increased; this material is called enriched uranium. Uranium that has been processed to remove uranium-235 is called depleted uranium.

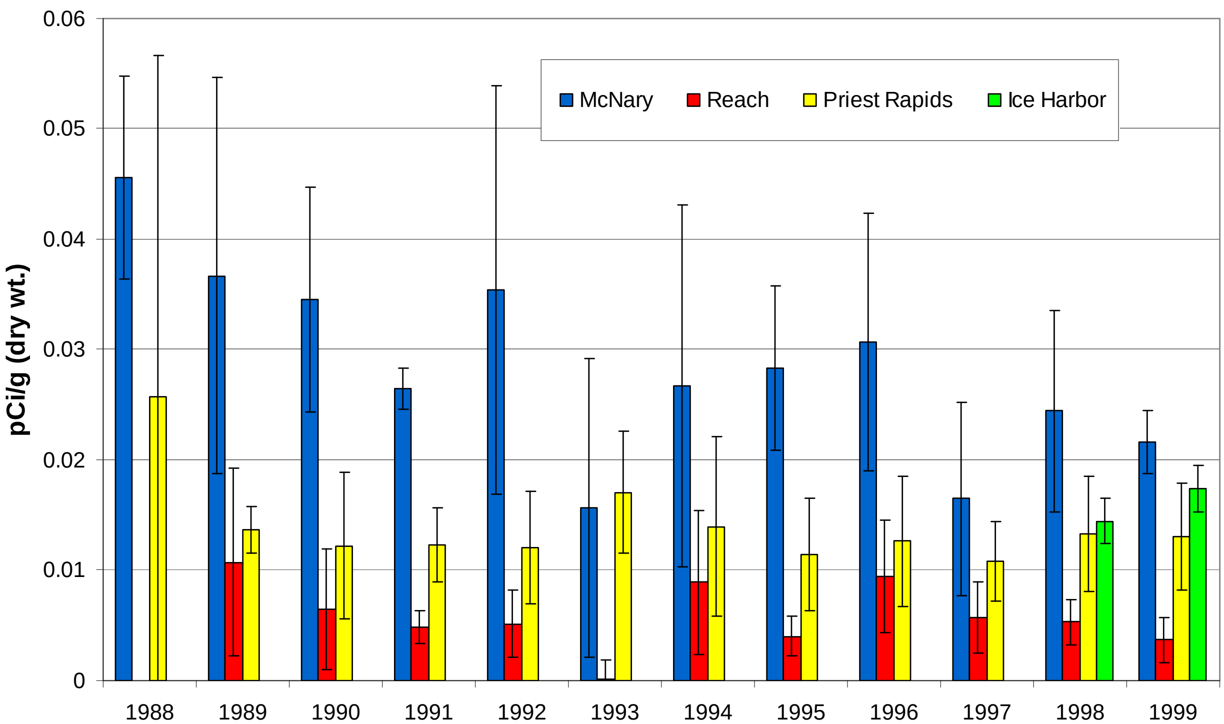

Figure 4.10. Average Concentrations of Strontium-90 in Columbia and Snake River Sediments. Because most results for 2000 through 2004 were below the detection limits, the average concentrations of strontium-90 at Priest Rapids Dam, the Hanford Reach, McNary Dam, and Ice Harbor Dam are shown for only 1988 through 1999.

Uranium inputs to the Hanford Reach of the Columbia River come from a variety of sources including natural, agricultural, and Hanford Site releases. Operations at the Hanford Site have employed natural, enriched, and depleted uranium; thus, both the environmental concentrations and the isotopic ratios are important factors when evaluating potential Hanford Site contributions to Columbia River sediment. Riverbank spring water samples collected along the Hanford Site 300 Area (adjacent to a contaminated groundwater plume) have concentrations of uranium and gross alpha radioactivity that can exceed drinking water standards, with both concentrations decreasing rapidly upon release to the river (Poston et al. 2005; Patton et al. 2002). Columbia River water samples collected downstream from irrigation returns on the Franklin County shore (opposite to the Hanford Site) have elevated uranium concentrations, compared to mid-channel, and are likely related to the use phosphate fertilizer which contain traces of uranium (Poston et al. 2005).

Different contract analytical laboratories and analytical methods were used to determine the isotopic concentrations of uranium in Columbia and Snake River sediment samples during the period covered in this report (Section 3.4). Table 4.3 summarizes the isotopic concentrations reported for the U-LEPS analytical method, while Table 4.4 lists results obtained with the U-AEA method. The different analytical techniques make temporal comparison from 1988 through 2004 difficult. The major problems are the lack of uranium-234 values for the U-LEPS results, higher detection limits and a high percentage of undetected results for uranium-235 for the U-LEPS results, and differences between using the directly counted U-LEPS values compared to the U-AEA method.

Table 4.3. Average Concentrations of Uranium Isotopes for Columbia and Snake River Sediments Determined via Low-Energy Photon Detection System

	Isotope	(pCi/g)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
McNary Dam	U-235	Mean	0.045	0.065	–	–	0.065	0.056	0.032	0.16	0.037	0.088	–	–	–	–	–	–	–
–	–	*Std Dev*	*0.13*	*0.10*	–	–	*0.049*	*0.070*	*0.063*	*0.049*	*0.063*	*0.090*	–	–	–	–	–	–	–
–	U-238	Mean	0.78	0.62	–	–	1.2	1.0	1.4	1.9	1.6	1.6	–	–	–	–	–	–	–
–	–	*Std Dev*	*0.12*	*0.20*	–	–	*0.14*	*0.44*	*0.44*	*0.41*	*0.6*	*0.38*	–	–	–	–	–	–	–
Priest Rapids Dam	U-235	Mean	0.063	0.038	–	–	0.052	0.059	0.068	0.16	0.055	0.10	–	–	–	–	–	–	–
–	–	*Std Dev*	*0.042*	*0.045*	–	–	*0.046*	*0.025*	*0.081*	*0.12*	*0.095*	*0.029*	–	–	–	–	–	–	–
–	U-238	Mean	0.73	0.76	–	–	0.80	1.0	1.0	1.4	1.1	1.2	–	–	–	–	–	–	–
–	–	*Std Dev*	*0.049*	*0.13*	–	–	*0.058*	*0.21*	*0.36*	*0.70*	*0.33*	*0.21*	–	–	–	–	–	–	–
Hanford Reach	U-235	Mean	–	0.080	–	–	0.046	0.060	0.043	0.093	0.091	0.039	–	–	–	–	–	–	–
–	–	*Std Dev*	–	*0.015*	–	–	*0.047*	*0.065*	*0.011*	*0.18*	*0.072*	*0.030*	–	–	–	–	–	–	–
–	U-238	Mean	–	0.64	–	–	0.80	1.1	0.92	1.9	1.8	1.0	–	–	–	–	–	–	–
–	–	*Std Dev*	–	*0.057*	–	–	*0.27*	*0.22*	*0.45*	*0.44*	*0.30*	*0.24*	–	–	–	–	–	–	–

Table 4.4. Average Concentrations of Uranium Isotopes for Columbia and Snake River Sediments Determined via Alpha Energy Analysis

