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LITERATURE AND DATA REVIEW FOR THE SURFACE-WATER PATHWAY: COLUMBIA RIVER AND ADJACENT COASTAL AREAS

Hanford Environmental Dose Reconstruction Project

W. H. Walters
R. L. Dirkes
B. A. Napier

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Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

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This document has been reviewed and approved by the Technical Steering Panel.

John E. Till

J. E. Till, Chair
Technical Steering Panel

November 8, 1992

Date

PREFACE

The Hanford Environmental Dose Reconstruction (HEDR) Project was undertaken in 1987 at the recommendation of the Hanford Health Effects Review (HHER) Panel. The HHER Panel had been formed to consider the potential health implications of historic releases of radioactive materials from the Hanford Site.

The Centers for Disease Control (CDC) provides funding for the project; Battelle, Pacific Northwest Laboratories (BNW) performs the research. The HEDR research is directed by an independent Technical Steering Panel (TSP). The 18-member panel consists of experts in the various technical fields of importance to project work and representatives of the states of Washington, Oregon, and Idaho; Native American tribes; and the public.

This document is an updated version of the previous version dated April 1992. Changes from the April 1992 version are shown in italics. The document number for the April 1992 version was PNL-8083 HEDR; the current (November 1992) version is numbered PNWD-2034 HEDR. The report numbering system changed from the "PNL" designator (when HEDR work was under contract to the U.S. Department of Energy) to the "PNWD" designator in June 1992 (when the work came under contract to the Centers for Disease Control). Appendix D is a record of the TSP comments and BNW responses. Comment numbers from Appendix D appear in left margin opposite text changes.

The scope of this report is to 1) describe the *segments* of the Columbia River system and the adjacent coastal areas that were involved in the transport and distribution of radionuclides released at Hanford; 2) review and summarize river and coastal area monitoring data (Hanford and offsite sources) providing radionuclide concentrations for water, sediment, and biota; 3) review and summarize the reports and studies pertaining to the release and transport of radionuclides in the *Columbia* River; and 4) calculate preliminary dose estimates for selected locations and times to include freshwater and marine food sources.

Because of the extent and complexity of the database and related information, an analysis of the *material reviewed for this study* is beyond the scope of this report. While it is recognized that the data quality will vary among the many sources and sampling techniques, the data analysis and data quality evaluation will be carried out in later studies during FY *1993*.

ABSTRACT

As part of the Hanford Environmental Dose Reconstruction *(HEDR)* Project, Battelle, Pacific Northwest Laboratories reviewed literature and data on radionuclide concentrations and distribution in the water, sediment, and biota of the Columbia River and adjacent coastal areas. Over 600 documents were reviewed including Hanford reports, reports by offsite agencies, journal articles, and graduate theses. Radionuclide concentration data were used in preliminary estimates of individual dose for the *period* 1964 *through* 1966. This report summarizes the literature and database *reviews* and the results of the preliminary dose estimates.

Sampling of river water began in 1945. Riverbed sediments *were first sampled* in 1948. Routine sampling was confined to the Hanford to Pasco (Washington) reach of the Columbia River until 1950 when water samples were collected at Bonneville Dam. Routine sampling of river biota in the Hanford area began in 1950. *From 1951 through 1957*, environmental monitoring by Hanford contractors increased significantly in the Hanford area and downstream. *Beginning in the early 1960s, the Hanford monitoring program was gradually modified to emphasize the Hanford reach down to McNary Dam, although some downstream locations continued to be sampled (e.g., Willapa Bay oysters). The monitoring program was modified as a result of experience gained from previous years, new developments (radiation exposure guidelines), and the need to obtain better monitoring data for dose estimates.*

Comprehensive monitoring and studies by offsite agencies began in 1960 and continued into the early 1980s. Much of the work was conducted below The Dalles Dam out to the coastal areas of Washington and Oregon. The work of these agencies focused on the uptake of radionuclides by freshwater and marine biota and the distribution of reactor effluent along the coastal areas. Other work investigated the *sorption* of radionuclides by river sediments. Gross beta measurements *for water, sediment, and biota* are *the only* available *data from offsite sources (and Hanford) for 1945 through 1957. Radiochemical analyses are also available for radionuclides such as tritium, phosphorus-32,*

strontium-89, and strontium-90. After 1957, gamma spectrum measurements were *used* to determine activity levels of specific radionuclides.

For this report, preliminary dose estimates were calculated for several locations from Richland, Washington, to Willapa Bay, Washington. Maximally exposed individuals were those who consumed significant quantities of fish or seafood. The important radionuclides were zinc-65, arsenic-76, and phosphorus-32. The drinking-water pathway was the most important for typical individuals, who were assumed to have eaten much less fish or seafood. The important radionuclides were arsenic-76, neptunium-239, and zinc-65.

EXECUTIVE SUMMARY

This literature review investigated the availability of radiological data and information for the Columbia River and adjacent coastal areas (see Plates 1 and 2 in pockets at the back of this report for locations mentioned in this summary and in the report). A major objective was to locate data on the concentrations of radionuclides in water, sediment, and biota for the surface-water transport pathway. Because the database will be used to reconstruct past *radiation* levels for the surface-water system, the size, geographic extent, and continuity (location and time) of the historical database are of prime importance. The historical nature of the *Hanford Environmental Dose Reconstruction* Project rules out supplementing the existing database through new data collection; therefore, the use of mathematical methods will be required to fill any serious gaps in the database. Mathematical approaches that could be used to fill the gaps will be investigated during the follow-on development work on the conceptual model.

Studies of reactor effluent by Hanford and offsite contractors provided a significant amount of information on the directional movement of the reactor effluent in the *Columbia* River and adjacent coastal areas. The results of these studies identified some of the reasons for variability in radionuclide concentrations in the water, sediment, and biota. They also provided information on the uptake, release, and distribution of radionuclides by river and coastal sediments.

During the literature review, data were selected *for preliminary dose estimates* from several locations along the river. The locations extended from Richland, Washington, downstream to Astoria, Oregon, and along the Washington coast to Willapa Bay. The dose estimates considered *untreated* drinking water, freshwater fish, and various seafoods.

MONITORING LOCATIONS AND TIME PERIODS

58,59,60 From 1945 to 1950, monitoring of *beta activity* in water and sediment (sediment sampling began in 1948) was conducted primarily in the vicinity of the reactors and downstream *of* the 300 Area, which is just upstream of

Richland. The only sampling *conducted* farther downstream was at Richland and Pasco. The Yakima River was sampled as an indicator of background *radioactivity* levels in water samples. There were no sampling locations downstream of Pasco until 1950, when water sampling began at Bonneville Dam. Sediment sampling was conducted only in the Hanford reach (from *Wills' Ranch* to the Umatilla-McNary Dam location). Most of the sediment samples were collected near the reactors, but others were collected at Richland, Kennewick, and the Pasco bridge. No monitoring or investigative studies were conducted by off-site contractors during this period. Thus, *until 1950,* there are no radiological data available *for the area* downstream of Pasco, and then only for the Bonneville Dam location. *Also, only total nonvolatile beta activity was measured because samples antedated gamma spectroscopy.*

Beginning in 1951, and lasting until 1958 when gamma spectroscopy equipment became available, many more water sampling locations were added downstream of Pasco. Locations were added at McNary Dam in 1951. By 1957, twelve locations, between McNary Dam and Vancouver, Washington, had been added. Most of the water sampling *below McNary Dam* was conducted during 1953 and 1957, with only intermittent sampling for the other years. From 1951 to 1957, sediment sampling was extended to McNary Dam and to Paterson, Washington, about 18 miles downstream of McNary. Sediment was sampled at *no* other downstream locations.

Routine sampling of fish *began* in 1950, but only in the Hanford reach of the river. Various studies of biota continued and the number of samples increased during the 1950s, with most, but not all, of the effort remaining in the Hanford reach. Hanford contractors began sampling shellfish near the mouth of the Columbia River in 1953. From 1950 to 1977, fish and shellfish were routinely sampled and analyzed by Hanford contractors, with much of the effort concentrated on freshwater whitefish in the Hanford reach and Willapa Bay oysters from the Washington coast. Whitefish from the river and oysters from Willapa Bay were popular *food* sources for humans.

It was also during the early 1950s that the U.S. Public Health Service (USPHS) began its water-quality and biota studies. This effort, which lasted about 3 years, was the first radiological monitoring *for the Columbia River* program by an offsite agency. The USPHS water-quality and biota studies began in 1951 and continued into 1953. The results *provided* the first independent database for comparison with the Site monitoring by Hanford contractors. The sampling work was limited to the length of river from *Wills' Ranch* to Paterson, Washington, downstream of McNary Dam. Only brief, exploratory surveys were conducted at Bonneville Dam, at Portland, Oregon, and at the mouth of the Columbia River.

Although the sampling locations and frequency increased significantly from 1945 through 1957, the results were reported as *total nonvolatile* beta concentrations. While beta concentrations are not suitable for direct use in dose calculations, they can be used *for screening purposes* in preliminary dose estimates as described in Section *10.0* of this report.

After 1957, concentrations of specific radionuclides became available for water, sediment, and biota samples collected by Hanford contractors. Beginning about the same time, Hanford contractors began *revising* the monitoring program. Sediment, which was not sampled in 1958, was sampled once more in 1959, but sampling was discontinued after that year because information on radionuclide concentrations in sediment was not directly usable in dose estimates. Hanford contractors continued to collect water *samples*, but the number of locations decreased significantly to several locations of specific interest. Most of these were in the Hanford to McNary Dam reach of the river. After 1958, water sampling locations downstream of McNary were limited to five sites: 1) Paterson, Washington (1959 only); 2) The Dalles, Oregon (1963 and 1964); 3) Hood River, Oregon (1959 only); 4) Bonneville Dam (1964 through 1975); and 5) Vancouver, Washington (1959 through 1963).