	Isotope	(pCi/g)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
McNary Dam	U-234	Mean	–	–	1.1	1.2	–	–	–	–	–	–	0.72	0.66	0.79	0.77	0.82	0.83	0.93
–	–	*Std Dev*	–	–	*0.12*	*0.12*	–	–	–	–	–	–	*0.14*	*0.13*	*0.070*	*0.14*	*0.044*	*0.15*	*0.098*
–	U-235	Mean	–	–	0.027	0.048	–	–	–	–	–	–	0.026	0.021	0.020	0.024	0.024	0.024	0.028
–	–	*Std Dev*	–	–	*0.005*	*0.018*	–	–	–	–	–	–	*0.007*	*0.004*	*0.003*	*0.005*	*0.010*	*0.002*	*0.004*
–	U-238	Mean	–	–	1.0	0.99	–	–	–	–	–	–	0.58	0.52	0.64	0.59	0.70	0.66	0.74
–	–	*Std Dev*	–	–	*0.094*	*0.10*	–	–	–	–	–	–	*0.10*	*0.084*	*0.044*	*0.098*	*0.001*	*0.088*	*0.065*
Priest Rapids Dam	U-234	Mean	–	–	0.88	0.92	–	–	–	–	–	–	0.52	0.50	0.68	0.64	0.62	0.70	0.72
–	–	*Std Dev*	–	–	*0.18*	*0.061*	–	–	–	–	–	–	*0.19*	*0.25*	*0.068*	*0.25*	*0.14*	*0.041*	*0.16*
–	U-235	Mean	–	–	0.033	0.037	–	–	–	–	–	–	0.017	0.017	0.023	0.027	0.023	0.019	0.025
–	–	*Std Dev*	–	–	*0.007*	*0.010*	–	–	–	–	–	–	*0.007*	*0.010*	*0.004*	*0.013*	*0.002*	*0.004*	*0.012*
–	U-238	Mean	–	–	0.84	0.81	–	–	–	–	–	–	0.45	0.44	0.61	0.53	0.54	0.62	0.61
–	–	*Std Dev*	–	–	*0.14*	*0.11*	–	–	–	–	–	–	*0.16*	*0.22*	*0.064*	*0.099*	*0.12*	*0.059*	*0.13*
Hanford Reach	U-234	Mean	–	0.76	1.4	1.8	–	–	0.18	0.12	–	–	0.23	0.18	0.40	0.22	0.61	0.26	0.25
–	–	*Std Dev*	–	*0.17*	*0.77*	*0.30*	–	–	*0.073*	*(n = 1)*	–	–	*0.086*	*0.027*	*0.20*	*0.17*	*0.70*	*0.10*	*0.10*
–	U-235	Mean	–	0.024	0.055	0.11	–	–	0.007	0.002	–	–	0.009	0.006	0.015	0.008	0.021	0.010	0.009
–	–	*Std Dev*	–	*0.015*	*0.034*	*0.059*	–	–	*0.003*	*(n = 1)*	–	–	*0.005*	*0.002*	*0.008*	*0.005*	*0.022*	*0.010*	*0.008*
–	U-238	Mean	–	0.75	1.34	1.9	–	–	0.17	0.121	–	–	0.22	0.17	0.37	0.19	0.52	0.24	0.28
–	–	*Std Dev*	–	*0.22*	*0.66*	*0.42*	–	–	*0.069*	*(n = 1)*	–	–	*0.079*	*0.026*	*0.15*	*0.13*	*0.55*	*0.082*	*0.11*
Ice Harbor Dam	U-234	Mean	–	–	–	–	–	–	–	–	–	–	0.83	0.69	–	0.92	–	–	1.9
–	–	*Std Dev*	–	–	–	–	–	–	–	–	–	–	*0.33*	*0.34*	–	*0.15*	–	–	*(n = 1)*
–	U-235	Mean	–	–	–	–	–	–	–	–	–	–	0.020	0.034	–	0.018	–	–	0.050
–	–	*Std Dev*	–	–	–	–	–	–	–	–	–	–	*0.007*	*0.021*	–	*0.003*	–	–	*(n = 1)*
–	U-238	Mean	–	–	–	–	–	–	–	–	–	–	0.59	0.49	–	0.62	–	–	1.2
–	–	*Std Dev*	–	–	–	–	–	–	–	–	–	–	*0.19*	*0.222*	–	*0.085*	–	–	*(n = 1)*

Because of the difference in analytical methods, detailed temporal plots for uranium isotopes were produced for the most recent period from 1998 through 2004 when the same analytical laboratory and analytical method (U-AEA) were used. Figures 4.11, 4.12, and 4.13 show the annual average concentration of uranium isotopes in Columbia and Snake River sediment samples from 1998 through 2004. In general, the samples analyzed by U-LEPS reported higher concentrations of uranium isotopes; however, a large number of the uranium-235 values were undetected.

For 1998 through 2004, annual average concentrations of uranium-234 were below 1.0 pCi/g for all locations. One exception was the average concentration of uranium-234 at Ice Harbor Dam in 2004, which had an elevated value of 1.9 pCi/g. For a given location, annual average uranium-234 concentrations were similar for this period. Annual average uranium-234 concentrations varied between locations, with Ice Harbor Dam higher than McNary Dam, which was higher than Priest Rapids Dam. Concentrations of uranium-234 generally were lower for sediment from the Hanford Reach compared to those from the other locations and may have been influenced by the larger sediment grain size found at the locations in the Hanford Reach (Blanton et al. 1995; Patton and Crecelius 2001).