Beginning about 1960, offsite agencies *began* a series of studies and monitoring programs *that* involved the states of Washington and Oregon, their state universities, and the U.S. Geological Survey (USGS). Much of the work focused on the Columbia River estuary and adjacent coastal areas and was oriented toward transport processes. Most of the data are not useful for dose calculations but do provide very good information regarding the disposition of reactor effluent. The *most useful* data are those radionuclide concentrations measured in fish and shellfish; these data were found in various reports, journal articles, and graduate theses. Some of these data were used to calculate the preliminary dose estimates presented in Section *10.0*. Other useful data are radionuclide concentrations in water and biota from the Oregon State Department of Health. From 1961 through 1977, Department staff routinely sampled Columbia River water from The Dalles downstream to the mouth of the river, as well as estuarine and coastal fish and shellfish. Some sampling *is currently conducted every year* but *is* very limited. Although sampling was *primarily conducted on a* quarterly *basis* for each year, the results provide at least a partial database for *evaluating* activity levels in water and biota at downstream locations. *The data can also be used* in testing the credibility of computed water concentrations for downstream locations and time periods.

REACTOR EFFLUENT RELEASES AND TRANSPORT

A review of the Hanford contractor reports indicates a significant amount of variability in effluent releases from the reactor outfalls in the river. As a group, the reports discussing *variations* in effluent activity levels identify six primary factors for the variations: 1) increase in number of reactors on line and operating power levels, 2) activation of natural elements in raw river water, 3) chemical additives, 4) rupture of fuel elements, 5) reactor *purges* to remove radioactive film buildup, and 6) length of time effluent *remained* in retention basins (amount of decay).

61 As the number of reactors increased from three in 1945 to eight by 1955, the quantity of radionuclides released to the river increased. Beginning in 1957, the operating power levels were also gradually increased with correspondingly higher radionuclide releases to the river. The natural increase or decrease in the *quantities of* elements in raw river water is a seasonal event, with higher *quantities* of these elements occurring during the spring flood season. The *elements* were also source (drainage basin) dependent. Chemical additives were continually used during reactor operations. Fuel element ruptures and reactor purging were discrete events lasting hours and occurring on an intermittent basis. *Basin retention times were not constant and were gradually shortened over the years because of increased power levels and because the basins were not modified to accommodate a larger effluent discharge.*

Once reactor effluent was discharged from the outfalls, it traveled downstream in a relatively narrow plume several hundred feet wide *(Plate 2)*. Although the plume gradually mixed laterally, it was still distinguishable at Pasco. Beyond Pasco, the flow patterns in the McNary reservoir and Snake River inflow preclude any definitive measurements. The plume tended to hug the reactor shoreline (west shoreline) downstream past Richland to the Yakima River confluence. Beyond that point, the plume was found along the Pasco shore, possibly as a result of being forced across the channel by the Yakima River inflow. *In the vicinity of the reactors*, water concentration measurements along the plume centerline were five to seven times *higher than* those *for* ambient river water. Near Pasco, the concentrations were much closer *in value* but differences were still distinguishable.

Shoreline springs that released retention basin leakage through river bank soils were another possible contributor to higher water concentrations along the plant shore. Basin leakage releases through the shoreline were *first noticed* at B, D, and F reactors during *1945. Shoreline seepage from the basins was still a concern at B, C, D, and F reactors during the 1950s.*

The rate of transport of the effluent downstream to the Columbia River mouth is of key importance with respect to radionuclide decay and activity levels. Hanford contractors began in 1955 to *identify* a relationship between river discharge and downstream travel time of effluents. By the early 1960s, travel times from the reactor area to Astoria, Oregon, *had been determined.* Travel times *were estimated using field data* from the reactor area to eight locations from Pasco, Washington, to Astoria, Oregon, for four ranges of discharge. *Because* McNary Dam was in place in 1955 and The Dalles Dam was filling, *travel* times are not valid for years *before* 1955. Travel times for those years would be shorter and would need to be determined mathematically.

SEDIMENT AND RADIONUCLIDE TRANSPORT STUDIES

By the 1950s, the role of river sediment in the uptake and storage of radionuclides and the effect of sediments on concentrations in the water were recognized. Hanford contractors and the USGS conducted a number of studies into sediment storage effects. It was also determined that the sediments could release radionuclides back into the river water, causing an increase in concentration exceeding that expected from effluent releases. This process provided another factor for variation in water concentrations.

During the early 1960s, in cooperation with Hanford contractors, the USGS began studying the uptake of radionuclides by river sediments. These cooperative studies continued through most of the 1960s, with final reports being published in the early 1970s. The reports produced data on sediment concentrations and a considerable amount of information on uptake and release of radionuclides by sediment. Water concentration data are also included in the reports. The USGS studies were strongly oriented toward river processes and did not provide the lengthy and consistent sampling needed for dose calculations. Nonetheless, the results provide some data to assist in determining activity levels at locations downstream of McNary Dam during the sampling period.

Comprehensive programs to monitor the *radiation from* shoreline sediments began in 1959. Before that time, only exploratory measurements had been made in the vicinity of the reactors. Shoreline monitoring continued into the late 1970s, but was not conducted on a continuing yearly basis. These shoreline surveys included the surfaces of channel islands and the measurement of exposure rates for boaters on the river. The highest overall rates were found along the reactor areas, as would be expected, with the maximum measured on the island offshore of the 100-D Area. Below the reactor areas, the exposure rates decreased, but not uniformly. Survey results reported by Sula (1980) found no definitive downstream decrease in shoreline exposure rates from below the reactor areas to the confluence of the Snake River.

PRELIMINARY DOSE ESTIMATES

37 Using radionuclide concentration data from various monitoring programs and studies summarized in this report, preliminary dose estimates for the years 1964 through 1966 were calculated for five locations along the river: 1) Richland, Washington, 2) McNary Dam area, 3) Bonneville Dam area, 4) Astoria, Oregon, and 5) Willapa Bay, Washington. The estimates considered a maximally exposed individual and a typical individual. *The 1964-1966 period*

was selected because for this period individual radionuclides were monitored and data for otherwise unmonitored locations were available.

Maximally exposed individuals were assumed to have eaten significant quantities of fish or seafood from the Columbia River. Included in the doses were contributions from drinking water, swimming, boating, and exposure to shoreline contamination. For the *maximally exposed* individual, the most important pathway was consumption of nonmigratory fish. The important radionuclides were zinc-65, arsenic-76, and phosphorus-32, with zinc-65 the most important at downstream locations because of its relatively longer half-life. The doses decreased downstream except for slight increases at Bonneville with the addition of *migratory* salmon to the diet and at Astoria with the addition of shellfish to the diet.

39 *Drinking water was the most important exposure pathway for typical individuals because they were assumed to eat very small quantities of fish.* The important radionuclides in the Hanford reach (from the reactor area to Umatilla and McNary Dam) were arsenic-76, neptunium-239, and zinc-65. At locations farther downstream, zinc-65 and phosphorus-32 were the most important. Examples of annual doses for 1964 are shown in Table ES.1.

FOLLOW-ON WORK

31,62 *The data and information summarized in the report, including the preliminary dose estimates, will be evaluated during follow-on work conducted in FY 1993 to determine the extent to which the data can be used to support radionuclide transport calculations and final dose estimates.* The amount, continuity, and variability of river data, together with the changes in the river system (e.g., dams), have a direct bearing on usefulness *of the data* and computational techniques proposed for reconstructing concentrations in water, sediment, and possibly biota. The data analysis will be used to produce a conceptual model of the Columbia River that will describe the processes affecting radionuclide transport and distribution and the relationship between the key variables. From the conceptual model work, several alternative approaches will be proposed for providing the necessary database to support dose estimates.

40 TABLE ES.1. Preliminary Estimates of Annual Doses from Columbia River Pathways for 1964

Location	Maximally Exposed Individual (*mrem*)	Typical Individual (*mrem*)
Richland	*160*[a] *(25)*[b]	*7.8* *(15)*
McNary	*17* *(3.1)*	*1.0* *(1.9)*
Bonneville	21 *(1.2)*	*0.4* *(0.7)*
Astoria	*40* *(0.8)*	3.1 *(0.5)*
Willapa Bay	*16*	*1.6*

(a) Dose received from all sources including treated drinking water except Willapa Bay.
(b) Dose received from drinking untreated water only. Computed as a separate issue. Not to be added to the dose defined under (a).

ACKNOWLEDGMENTS

This report was prepared for the Technical Steering Panel, which serves as the technical director of the Hanford Environmental Dose Reconstruction Project, as a summary of data and information on the Columbia River dose pathway. In accomplishing this task, the authors received assistance and reviews from many people.

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(Plates are in pockets in the back of the report)

TABLES

1.0 INTRODUCTION

The Surface-Water Transport Task is part of the Hanford Environmental Dose Reconstruction (HEDR) Project, which was established to estimate the radiation doses people may have received from operations that began at the Hanford Site in 1944. The technical work is being conducted by staff at Battelle, Pacific Northwest Laboratories (BNW) under the direction of an independent Technical Steering Panel (TSP).

This task addresses the radioactivity in the Columbia River, which received cooling-water effluent from the eight Hanford once-through-cooled reactors[a] and was the major pathway for waterborne radionuclides. The pathway began at the Hanford Site and continued downstream past the mouth of the Columbia River to the adjacent coastal and ocean areas. The overall objective of the task is to provide radionuclide concentrations at locations along the pathway for water, sediment, and biota. These concentrations will be used in final dose estimates. Preliminary dose estimates for several years are provided in Section 10.0.