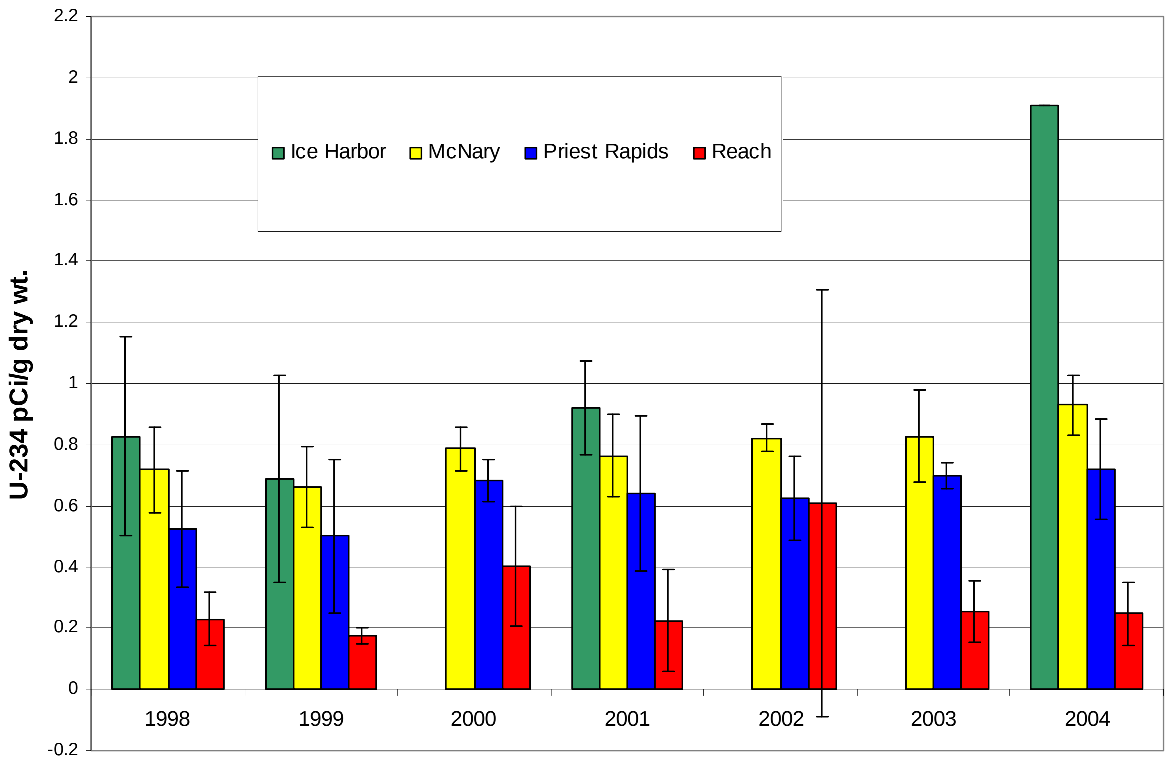

Figure 4.11. Average Concentrations of Uranium-234 in Columbia and Snake River Sediments. Values for 1998 through 2004 were determined via alpha energy analysis.

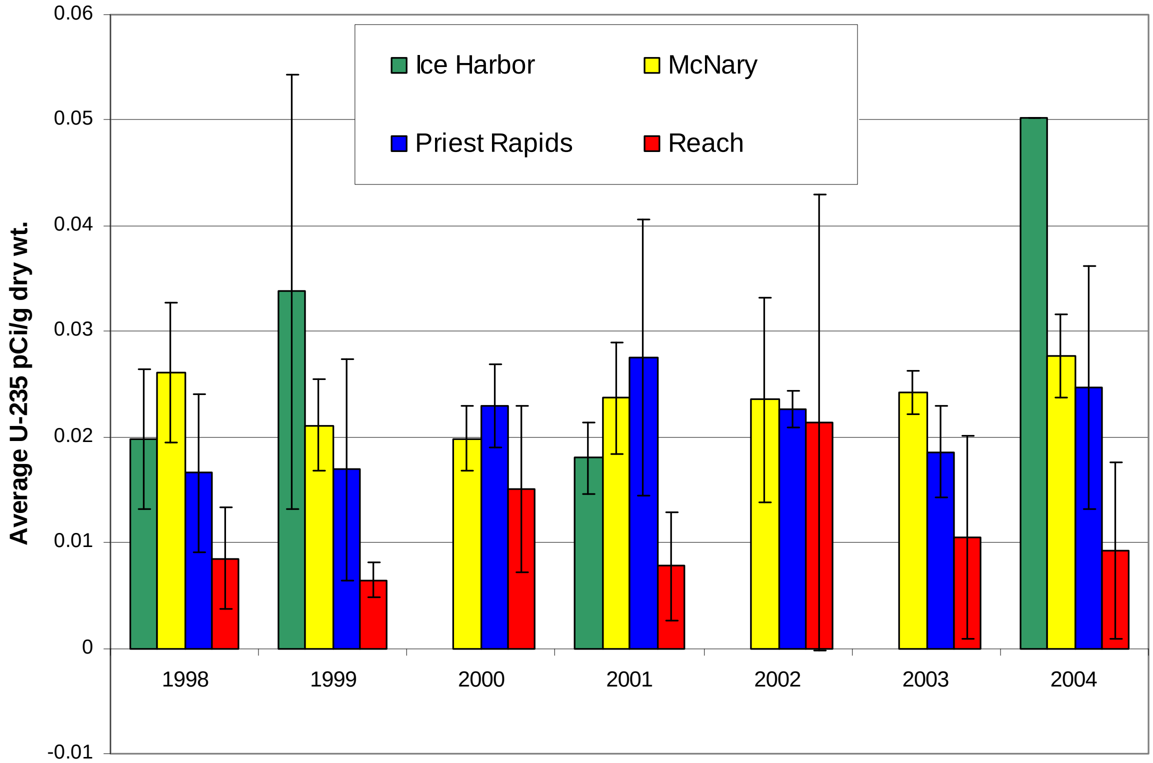

Figure 4.12. Average Concentrations of Uranium-235 in Columbia and Snake River Sediments. Values for 1998 through 2004 were determined via alpha energy analysis.

For 1998 through 2004, annual average concentrations of uranium-235 were below 0.03 pCi/g for all locations except Ice Harbor Dam. Similar values were observed for sediment collected upstream from both Priest Rapids and McNary dams. The average concentrations of uranium-235 at Ice Harbor Dam were elevated in 1999 (0.034 pCi/g) and 2004 (0.050 pCi/g). Concentrations of uranium-235 generally were lower for sediment from the Hanford Reach compared to those of the other locations and may have been influenced by the larger sediment grain size found at the sampling sites in the Hanford Reach (Blanton et al. 1995; Patton and Crecelius 2001).

For 1998 to 2004, annual average concentrations of uranium-238 were below 0.8 pCi/g for all locations, with similar values for sediment collected upstream from Priest Rapids, McNary, and Ice Harbor dams. One exception was the average concentration of uranium-238 at Ice Harbor Dam in 2004, which had an elevated value of 1.2 pCi/g. Concentrations of uranium-238 generally were lower for sediment from the Hanford Reach compared to those from the other locations and may have been influenced by the larger sediment grain size found at the sampling locations in the Hanford Reach (Blanton et al. 1995; Patton and Crecelius 2001).

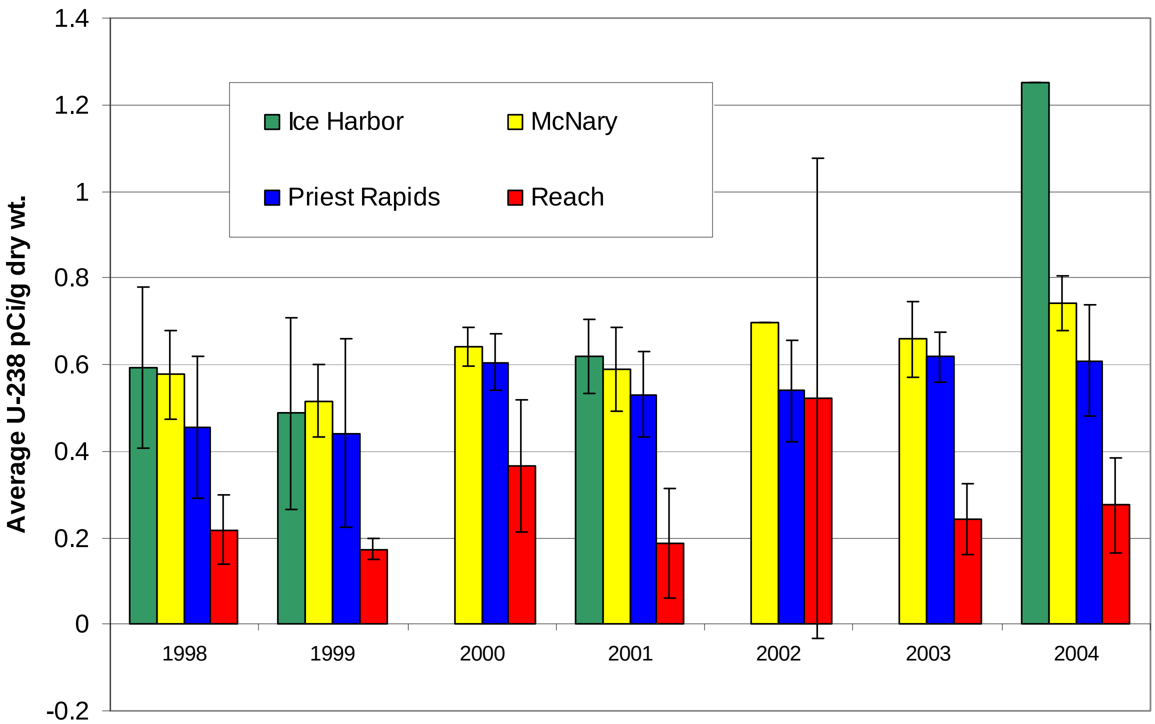

Figure 4.13. Average Concentrations of Uranium-238 in Columbia and Snake River Sediments. Values for 1998 through 2004 were determined via alpha energy analysis.

4.4 Plutonium Isotopes (Plutonium-238, -239/240) in Columbia and Snake River Sediments

Plutonium does not occur naturally but is produced by neutron irradiation of uranium in nuclear reactors. The major plutonium isotopes of environmental concern at the Hanford Site are plutonium-238 (half-life of 87.7 yr), plutonium-239 (half-life of 24,000 yr), and plutonium-240 (half-life of 6,580 yr). For plutonium-238, approximately 0.2 half-life passed (~87% of original material would remain) during the time since the last single-pass reactor shut down (1971) and this reporting period began in 1988. By the end of the reporting period in 2004, approximately 0.4 half-lives had passed (~76% of original material would remain). The half-lives of plutonium-239 and plutonium-240 are extremely long, and essentially no radioactive decay would have occurred for any material released from operations at the Hanford Site. Weapons-grade plutonium is composed largely of plutonium-239 (94% or greater), with plutonium-240 making up most of the remaining material (Gephart 2003). Plutonium-238 is a minor by-product of plutonium production and is a minor component of radioactive fallout. The analytical technique used for analyzing plutonium in river sediment samples is able to separate plutonium-238 from other plutonium isotopes. However, the method does not separate plutonium-239 and plutonium-240. For this reason, results are reported as the combined activity from both plutonium-239 and plutonium-240 (plutonium-239/240).

Small amounts of plutonium isotopes were released to the river following rupture of fuel rods in the single-pass reactors and also by activation of naturally occurring uranium in the cooling water (Gephart

2003). However, these releases would likely have been small compared to the contribution coming from fallout from atmospheric weapons testing. Plutonium is adsorbed readily to soil and sediment and is not highly mobile in the vadose zone or groundwater. The Hanford Site does not have extensive groundwater plumes contaminated with plutonium, and transport through the groundwater to the Columbia River is not a viable pathway.

Plutonium-238 was detected for at least 70% of the sediment samples collected at Priest Rapids and McNary dams, with detected values reported for roughly 50% of the samples collected at the Hanford Reach and Ice Harbor Dam. No observed trend occurred for the percentage of detected values for plutonium-238 over the reporting period. Plutonium-238 results are not available for the samples collected in 2002 due to analytical difficulties. Annual average concentrations of plutonium-238 for sediment at McNary Dam were elevated compared to those from Priest Rapids Dam and the Hanford Reach for 1988 through 1991, 1994, and 2000 (Figure 4.14). For 1988 through 2004, annual average concentrations of plutonium-238 were below 0.002 pCi/g for all locations, with the highest annual average concentration of plutonium-238 at McNary Dam in 1994 (0.0016 ± 0.0014 pCi/g). Concentrations of plutonium-238 generally were slightly lower for sediment from the Hanford Reach compared to those of the other locations (Figure 4.14) and likely reflect the larger sediment grain size found at the locations in the Hanford Reach (Blanton et al. 1995; Patton and Crecelius 2001).

Plutonium-239/240 was detected in all sediment samples collected during the reporting period. For 1988 through 2004, annual average concentrations of plutonium-239/240 were below 0.014 pCi/g for all locations. Over the period of this report, the range of annual average concentrations for plutonium-239/240 reported for sediment collected from Priest Rapids, McNary, and Ice Harbor dams were similar, with the

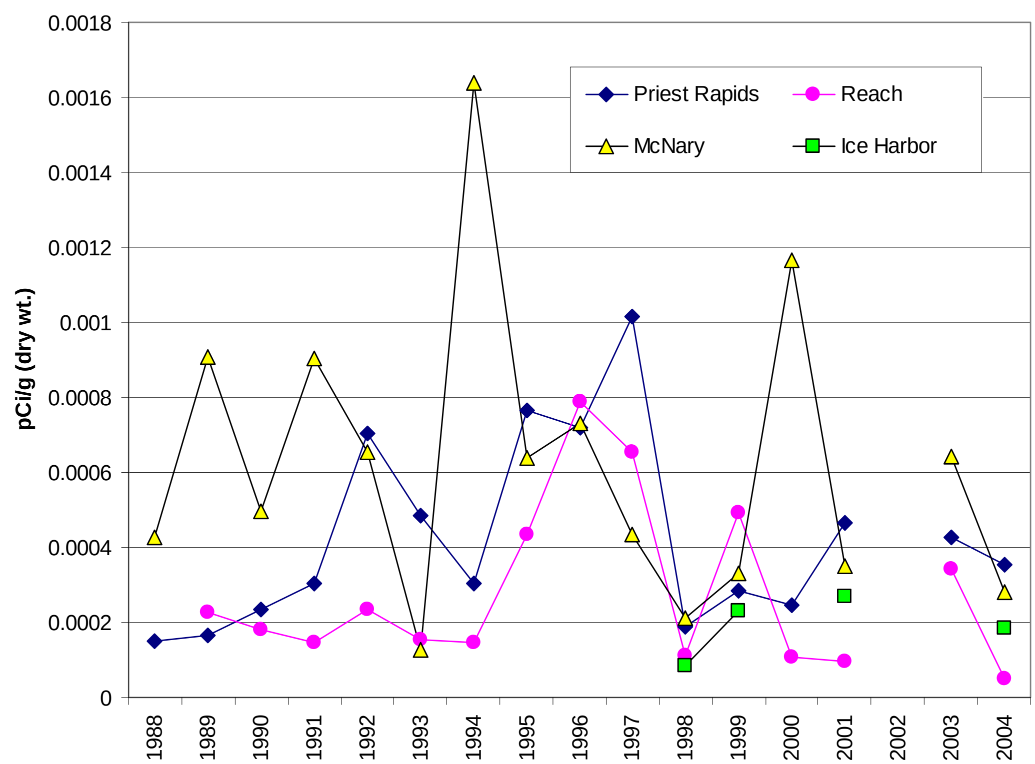

Figure 4.14. Average Concentrations of Plutonium-238 in Columbia and Snake River Sediments

exception of 1988 and 1989 values at McNary Dam, which were elevated compared to those at Priest Rapids Dam (Figure 4.15). The differences between plutonium-239/240 levels at McNary and Priest Rapids dams in 1988 and 1989 appear to be the result of low concentrations at Priest Rapids Dam rather than elevated concentrations at McNary Dam compared to overall trend data from 1988 through 2004. Concentrations of plutonium-239/240 were lower for sediment from the Hanford Reach compared to sediments from the other locations and likely reflect the larger sediment grain size found at the locations in the Hanford Reach (Blanton et al. 1995; Patton and Crecelius 2001).