The purpose of this report is to summarize the significant results of a literature and database review conducted during FY 1991. The review included available reports and data prepared by Hanford contractors and offsite sources. The period of interest was from 1944 to 1990, with emphasis on the period from 1944 through 1972, when some or all of the eight once-through-cooled reactors were operating. Although a detailed summary of all the literature and data gathered is beyond the scope of this report, all documents reviewed are listed in the references or in the appendixes. Sets of data determined to be potentially useful or descriptive for the river pathway are presented as maximum values, average values, or ranges of values in tables and graphics.

Following the Executive Summary, this report contains 12 sections, four appendixes, and two plates. Section 2.0 presents the technical approach of

(a) In once-through-cooling, water drawn from the river passes through the reactor core and is returned to the river after some retention time.

the study. In Section *3.0*, the surface-water pathway from the Hanford reactors to the coastal areas is described. Section *4.0* discusses the ecology of the Columbia River, with emphasis on the fish pathway. Factors affecting the composition and variability of reactor effluent water are summarized in Section *5.0*. Section *6.0* describes the development of Columbia River monitoring programs at Hanford from 1945 to the present, and Section *7.0* summarizes monitoring results. Section *8.0* discusses results of special studies conducted by Hanford contractors. *The studies pertained directly* to transport processes of the river. Section *9.0* summarizes monitoring and studies by offsite agencies. Section *10.0* presents preliminary results of dose calculations for selected periods and data sets from Hanford and offsite sources. *Section 11.0 provides final discussion and recommendations.* Section *12.0* provides a list of references *cited in this report*. Appendix A provides a brief summary of the Columbia River hydrologic data available for use in evaluating radiological data and transport calculations. Appendix B *contains a list of units and* a table of radionuclides discussed in the report and their half-lives. Appendix C is a bibliography of additional references examined during the preparation of this report but not cited in the text. *Appendix D is a record of TSP comments and BNW responses.* Two plates are provided in pockets in the back of the report to help the reader follow the discussions that refer to locations and activities along the Columbia River from the Hanford Site to the river mouth.

2.0 TECHNICAL APPROACH

This literature review covered two general categories of source documents: 1) those prepared by Hanford Site contractors and 2) those prepared by offsite agencies. Documents originating at the Hanford Site were identified through the HEDR Information Resources Task (Task 11), as described by Shipler (1992).

Documents prepared by offsite agencies were obtained by the principal investigators directly from the originating agencies. Most of these offsite sources were known, although the extent of their document holdings was not. Agencies that have radiological data and information for the Columbia River pathway are the state health organizations of Washington and Oregon and the state universities that offer related programs of study in marine science. The primary federal agencies are the U.S. Geological Survey (USGS) and the U.S. Public Health Service (USPHS). Nonradiological river data were obtained from both the USGS and the U.S. Army Corps of Engineers.

Each document was reviewed for possible use in the HEDR Project. All of the Hanford-originated environmental monitoring reports (mostly data) are part of a permanent database regardless of the amount of data and information included. Titles appear in the list of references (Section *12.0*) if they are cited in the body of this report; otherwise, they appear in Appendix C. Topical reports on special studies of the Columbia River system originating from Hanford are similarly listed. Special studies related to the transport and deposition of radionuclides in the Columbia River are summarized in this report, together with information regarding reactor operations and effluent releases. Much of this special study information was scattered throughout numerous reports and has been assembled in various sections in *this* report.

Visits were made to offsite agency libraries (state universities and science centers), and catalog searches were conducted onsite. All documents found in this way that contained radiological data and information on the Columbia River and adjacent coastal areas were reviewed for possible use in the project. The list of references in each document was also reviewed for other source documents. Other agencies were contacted directly for assistance in locating copies of their river-related publications. The data and information from offsite agencies are organized by agency in this report.

The data and information from all sources were reviewed for radionuclide activity level measurements in Columbia River water. Activity levels in river and coastal sediment and biota sampled within or affected by the reactor effluent pathway were also reviewed. Because an extensive presentation of monitoring data is beyond the scope of this report, only ranges of activity levels, maximum values, or averages are included in *this summary*. These values are included to provide some idea of the levels present during the years of Hanford operations. River and coastal locations and the periods of monitoring and special studies are discussed. No calculations or data analyses were conducted, except for calculation of the preliminary dose estimates presented in Section *10.0*. Because the documents spanned a period from 1945 to 1990, the reported units of activity levels changed. No conversion of units to a common system was attempted for this report; therefore, all units given are the same as in the original documents. *A list of units commonly used is provided in Appendix B.*

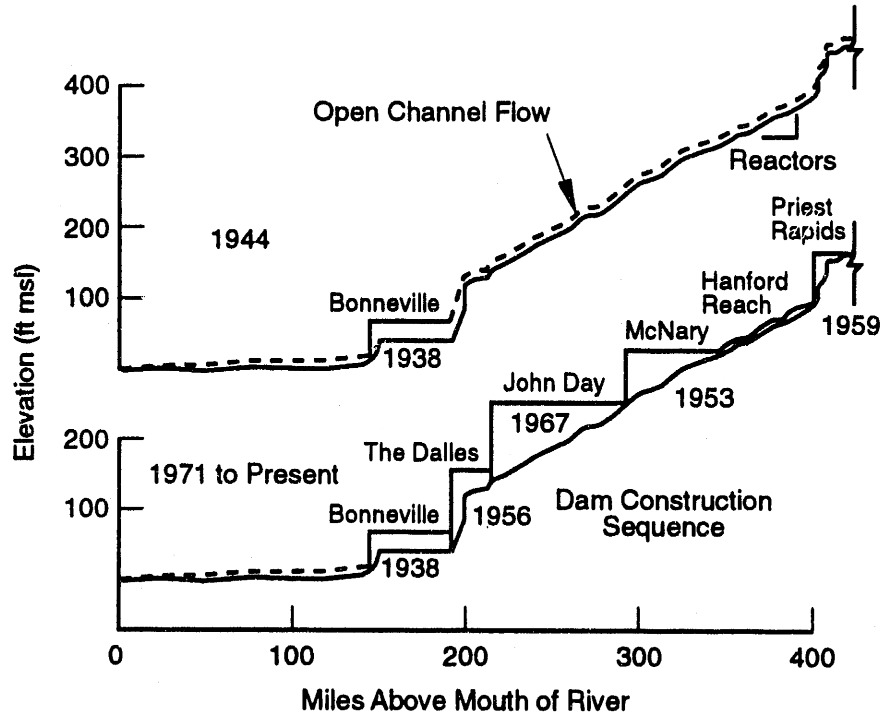
3.0 SURFACE-WATER PATHWAY

50 The effluent pathway began in September 1944 at the reactor farthest upstream (100-B) at river mile (RM) 384 above the mouth of the Columbia River. Two other reactors, 100-D at RM 377.6 and 100-F at RM 369, were contributing effluent by early 1945. By 1955, all the once-through-cooled reactors were operating. Unlike the original eight Hanford production reactors, a ninth reactor (100-N, also referred to as N-reactor) was designed with a closed-loop primary cooling system that used the river as a source of secondary cooling water. In the original eight reactors, cooling water was treated, pumped through the reactor, stored temporarily in a retention basin, and then discharged to the river. In contrast, N-reactor recirculated its primary cooling water through the core to steam generators, where heat from the reactor core was exchanged to a secondary cooling system that provided steam to turbines for electric power generation. After leaving the steam generators, the primary circuit cooling water was pumped back into the reactor. During reactor operations, leakages occurred from the primary system, which were diverted to a holding crib and trench system. The crib and trench system allowed the leakage effluent to percolate into the underlying geologic media where most of the radionuclides were retained by the soil.[a]

From the time the first reactor (100-B) went on line in September 1944, until 1971, cooling water was discharged into the river in a continuous release, as long as at least one of the reactors was operating. Several days after the startup of 100-B, the first radioactive effluent reached the mouth of the Columbia River and began contributing to a plume that *extended* into the Pacific Ocean and along the coastal areas. Plate 1 (in a pocket in the back of this report) *shows* the Columbia River as *it* exists today with all the dams in place. Figure 3.1 shows the river profile as it was in 1944 and the sequence of dam construction from 1953 to 1967.

Once effluent was discharged into the river, concentration and distribution of radioactivity in the river water *depended* largely on river discharge

(a) *C. M. Heeb, personal communication to W. H. Walters, September 1992.*



<u>FIGURE 3.1</u>. Columbia River Profile Showing Conditions in 1944 and Dam and Reservoir Construction in Later Years *(ft msl = feet above mean sea level)*

and uptake of radionuclides by sediment and algae. Primary hydrologic factors were the seasonal variations in water volume and flow velocities. Water volume directly affects the concentration by dilution. Flow velocity controls the rate of transport through the system and, therefore, influences the degree of radionuclide decay *occurring* by the time any one point downstream is reached. *Both suspended and bed sediment sorb radionuclides from the water with the suspended sediment contributing to radionuclide accumulation in the riverbed upon settling out.* Through this process, the sediment removes some of the radionuclides from the water and acts as a "sink" for a portion of the radioactivity. This sediment sink also provides a medium for certain biota to take up radionuclides, thus introducing them into the food chain. *The sediment-radionuclide complex can also be resuspended during high river discharges adding to the ambient radionuclide concentrations in river water.*

For purposes of discussion, the Columbia River pathway is separated into three river reaches and the coastal area impacted by reactor effluent. The reach from Hanford to McNary Dam includes the reactors and is where Hanford contractors conducted most of their monitoring and studies. The reach from McNary Dam to Bonneville Dam included only one reservoir in 1944, but by 1967 was totally controlled by dams and reservoirs. The reach from Bonneville Dam to the mouth includes the river's estuary and is where tidal processes dominate the transport of radionuclides.