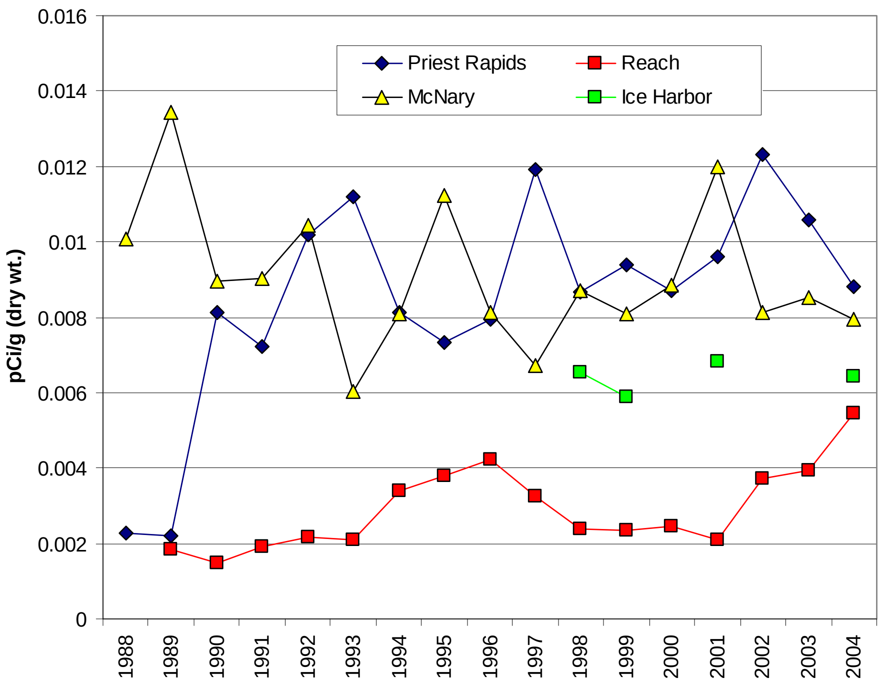

Figure 4.15. Average Concentrations of Plutonium-239/240 in Columbia and Snake River Sediments

4.5 Radionuclides in Sediment at Hanford Reach Riverbank Springs

The Columbia River is the discharge zone for the unconfined aquifer at the Hanford Site. The Hanford Site groundwater provides a means of transportation to the Columbia River for chemical and radionuclide contaminants that have leached in the aquifer from past operational and waste disposal practices. Routine monitoring of riverbank spring water and sediment provides a means of assessing the potential human and ecological risk associated with groundwater discharges (Dirkes 1990). Most of the Hanford Site monitoring effort has focused on measuring concentrations of contaminants in riverbank spring water; however, the concentrations of contaminants in the sediment also are of interest because of the potential for contaminants to accumulate on the sediment.

The collection of sediment samples from riverbank spring discharge locations at the Hanford Site began during 1993 at the Hanford town site and the 300 Area. The sediment monitoring was expanded in 1995 to include riverbank springs in the 100-B, 100-K, and 100-F Areas. Shoreline substrates at the riverbank spring locations at the 100-N, 100-D, and 100-H Areas are composed largely of large cobble and gravels and are generally unsuitable for sediment sampling. A summary of the overall concentrations of radionuclides in riverbank spring sediment is provided in Table 4.5. Average concentrations are reported as the mean ± 1 standard deviation of the mean.

Table 4.5. Summary Data for Reported Radionuclides[a] in Sediment Samples at Hanford Site Riverbank Spring Discharges (1993 to 2004)

Location	Det[b]Total	Max	Min	Mean	Std Dev
Beryllium-7					
100-B Area	2/10	0.30	−0.061	0.092	0.11
100-K Area	0/4	0.15	−0.066	0.062	0.10
100-H	0/2	0.29	0.022	0.16	0.19
100-F Area	0/10	0.18	−0.34	0.045	0.15
Hanford Town Site	3/11	0.42	−0.06	0.150	0.13
300 Area	2/17	0.22	−0.044	0.097	0.066
Europium-152					
100-B Area	0/2	0.0097	−0.00041	0.0046	0.0072
100-K Area	0/1	−0.0059	−0.0059	−0.0059	NA
100-H	0/2	0.061	0.019	0.040	0.029
100-F Area	1/3	0.27	0.018	0.14	0.13
Hanford Town Site	2/3	0.28	0.11	0.21	0.093
300 Area	0/5	0.064	−0.024	0.021	0.036
Potassium-40					
100-B Area	10/10	16	12	14	0.85
100-K Area	4/4	15	13	14	0.69
100-H	2/2	16	15	15	1.1
100-F Area	10/10	19	14	16	1.4
Hanford Town Site	11/11	16	13	15	1.2
300 Area	17/17	20	13	15	1.5
Antimony-125					
100-B Area	0/9	0.44	−0.043	0.0049	0.24
100-K Area	0/3	0.013	−0.0045	0.0038	0.0090
100-H	0/2	0.0081	0.0059	0.0070	0.0016
100-F Area	0/9	0.044	−0.011	0.0092	0.017
Hanford Town Site	1/10	0.031	−0.018	0.0089	0.01500
300 Area	0/16	0.017	−0.034	−0.0033	0.016

Location	Det/Total	Max	Min	Mean	Std Dev
Cobalt-60					
100-B Area	1/10	0.051	0.00088	0.015	0.016
100-K Area	0/4	0.015	0.0044	0.0081	0.0050
100-H	0/2	0.012	0.011	0.012	0.0005
100-F Area	1/10	0.044	0.00027	0.017	0.015
Hanford Town Site	6/11	0.090	0.022	0.052	0.023
300 Area	2/17	0.020	−0.011	0.0077	0.0081
Europium-154					
100-B Area	0/10	0.019	−0.062	−0.017	0.022
100-K Area	0/4	0.016	−0.034	−0.0075	0.020
100-H	0/2	0.022	−0.0067	0.0076	0.020
100-F Area	0/10	0.03	−0.049	−0.0038	0.021
Hanford Town Site	1/11	0.039	−0.068	−0.0021	0.0303
300 Area	1/17	0.110	−0.065	0.013	0.037
Radium-226					
100-B Area	1/1	0.53	0.53	0.53	NA
100-K Area	NS	NS	NS	NS	NS
100-H	NS	NS	NS	NS	NS
100-F Area	2/2	0.75	0.56	0.65	0.14
Hanford Town Site	1/1	0.84	0.84	0.84	NA
300 Area	1/1	0.71	0.71	0.71	NA
Strontium-90					
100-B Area	0/10	0.0068	−0.026	−0.0011	0.0096
100-K Area	1/4	0.017	0.0012	0.010	0.007
100-H	0/2	−0.0081	−0.010	−0.0091	0.0014
100-F Area	1/10	0.013	−0.020	0.00042	0.0099
Hanford Town Site	3/11	0.022	−0.012	0.0040	0.0089
300 Area	3/16	0.020	−0.020	0.0031	0.011

Location	Det/Total	Max	Min	Mean	Std Dev
Cesium-137					
100-B Area	9/10	0.14	0.024	0.074	0.035
100-K Area	4/4	0.19	0.10	0.14	0.042
100-H	2/2	0.20	0.15	0.17	0.036
100-F Area	10/10	0.32	0.071	0.16	0.082
Hanford Town Site	11/11	0.29	0.099	0.21	0.053
300 Area	15/17	0.27	0.015	0.10	0.080
Europium-155					
100-B Area	1/10	0.11	0.043	0.074	0.022
100-K Area	1/4	0.13	0.020	0.062	0.049
100-H	0/2	0.070	0.061	0.066	0.0063
100-F Area	1/10	0.073	0.020	0.045	0.019
Hanford Town Site	3/11	0.1	0.046	0.068	0.018
300 Area	2/17	0.13	0.029	0.061	0.025
Radium-228					
100-B Area	1/1	0.86	0.86	0.86	NA
100-K Area	NS	NS	NS	NS	NS
100-H	NS	NS	NS	NS	NS
100-F Area	2/2	1.0	0.89	0.96	0.11
Hanford Town Site	1/1	1.3	1.3	1.3	NA
300 Area	1/1	1.2	1.2	1.2	NA
Uranium-234					
100-B Area	7/7	0.49	0.18	0.32	0.13
100-K Area	2/2	0.30	0.26	0.28	0.030
100-H	2/2	0.43	0.36	0.39	0.052
100-F Area	7/7	0.70	0.28	0.49	0.14
Hanford Town Site	7/7	0.75	0.41	0.56	0.11
300 Area	14/14	11	0.28	2.7	2.7

Table 4.5. (contd)

Location	Det/Total	Max	Min	Mean	Std Dev	Det/Total	Max	Min	Mean	Std Dev
Uranium-235						**Uranium-238**				
100-B Area	6/7	0.029	0.0053	0.013	0.0080	7/7	0.41	0.17	0.28	0.10
100-K Area	2/2	0.0091	0.0085	0.0088	0.0004	2/2	0.28	0.24	0.26	0.028
100-H	2/2	0.012	0.010	0.011	0.0015	2/2	0.39	0.32	0.36	0.052
100-F Area	7/7	0.060	0.016	0.026	0.015	7/7	0.65	0.28	0.44	0.12
Hanford Town Site	7/7	0.024	0.011	0.017	0.0049	7/7	0.60	0.33	0.46	0.077
300 Area	14/14	0.38	0.0099	0.11	0.095	14/14	10	0.29	2.5	2.4

(a) The total represents the number of reported results in the Hanford Environmental Information System database.
(b) Det = reported by the analytical laboratory as a detected value.
Results for Zn-65, Zr/Nb-95, Ru-106, Cs-134, and Ce/Pr-144 are not shown, all values were reported as undetected.
Only one result was reported for Mn-54 (100-B Area 0.023 ± 0.0089 pCi/g on 8/28/1995).
Only one result was reported for Pu-238 (Hanford town site 0.000078 ± 0.00014 pCi/g on 9/25/1994, undetected value).
Only one result was reported for Pu-239/240 (Hanford town site 0.0027 ± 0.00074 pCi/g on 9/25/1994).
Uranium isotopic results are for alpha energy analysis.

4.5.1 Gamma-Emitting Radionuclides

In general, the results for gamma-emitting radionuclides in riverbank spring sediments from the Hanford Site were similar to the concentration reported earlier for the Columbia River sediment from the Hanford Reach and Priest Rapids Dam. Potassium-40 and cesium-137 were the only gamma-emitting radionuclides routinely reported above the minimum detectable concentrations, with periodic detections reported for beryllium-7, manganese-54 (1 of 10), cobalt-60, europium isotopes, radium-226, radium-228, and antimony-125 (1 of 10).

At all locations, naturally occurring potassium was similar for both river and riverbank spring sediment samples. Overall average cesium-137 concentrations were typically lower for riverbank spring sediment samples compared to river sediment from Priest Rapids Dam and the Hanford Reach (Figure 4.16). Because of the short half-lives for manganese-54 and antimony-125 and values at or near the detection limit, the detected values likely resulted from the random probability of counting statistics or possibly an artifact of the analytical process (e.g., difficulty in identifying specific gamma spectrum peaks near the detection limit).

For all locations, the concentrations of gamma-emitting radionuclides in riverbank spring sediment samples were below those that would result in a 1-mrem effective dose equivalent to the hypothetical maximally exposed individual using a shoreline exposure scenario (i.e., 500 hr/yr of external exposure to 1,250 m^2 of sediment, with no ingestion or inhalation pathways; DOE/RL-91-50).

4.5.2 Strontium-90

The overall average concentrations of strontium-90 in riverbank spring sediments from the Hanford Site were similar to the concentration reported earlier for the Columbia River sediments from the Hanford Reach and Priest Rapids Dam (Figure 4.17). Strontium-90 is a contaminant of particular interest at the 100-N Area. However, the riverbank springs at the 100-N Area are composed primarily of large cobble and gravels, which are generally unsuitable for sediment sampling, so routine samples of sediment from the 100-N Area are not collected. A combined study by the Washington State Department of Health and the Surface Environmental Surveillance Project (Van Verst et al. 1998) reported localized elevated concentrations of strontium-90 in sediment samples collected along the 100-N Area shoreline. However, the amount of sediment available was limited and was collected using special techniques from depressions under large rocks.

4.5.3 Uranium Isotopes

The overall average concentrations of uranium isotopes in sediment samples from the Hanford Site riverbank springs were similar to levels in Columbia River sediment, with the exception of the 300 Area where the average uranium concentrations are usually two to three times the background concentrations measured at Priest Rapids Dam (Figure 4.18, 4.19, and 4.20). For the riverbank spring water samples at the 300 Area in association with the sediment samples, the concentration of uranium in riverbank spring water for some discharge locations routinely exceeds the Washington State ambient surface water quality criterion of 30 µg/L (~27 pCi/L; Poston et al. 2004). In addition, at some 300 Area locations the riverbank spring water also exceeds the Washington State ambient surface water quality criterion for gross alpha (15 pCi/L; Poston et al. 2004). Elevated uranium concentrations are present in the groundwater at the 300 Area, which was used for fabricating uranium fuel rods, waste storage and disposal, and a wide range of research activities. Elevated uranium concentrations for 300 Area riverbank spring sediment have been reported previously (Patton et al. 2002; Poston et al. 2004). The maximum reported concentration for uranium isotopes for sediment from the 300 Area riverbank spring location is approximately 20% of the 50 pCi/g concentrations that would result in a 1-mrem dose to the hypothetical maximally exposed individual (Table 3.1; DOE/RL-91-50).