65 There are numerous references available from which descriptive information on the Columbia River can be obtained. The primary references used in this section are the reports and maps listed in Appendix A, especially the documents published by the Columbia River Estuary Data Development Program (CREDDP 1984a, 1984b) *sponsored by the Pacific Northwest River Basins Commission (PNRBC)*. The text by Pruter and Alverson (1972) was another primary source. The river mile values, as *used* in the text, were obtained from an index prepared by the PNRBC (1962).

3.1 PATHWAY FROM HANFORD TO McNARY DAM

The effluent pathway began at the reactor (100-B) farthest upstream, at RM 384 above the mouth of the Columbia River. As other reactors came on line over the years following 1944, the area in which effluents were released extended from RM 384 downstream to RM 369. Releases to the river from retention basins came from outfall lines (pipes) near the river bottom and took the form of a narrow plume that gradually spread and dispersed downstream. Because of the location *along the same shoreline* and proximity of the reactor outfalls to each other, these plumes tended to coalesce and hug the Richland side of the river. The various channel islands, the roughness of the channel bed (i.e., the presence of boulders), the location of pools and riffles, and the curvature of the river's natural flow all affected the rate at which the plume spread and mixed with the river water. Under some flow conditions, the plume was not entirely mixed over the full river width until it approached Pasco in the vicinity of RM 330. The phenomenon of downstream plume mixing, as it occurs in the reach from Hanford to McNary, will be discussed in more detail in Section *8.0*. The river system from the Hanford reactors to McNary Dam is shown in Plates 1 and 2.

Three tributaries join the Columbia River between Hanford and McNary Dam: the Yakima River at RM 335, the Snake River at RM 324, and the Walla Walla River at RM 315. All three, but especially the Snake River, dilute the effluent and contribute a significant volume of sediment to the Columbia River.

The mean annual discharge of the Columbia River at Hanford is 121,512 cubic feet per second (cfs). The mean annual discharges for the tributaries are as follows: the Yakima River at Kiona, Washington (3661 cfs); the Snake River at Ice Harbor Dam (53,948 cfs); the Walla Walla River at Touchet, Washington (593 cfs) (Williams and Pearson 1986).

When the first reactors came on line during the 1940s, McNary Dam (RM 292) did not exist. Construction of the dam began during the early 1950s and culminated with the raising of the pool upstream of the dam in December 1953. This created Lake Wallula, a body of water with a maximum depth of about 100 feet and a length of about 62 miles. Before the construction of McNary Dam at RM 292, the flow, with its effluent and sediment loads, passed through Wallula Gap and past Umatilla, Oregon (near the present damsite), under free-flow conditions. Since construction of the dam, the flow velocity within the influence of Lake Wallula is considerably reduced, and much of the sediment load is trapped behind the dam. However, as is true of the other Columbia River dams, some of the trapped sediment is resuspended and transported downstream by seasonal high discharges.

3.2 McNARY DAM TO BONNEVILLE DAM

The reach of river from McNary Dam to Bonneville Dam is shown in Plate 1. From 1944 to 1956, there were no dams on the river between the McNary-Umatilla, Oregon, site (RM 292) and Bonneville Dam (RM 146.1) as shown in Figure 3.1. The flow was unrestricted until the upper limit of the Bonneville reservoir was reached. This length of the Columbia River included many ancestral Native American fishing grounds, such as the Celilo Falls. With the construction of The Dalles Dam (RM 191.5) and raising of the reservoir pool in 1956, the Celilo Falls fishing ground was inundated (Pruter 1972). By 1967, the John Day Dam (RM 215.6) was also in operation, and the river in this reach consisted of three reservoir pools with no open channel flow. After 1969, Native American fishing grounds were largely confined to tributary streams and the reservoirs of Bonneville Dam and The Dalles Dam (Pruter 1972). With the construction of The Dalles and John Day dams, the river flow velocity *was* reduced and much of the sediment inflow was trapped in the reservoirs. Another characteristic of this length of *river, both before and after dam construction,* is that the river flows through the Columbia River Gorge with no appreciable flood plain.

Numerous small rivers and creeks discharge into the river between McNary and Bonneville dams. The three largest rivers, in downstream order, are John Day River (RM 218), the Deschutes River (RM 204.1), and the Klickitat River (RM 180.4). With the combined inflows, some dilution effects *occur*, but nothing comparable to that associated with the Snake River upstream of McNary Dam. The mean annual discharges of the tributaries are as follows: the Klickitat River near Pitt, Washington (1607 cfs) (Williams and Pearson 1986); the John Day River at McDonald's Ferry, Oregon (2103 cfs); the Deschutes River near Biggs, Oregon (5869 cfs) (Moffatt, Wellman, and Gordon 1990).

3.3 BONNEVILLE DAM TO COLUMBIA RIVER MOUTH

Below Bonneville Dam, the river enters the estuary of the Columbia River where the width, depth, and flow characteristics (tides, multiple channels) of the Columbia River change considerably (Plate 1). At about RM 52, the river is less than 1 mile wide, but increases to nearly 9 miles at about RM 20. There are several bays and headlands within the estuary, which *consist* of multiple channels separated by numerous islands, bars, and shoals. Deep areas (e.g., Gray's Point), where water depths approach 100 feet (Neal 1972), can be found in the estuary apart from the main channel.

The three largest tributaries contributing inflow below Bonneville Dam are the Willamette River (RM 101.5), the Lewis River (RM 87), and the Cowlitz River (RM 68). These tributaries all enter at a considerable distance upstream of the estuary. The mean annual discharges of the tributaries are as follows: the Willamette River near Portland, Oregon (33,310 cfs) (Moffatt, Wellman, and Gordon 1990); the Cowlitz River at Castle Rock, Washington (9330 cfs); the Lewis River at Ariel, Washington (4899 cfs).

At some point in the vicinity of RM 23 to 25, the maximum *extent* of ocean water *intrusion* occurs and marks the upstream extent of the Columbia River estuary (Neal 1972). Some disagreement exists concerning the definition of an estuary. Early definitions considered the entire tidal portion of a river to be the estuary; more recent practice is to consider only the segment of river subject to salinity intrusion as the estuary boundary (Neal 1972), although tidal effects can extend *farther* upstream into the freshwater areas. For the Columbia River, tidal fluctuations have been observed as far upstream as Bonneville Dam during low flow conditions. Under any flow conditions, tides are strong enough to reverse the flow as far as 53 miles upstream.

Because of the tidal conditions and flat channel gradient, Columbia River sediments deposit in the estuary. The upstream reaches of the Columbia River and its tributary system are the major source of sediment for the estuary; the size range of sediment is limited to the finer fractions, as is typical for estuaries. These finer fractions consist of fine sand, silt, and clay. These are also the sediment sizes that most readily sorb with radionuclides. Deposits of coarse sand and gravel are rare in the estuary and are found mostly in areas of extreme scour where transport velocities are high. Much of the silt and clay fractions remain in suspension or are resuspended often enough to be eventually flushed from the estuary out to the continental shelf. Only about 20% of the silts and clays transported to the estuary tend to remain there, primarily in peripheral bays and inactive (sluggish) channels of the middle to upper estuary (CREDDP 1984a, 1984b). The remaining limited range of sediments (fine to medium sand) is transported either along the estuary bed or by intermittent suspension. Because velocities in the estuary are reduced, fine to medium sand tends to persist as the dominant sediment size.

3.4 COASTAL AREAS

51,52 The initial mixing of Columbia River water (and associated reactor effluent) with ocean water occurs within the estuary as a result of tidal currents, wind-generated wave action, variation in water density, and the turbulent flow regime of the river. As the water and effluent move away from the mouth of the river, wind-wave action and open-sea processes become the dominant mixing processes. The volume of water leaving *(and entering)* the estuary is largely determined by *the tidal prism*. Seasonal drainage basin runoff, *however, is the major factor affecting the net outflow of water from the estuary*. As the water-sediment-effluent mixture is transported away from the river mouth, it gradually increases in both salinity and volume as it mixes, *both horizontally and vertically*, with ambient ocean water. The outflow tends to maintain the form of a plume with distinct boundaries that are sharper near the mouth and become less distinct with increasing distance along the plume. *The plume spreads north and south over 1000 kilometers and a seaward distance of about 600 kilometers (Barnes, Duxbury, and Morse 1972). The plume transports both dissolved radionuclides and those radionuclides sorbed to sediment originating from the river.*

The ocean plume has two dominant seasonal patterns, largely controlled by wind direction: during winter the plume lies north of the river mouth and inshore as a result of southerly winds, and during the summer the plume is directed south and offshore by northerly winds. The northerly plume movement extends beyond the Strait of Juan de Fuca, and the southerly movement extends to the border between Oregon and California (Barnes, Duxbury, and Morse 1972).

53 Coarser sediments that contain radionuclides and that pass the mouth of the Columbia River are mostly sands transported by bottom currents along the continental shelf. The directional pattern of these currents was determined during the 1960s by studying the movement of seabed drifters (perforated plastic discs) placed near the mouth of the river (Morse, Gross, and Barnes 1968; Barnes, Duxbury, and Morse 1972). Once the drifters were away from the direct influence of the river outflow, the predominant direction of movement was northward and toward the Washington coastal areas (e.g., Willapa Bay and Gray's Harbor). This evidently occurred regardless of the season. The northward pattern of movement extended to the Strait of Juan de Fuca and beyond to Vancouver Island, British Columbia. The study determined that the northward movement of drifters *was* affected in the area of the Strait with some movement of the drifters into Puget Sound. According to Barnes, Duxbury, and Morse

(1972), the Strait and submarine valley that extend seaward across the shelf apparently act as a partial barrier to northward movement. The authors presumed the Strait would have a similar effect on any sediment transported to this location from the Columbia River.

4.0 COLUMBIA RIVER ECOLOGY

The Columbia River supports a large and diverse community of plankton, periphyton, macrophytes, benthic invertebrates, and fish. It is the fifth largest river in North America and has a total length of about 2000 kilometers (~1240 miles) from its origin in British Columbia to its mouth at the Pacific Ocean. Eleven hydroelectric dams were constructed on the Columbia River between 1933 and 1968. As a result, except for the Hanford reach, the ecosystem has changed from free flowing throughout its length to one that is now a series of large flow-through lakes. This change from a lotic to lentic habitat severely altered the aquatic habitat and resulted in significant changes in the biotic communities. Organisms originally adapted to a flowing-water regime had to adapt to a still-water environment or perish. New still-water forms invaded these newly created habitats. As mentioned previously, a major Native American fishery located at Celilo Falls on the Columbia River above The Dalles was eradicated when The Dalles Dam was closed.

Major tributaries to the upper Columbia River include the Spokane, Okanogan, and Wenatchee rivers. No tributaries enter the Columbia River during its passage through the Hanford Site. Several major tributaries enter the Columbia River, especially in the lower reaches. These include the Yakima and Snake rivers, which enter the McNary pool; the Umatilla and John Day rivers, which enter the John Day pool; and the Deschutes River, which enters the Bonneville pool. The Willamette River enters the Columbia River below Bonneville Dam.

The Columbia River is a very complex ecosystem because of its size, number of manmade alterations, diversity of the biota, and size and diversity of its drainage basin. Streams in general, especially smaller ones, usually depend on organic matter from outside sources (terrestrial plant debris) to provide energy for the ecosystem. Large rivers, particularly the Columbia River with its series of large reservoirs, contain significant populations of primary energy producers (algae, plants) that contribute to the basic energy requirements of the biota. Phytoplankton (free-floating algae) and periphyton (sessile algae) are abundant in the Columbia River and provide food for herbivores such as immature insects and certain fishes, which in turn are consumed by carnivorous species. Figure 4.1 is a simplified diagram of the food-web relationships in selected Columbia River biota and represents probable major energy and contaminant pathways. This consumptive-based food web *is* based on known feeding habits.

4.1 PHYTOPLANKTON

Phytoplankton species identified from the Hanford reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae,

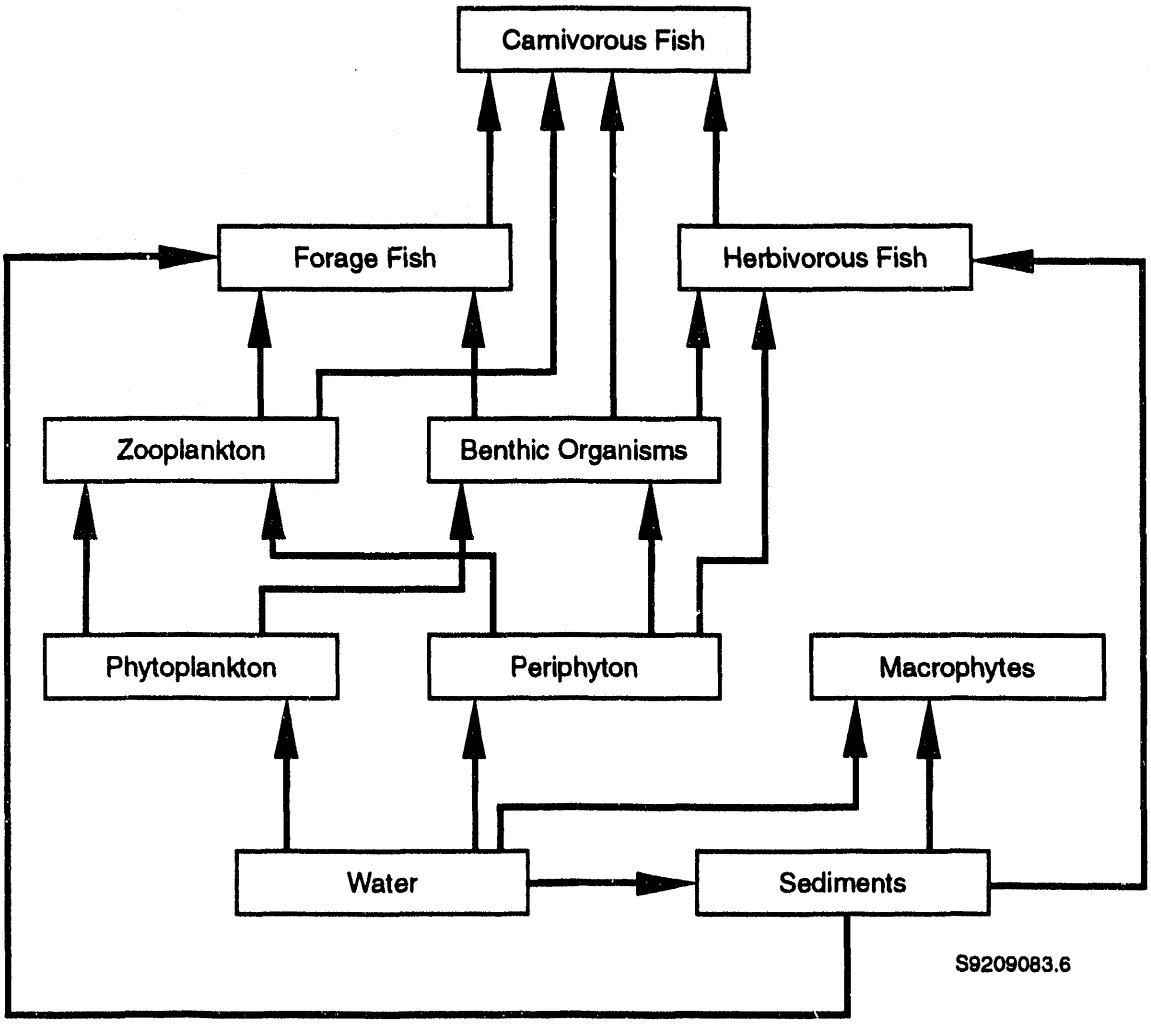
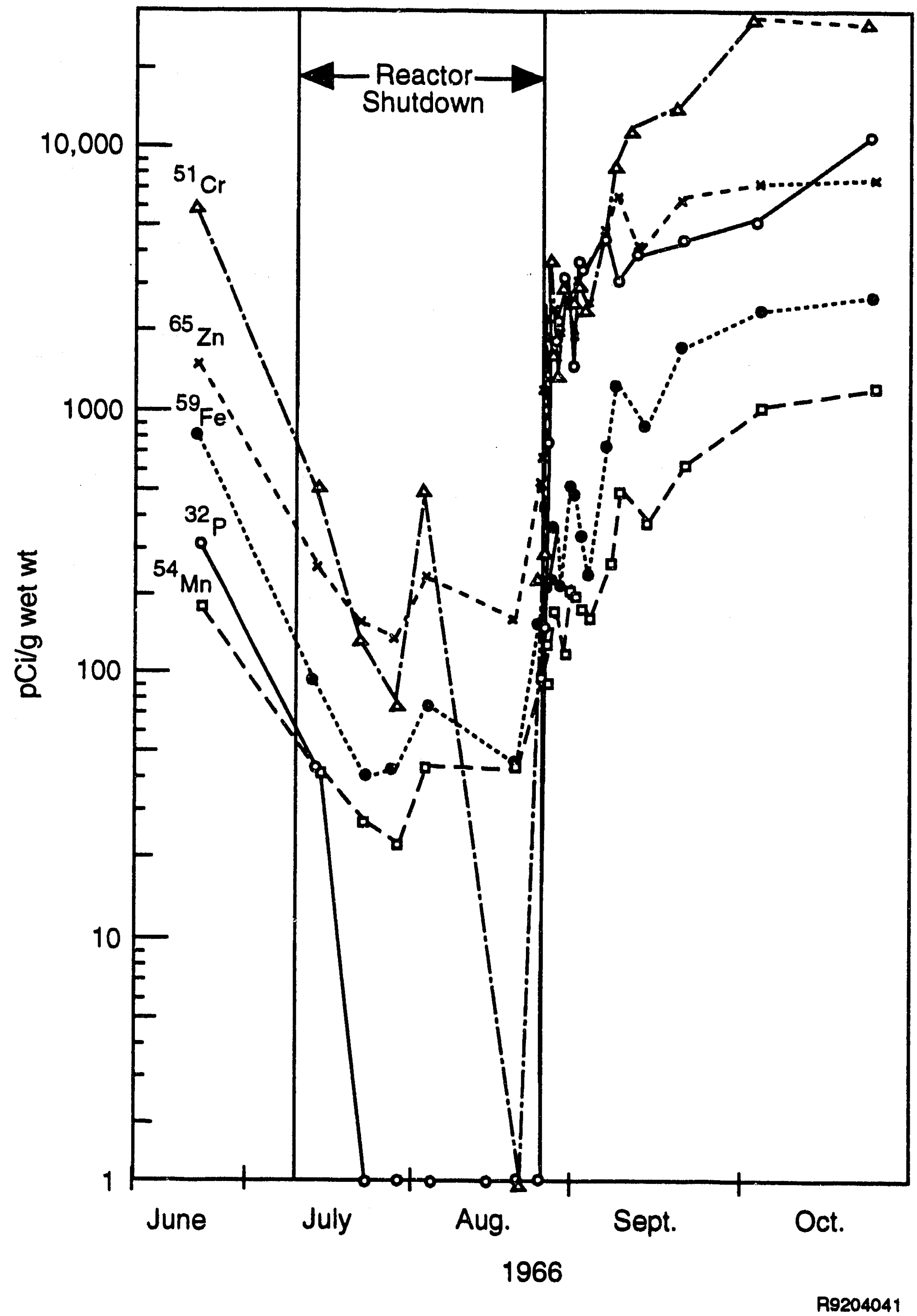


FIGURE 4.1. Simplified Food Web of Columbia River (adapted from Cushing 1991)

and dinoflagellates. Diatoms are the dominant algae in the Columbia River phytoplankton, usually representing more than 90% of the populations. The main genera include *Asterionella*, *Cyclotella*, *Fragilaria*, *Melosira*, *Stephanodiscus*, and *Synedra* (Neitzel, Page, and Hanf 1981). Plankton populations in the Hanford reach are typical of those forms found in lakes and ponds. They are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids reservoir, and by manipulation of water levels through dam operation in downstream reservoirs. A number of algae found as free-floating species in the Hanford reach of the Columbia River are actually derived from the periphyton; they are detached and suspended by the current and frequent fluctuations of the water level. Phytoplankton and zooplankton populations at Hanford are largely transient, flowing from one reservoir to another. There is generally insufficient time for characteristic endemic groups of phytoplankton and zooplankton to develop in the Hanford reach.