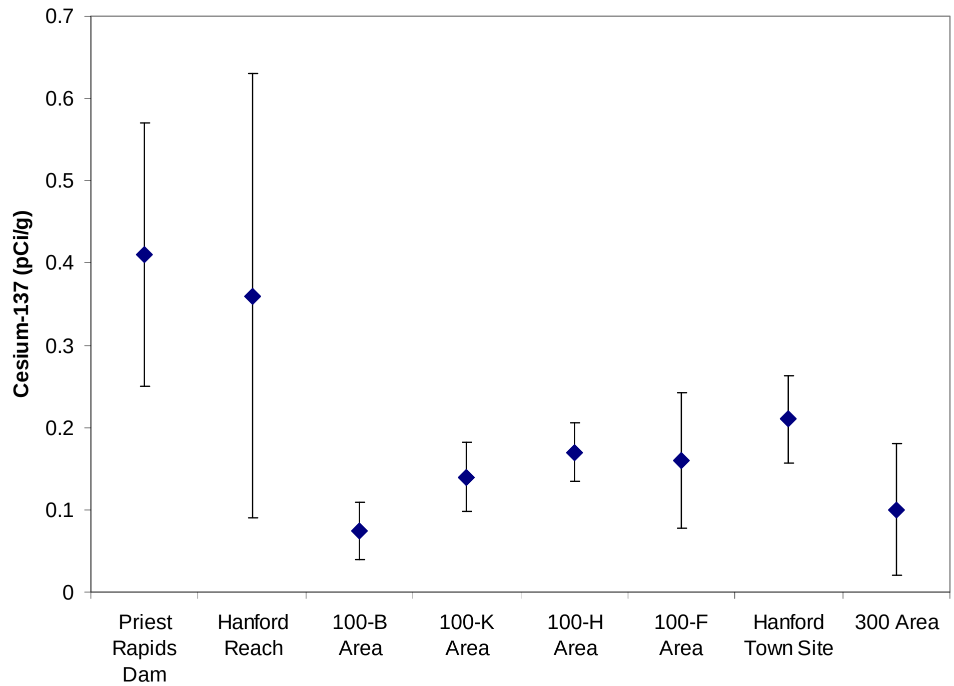

Figure 4.16. Overall Average Concentrations of Cesium-137 in Sediments from Hanford Site Riverbank Springs (Table 4.5) and Columbia River Sediment (Priest Rapids Dam and the Hanford Reach, Table 4.2)

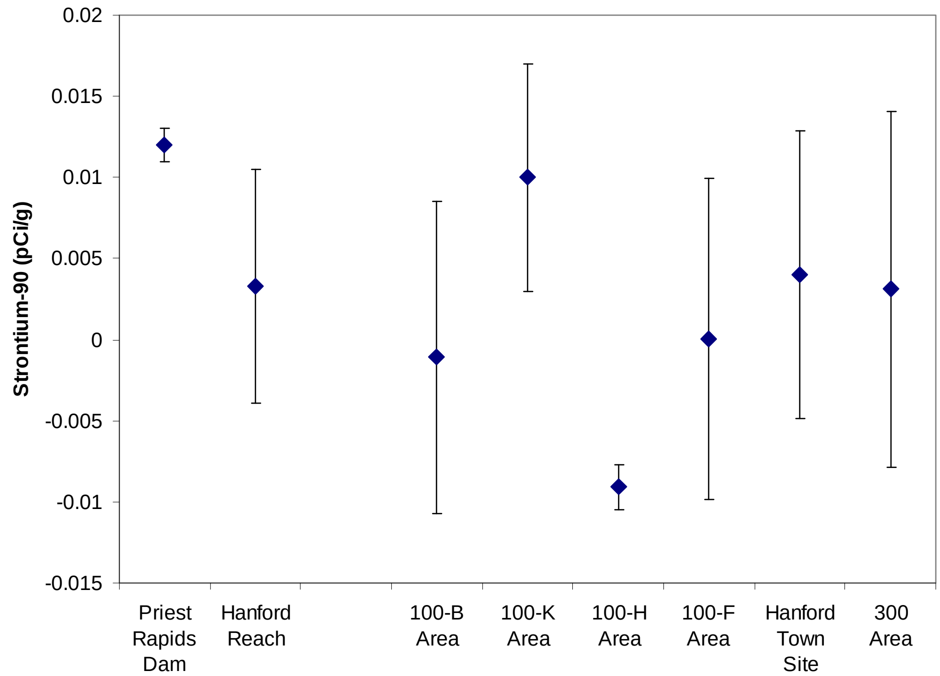

Figure 4.17. Overall Average Concentrations of Strontium-90 in Sediments from Hanford Site Riverbank Springs (Table 4.5) and Columbia River Sediment (Priest Rapids Dam and the Hanford Reach, Table 4.2)

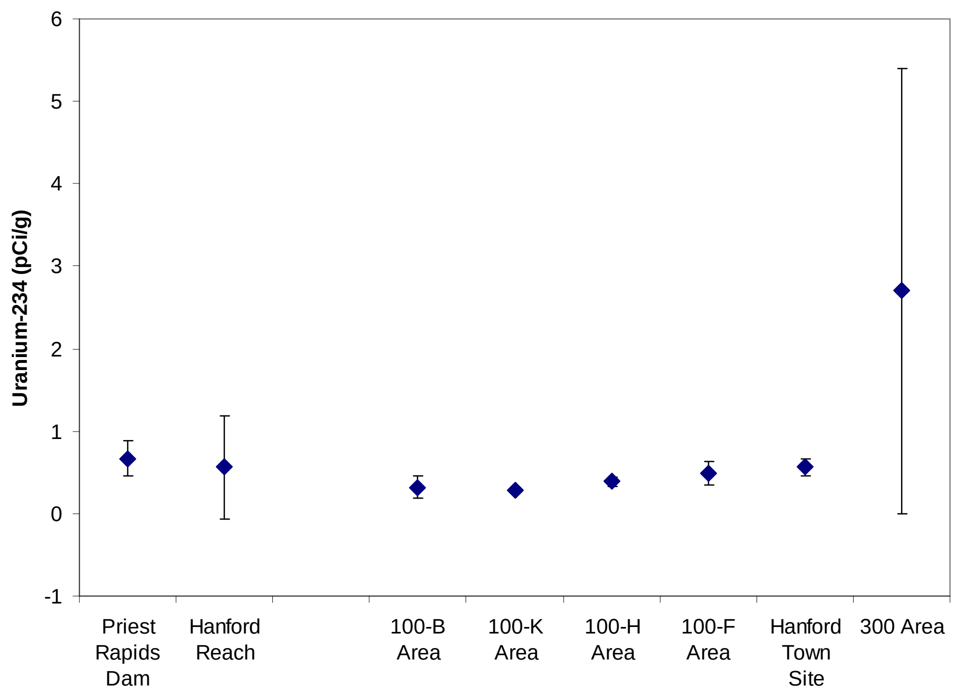

Figure 4.18. Overall Average Concentrations of Uranium-234 in Sediments from Hanford Site Riverbank Springs (Table 4.5) and Columbia River Sediment (Priest Rapids Dam and the Hanford Reach, Table 4.2)