The peak concentration of phytoplankton is observed in April and May, with a secondary peak in late summer/early autumn (Cushing 1967a). *Because sufficient phosphate and nitrate nutrient concentrations are always present*, the spring pulse in phytoplankton density is probably related to increasing light and water temperature rather than to availability of nutrients. Minimum numbers of phytoplankton are present in December and January. Green algae (Chlorophyta) and blue-green algae (Cyanophyta) occur in the phytoplankton community during warmer months, but in substantially fewer numbers than the diatoms.

66 Phytoplankton respond rapidly to changes in ambient concentrations of radionuclides by absorption and, more importantly, by adsorption because of their large surface-to-volume ratios. Phytoplankton are a primary food source for filter-feeding organisms such as caddisfly larvae and clams. Watson et al. (1969) documented the rapid loss and uptake of radionuclides during a brief closure of the Hanford reactors that resulted in a rapid lowering and subsequent increase of radionuclides in the water (Figure 4.2). In addition, Cushing et al. (1981) *described* the relatively rapid loss of radionuclides



54 FIGURE 4.2. Radionuclide Concentration in Columbia River Net Plankton *(caught in net)* for Chromium-51 (^{51}Cr), Zinc-65 (^{65}Zn), Iron-59 (^{59}Fe), Phosphorus-32 (^{32}P), and Manganese-54 (^{54}Mn) (Watson et al. 1969)

from phytoplankton following permanent closure of the plutonium-producing reactors at Hanford. This decline was found at Hanford, McNary reservoir, and Bonneville reservoir, with downstream decreases of lessening magnitude (Figure 4.3). Cushing (1967a) presented data showing the magnitude of radionuclide transport of phosphorus-32 and zinc-65 by phytoplankton (in terms of nanocuries per cubic meter [nCi/m^3] of water) at different times of the year. Transport was greatest in spring and late summer, coincident with increases in phytoplankton populations (Figure 4.4).

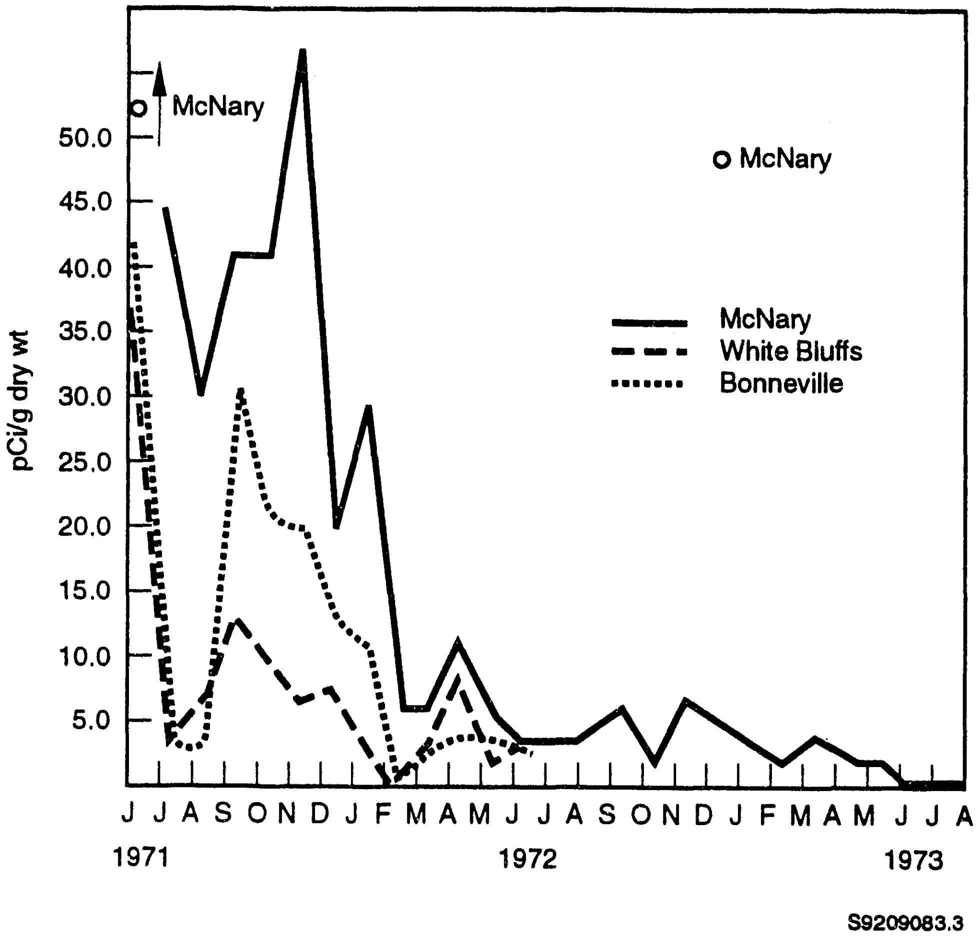
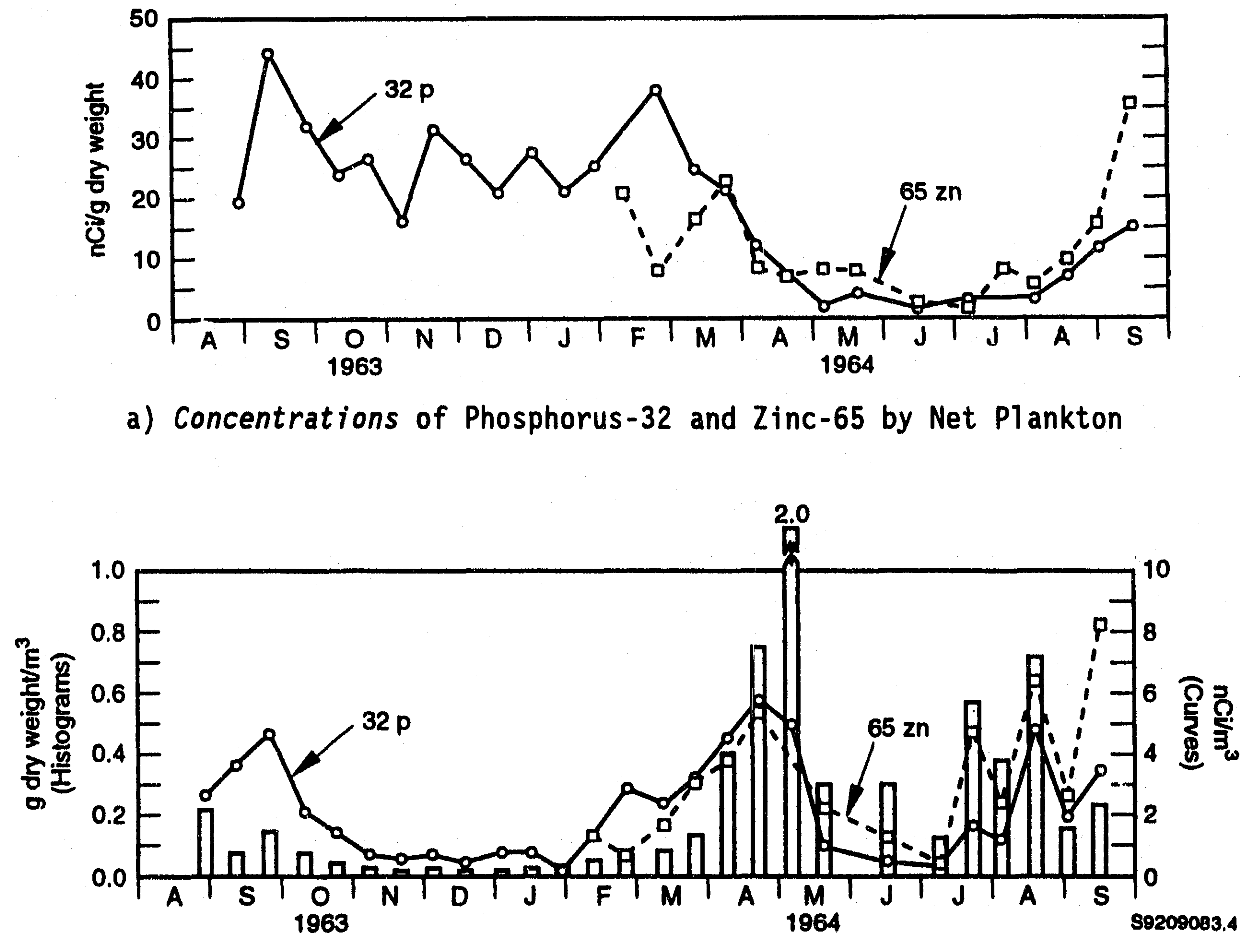


FIGURE 4.3. *Mean* Concentrations of Zinc-65 in Columbia River Phytoplankton Following Closure of Hanford Reactors. The value 1067 picocuries per gram (pCi/g) dry weight was found at McNary in June 1971 (Cushing et al. 1981).



a) *Concentrations* of Phosphorus-32 and Zinc-65 by Net Plankton

b) *Concentrations* of Net Plankton and Associated Phosphorus-32 and Zinc-65

FIGURE 4.4. Radionuclide Transport by Phytoplankton (Cushing 1967a)

4.2 PERIPHYTON

Communities of periphytic species (benthic microflora) develop on suitable solid substrata wherever there is sufficient light for photosynthesis. Peaks of production occur in spring and late summer (Cushing 1967b). Dominant genera are the diatoms *Acnanthes*, *Asterionella*, *Cocconeis*, *Fragilaria*, *Gomphonema*, *Melosira*, *Nitzchia*, *Stephanodiscus*, and *Synedra* (Page and Neitzel 1978; Page, Neitzel, and Hanf 1979; Beak Consultants Inc. 1980; Neitzel, Page, and Hanf 1981). This community is a significant food item for some fish species, especially suckers and carp.