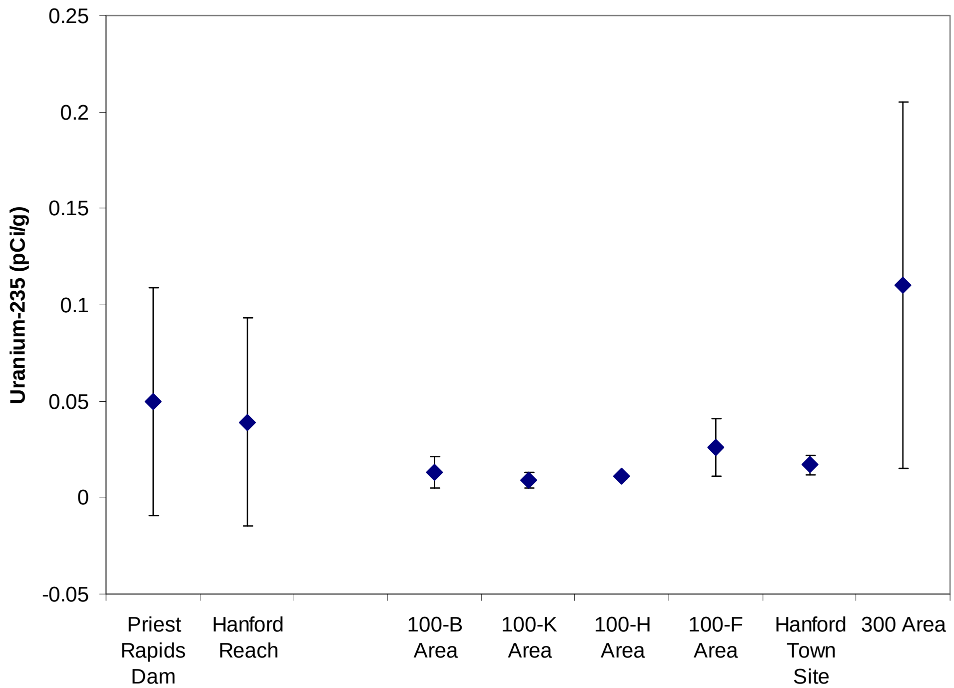

Figure 4.19. Overall Average Concentrations of Uranium-235 in Sediments from Hanford Site Riverbank Springs (Table 4.5) and Columbia River Sediment (Priest Rapids Dam and the Hanford Reach, Table 4.2)

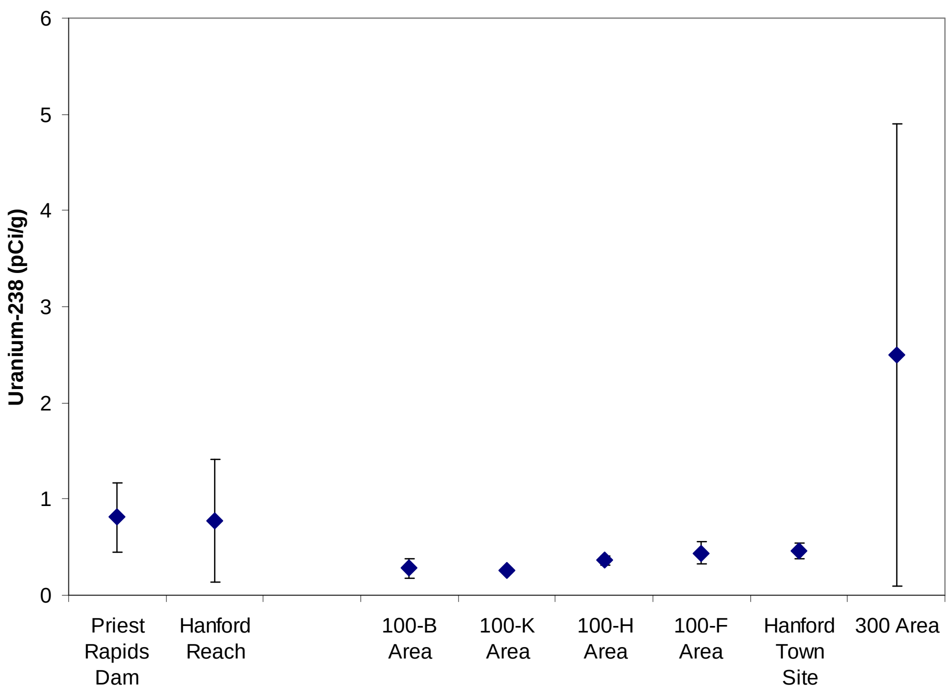

Figure 4.20. Overall Average Concentrations of Uranium-238 in Sediments from Hanford Site Riverbank Springs (Table 4.5) and Columbia River Sediment (Priest Rapids Dam and the Hanford Reach, Table 4.2)

5.0 Conclusions

Operation of the single-pass reactors at the Hanford Site resulted in the deposition of radionuclides, primarily short half-life activation products, at sediment accumulation areas in the Columbia River. Operation of the single-pass reactors ended in 1971, and a number of studies were conducted that documented the rapid decline in the radionuclide inventory in the sediment from the decay of short-lived radionuclides and the deposition of fresh sediment material (Fix 1976; Robertson and Fix 1977). For the period from 1975 through 1988, environmental monitoring of Columbia River sediment was limited.

From 1988 through 2004, Columbia River and Snake River sediments (upper layer) were collected under the Hanford Site Surface Environmental Surveillance Project to document concentrations and trends of radionuclides. Low concentrations of potassium-40, cesium-137, uranium isotopes, and plutonium isotopes were detected consistently in sediment samples over the entire sampling period. The concentrations of most radionuclides were similar to values measured upstream of the Hanford Site at Priest Rapids Dam. From 1988 through 1997, cobalt-60 was detected at higher concentrations for McNary Dam sediment than for Priest Rapids Dam sediment. However, by 1998 the concentrations of cobalt-60 in sediment samples were generally below the laboratory-reported detection limits. Europium isotopes were detected periodically from 1988 through 1996, with some indication of higher concentrations for McNary Dam sediment. From 1988 through 1992, strontium-90 was detected at higher concentrations for McNary Dam sediment than for Priest Rapids Dam sediment.

The collection of sediment samples from riverbank spring discharge locations at the Hanford Site began during 1993 at the Hanford town site and the 300 Area. The sediment monitoring was expanded in 1995 to include riverbank springs in the 100-B, 100-K, and 100-F Areas. Shoreline substrates at the riverbank spring locations at the 100-N, 100-D, and 100-H Areas are composed largely of large cobble and gravels and are generally unsuitable for sediment sampling. The concentrations of radionuclides in sediment collected from riverbank spring discharges along the Hanford Site shoreline were similar to levels at Priest Rapids Dam and the Hanford Reach sediment, with the exception of the 300 Area where the average uranium concentrations are usually two to three times higher.

For all locations, the concentrations of radionuclides in Columbia River sediment, Snake River sediment, and riverbank spring sediment samples were below concentrations that would result in a 1-mrem effective dose equivalent to the hypothetical maximally exposed individual using a shoreline exposure scenario (i.e., 500 hr/yr of external exposure to 1,250 m^2 of sediment, with no ingestion or inhalation pathways; DOE/RL-91-50).

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