Periphyton, like phytoplankton, have a large surface-to-volume ratio and thus accumulate high levels of radionuclides (Cushing 1967b). They also react similarly in terms of rapid uptake and *loss* in relation to ambient water concentrations. At low water levels, periphyton could contribute to the external dose received by people frequenting the shoreline.

4.3 MACROPHYTES

Macrophytes are sparse in the Columbia River because of the strong currents, rocky bottom, and frequently fluctuating water levels. Rushes (*Juncus* spp.) and sedges (*Carex* spp.) occur along the shorelines of the slack-water areas. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels. Commonly found plants include *Lemna*, *Potamogeton*, *Elodea*, and *Myriophyllum*. Where they exist, macrophytes have considerable ecological value. They provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. However, should some of the exotic macrophytes (Eurasian millfoil) increase to nuisance levels, they may encourage increased sedimentation of fine particulate matter. These changes could have a significant impact on the trophic relationships of the Columbia River.

4.4 ZOOPLANKTON

Zooplankton populations in the Hanford reach of the Columbia River are generally sparse. In the open water regions, crustacean zooplankters are dominant. Dominant genera are *Bosmina*, *Diaptomus*, and *Cyclops*. Densities are lowest in winter and highest in summer. Summer peaks are dominated by *Bosmina*, and *densities* range up to 4500 organisms/m^3. Winter densities are generally less than 50 organisms/m^3. *Diaptomus* and *Cyclops* dominate in winter and spring, respectively (Neitzel, Page, and Hanf 1983). Zooplankton are important food items for juvenile salmonids when they are living in the interstitial water among the rocks.

4.5 BENTHIC ORGANISMS

Benthic organisms are found either attached to or closely associated with the substratum. All major freshwater benthic taxa are represented in the Columbia River. Insect larvae such as caddisflies (Trichoptera), midges (Chironomidae), and black flies (Simuliidae) are dominant. Dominant caddisfly species are *Hydropsyche cockerelli*, *Cheumatopsyche campyla*, and *C. enonis*. Other benthic organisms include molluscs, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer *(Wolf 1976)*. Stomach contents of fish collected in the Hanford reach revealed that benthic invertebrates are important food items for nearly all juvenile and adult fish. There is a close relationship between food organisms in the stomach contents of fish and those in the benthic and invertebrate drift communities. Thus, this community is directly linked in the food pathway leading to *humans*. Certain molluscs and crayfish are potential food items for people and thus also are involved directly in food pathways leading to *humans*.

4.6 FISH

Gray and Dauble (1977) list 43 species of fish in the Hanford reach of the Columbia River. The brown bullhead (*Ictalurus nebulosus*) has been collected since 1977, bringing the total number of fish species identified in the Hanford reach to 44. Table 4.1 presents a selected list of species important as sport and commercial species and those important to Native Americans.

Based on their life histories, fish present in the Columbia River *are divided into two groups:* 1) anadromous species and 2) resident species. The predilection of these two groups in terms of their potential for accumulating radionuclides differs considerably. The anadromous species hatch in freshwater, grow and migrate to the ocean, and eventually return to freshwater to spawn. They are carnivorous, and actively feed as juveniles in the river and as they mature in the ocean, but do not feed during the spawning migration. Although they are most susceptible to accumulating radionuclides from the Columbia River food web during their brief residence as juveniles, there is

TABLE 4.1. Selected Fish Species Categorized by Interest Groups

Sport Fishing	Commercial Fishing	Native American Fishing
Steelhead trout	Steelhead trout	Steelhead trout
Chinook salmon	Chinook salmon	Chinook salmon
Mountain whitefish	Coho salmon	Coho salmon
Walleye	Sockeye salmon	Sockeye salmon
Smallmouth bass	White sturgeon	White sturgeon

evidence of some species accumulating radioactivity *before* their return to the Columbia River estuary (Kujala 1966). Muscle samples from spawned-out chinook salmon collected in the Hanford reach in 1988 indicated no measurable influence from radionuclides released to the Columbia River (Jaquish and Bryce 1989). *Alternatively*, resident fish species can spend essentially their entire life feeding on contaminated food and being exposed to external contaminants, thus offering the potential for much higher levels of contamination.

4.6.1 Anadromous Species

Anadromous species that use the Columbia River as a migration route include the chinook salmon, sockeye salmon, coho salmon, and steelhead trout; these are also the species with the greatest economic importance (Table 4.1). Fall chinook and steelhead trout spawn in the Hanford reach (from the reactor area to Umatilla and McNary Dam). These populations may potentially accumulate radionuclides during their freshwater rearing period. The various life stages of salmon and steelhead trout and the time when each is present in the Hanford reach *are* shown in Figure 4.5.

19 *The upper river bright stocks (URB) originate from the upper Columbia River (primarily the Hanford reach) and such tributaries as the Deschutes and Snake rivers. The relative contribution of URBs to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s to 50% to 60% of the total by 1988 (Dauble and Watson 1990).*

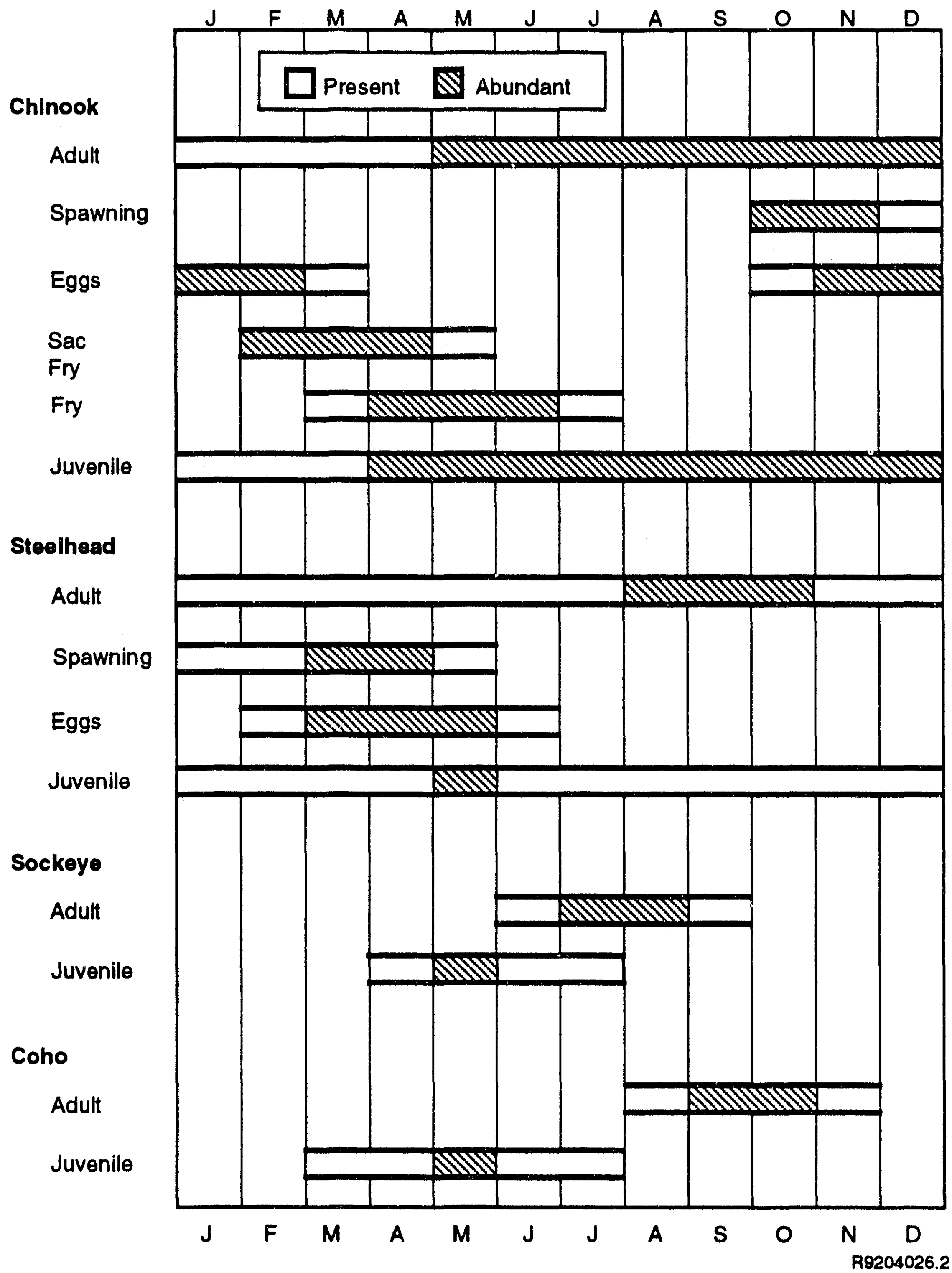


FIGURE 4.5. Expected Occurrence of Salmonids in Hanford Reach of Columbia River

The progressive damming of the Columbia River, beginning with the construction of Bonneville Dam in the lower reaches, has resulted in a concurrent reduction in the runs of anadromous salmonids. This reduction is attributed to a combination of factors, including blockage by the dams during adult migration, destruction of spawning habitat, and loss of downstream migrants as they *pass* through the turbines or *as they are* increasingly preyed upon by the large population of predator species that thrive in the lentic habitats created by the dams. The destruction of other mainstream Columbia River spawning grounds by dams has increased the relative importance of the Hanford reach for spawning (Watson 1970, 1973). Dauble and Watson (1990) present data illustrating the fluctuation in the numbers of salmon redds (nests for salmon eggs in gravel) observed in the Hanford reach from 1947 through 1988; these varied from nearly zero in 1956 to about 8000 in 1989 (Figure 4.6).

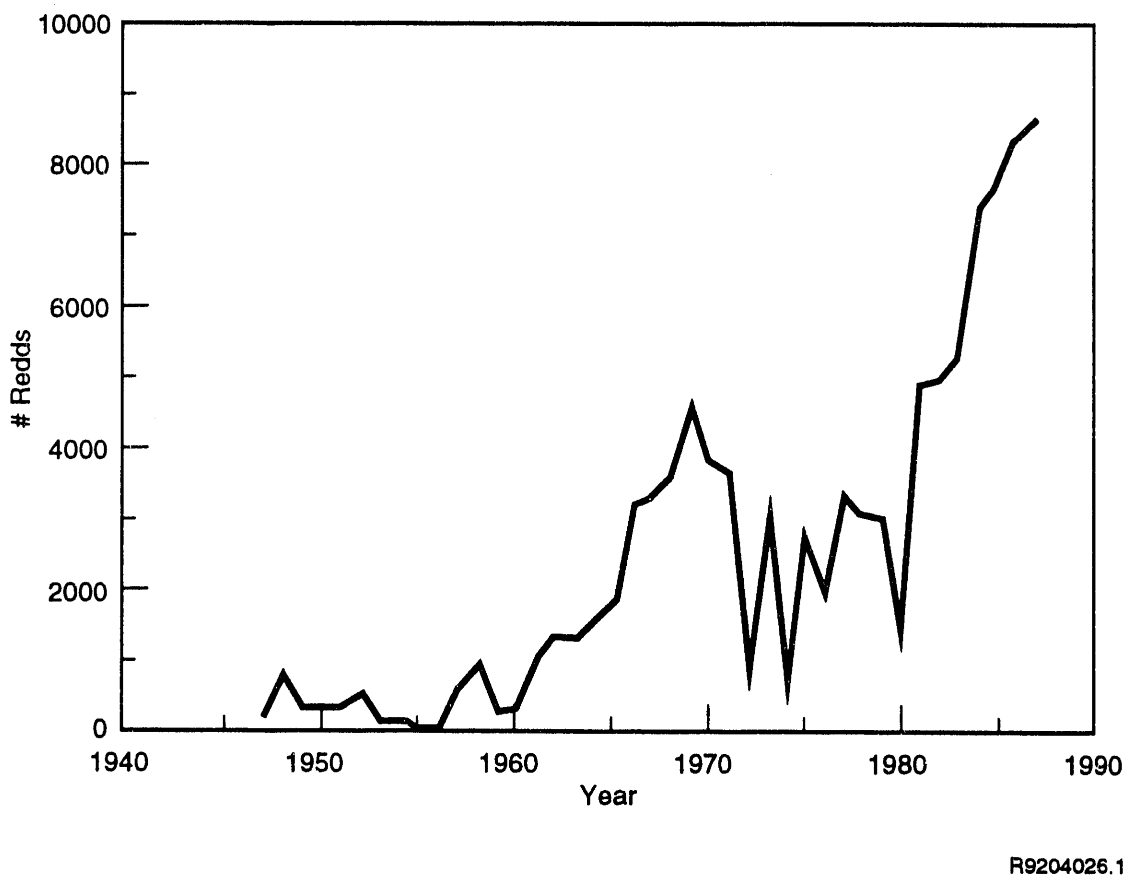


FIGURE 4.6. Hanford Reach Salmon Redd (Nest) Counts (Dauble and Watson 1990)

Based on counts at dams for the years 1962 to 1971, the upper *estimate* of steelhead spawning population in the Hanford reach *was* about 10,000 fish. The estimated annual sport catch for the period 1963 to 1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2700 fish (Watson 1973).

The American shad, another anadromous species, may also spawn in the Hanford reach. The upstream range of the shad has been increasing since 1956 when fewer than 10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream from Hanford, has risen to many thousands each year and the young-of-the-year have been collected in the Hanford reach. Unlike salmonids, the shad is not dependent on specific current and bottom conditions for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

4.6.2 Resident Species

Resident fish species are ecologically important to the structure and function of the Columbia River ecosystem. The resident fish population at Hanford is diverse, yet characteristic of many northwest rivers. Resident fish of importance to sport fishermen and Native Americans include the mountain whitefish, white sturgeon, smallmouth bass, crappie, channel catfish, walleye, and yellow perch. Large populations of rough fish including carp, shiners, suckers, and squawfish are also present. A large database exists on radionuclide concentrations in several resident fish species, dating from the 1940s to the present (Davis, Watson, and Palmiter 1956; Watson et al. 1970).

The range of the mountain whitefish includes southwestern Canada and the northwestern United States. Whitefish are a popular sport fish and may compete with other desirable species, including trout and juvenile salmon, for food and space. Whitefish are present year round in the Hanford reach and feed primarily near the bottom on aquatic insect larvae, including caddisflies (Trichoptera), midges and black flies (Diptera), mayflies (Ephemeroptera), and stoneflies (Plecoptera). Additionally, they sometimes prey on fish eggs (including their own), fish larvae, and small fish and may take eggs of salmon or trout. Whitefish containing measurable body burdens of Hanford-related radionuclides have been collected in the lower reaches of the Yakima River below the Hanford Site and near Priest Rapids Dam above the Site. This provides evidence that the resident population in the Hanford reach migrates to these locations (Watson and Davis 1957).

White sturgeon are a long-lived species that reside year round in the Hanford reach. They are primarily bottom feeders and can take up radionuclides both by ingesting contaminated sediments and via the aquatic food chain. Concentrations of various radionuclides were determined for white sturgeon tissues during radiological studies conducted in 1966 and 1967 (Watson et al. 1970). However, no attempt was made to determine relationships between fish age and radionuclide concentration in carcass or muscle tissue.

Because sturgeon cannot move upstream through fish ladders, their movements since 1960 have been restricted to the area bounded by Priest Rapids, McNary, and Ice Harbor dams. However, seasonal movement throughout the McNary pool is known to occur (Haynes 1978), and migration range could have been greater for sturgeon before construction of McNary and Priest Rapids dams. Thus, even for sturgeon captured near former production reactors, *their radionuclide burden* may not be directly related to radionuclide concentrations present at that location.

Large-scale suckers and carp are numerous in the Hanford reach and have feeding habits conducive to accumulating contaminants. They, like the sturgeon, ingest large quantities of fine detritus and periphyton, both of which have large surface-to-volume ratios and thus adsorb high levels of contaminants.

There is extensive literature concerning radionuclide burdens of species consumed by *humans*. They include data on zinc-65 levels in *humans* from consuming whitefish (Foster and Honstead 1967) and zinc-65 concentrations in oysters from Willapa Bay, Washington (Seymour 1966). This literature is discussed in Section 7.3. Some of this information is used in Section *10.0*.

5.0 REACTOR OPERATIONS AND EFFLUENT WATER COMPOSITION

Radionuclide composition and activity level of cooling water discharged to the *Columbia* River varied considerably as a result of several factors including the number of reactors and their power levels, seasonal changes in the parent elements in raw river water (i.e., the elements activated as they passed through the reactor core), chemicals used in water treatment, corrosion rates of reactor piping and fuel element cladding, occasional purging of radioactive film from reactor components, and *the* length of time effluent was retained in basins before discharge. Another factor was radionuclide releases from periodic fuel element ruptures (slug ruptures). The wide variations in these factors, together with the hydrologic variables of the Columbia River and dam construction, produced a complex combination of river water and reactor effluent during the years of reactor operation. Concentrations and distributions of radionuclides in the river were never constant, *in either* time or location, throughout the operational years.

The withdrawal and processing of raw river water involved filtration and chemical additives to provide the desired quality for reactor cooling water. Emergency operating procedures were also part of the water system design. Cooling water released from the reactors passed through a retention basin and spillway system to the outfall lines where the water was discharged to the river. An example design of a reactor water system is shown in Figure 5.1 (Ballinger and Hall 1991).

5.1 TIMETABLE OF REACTOR OPERATIONS

Reactor operating periods are shown in Figure 5.2. The 100-B reactor (RM 384) was the first on line in September 1944, followed by 100-D (RM 377.6) in December of the same year. The 100-F reactor (RM 369) came on line in February 1945. These three reactors contributed all of the radioactivity discharged to the river until about November 1949, when 100-H (RM 372.5) came on line. In October 1950, 100-DR (RM 377.6) came on line, followed by 100-C (RM 383.6) in November 1952. The last of the once-through-cooled reactors,

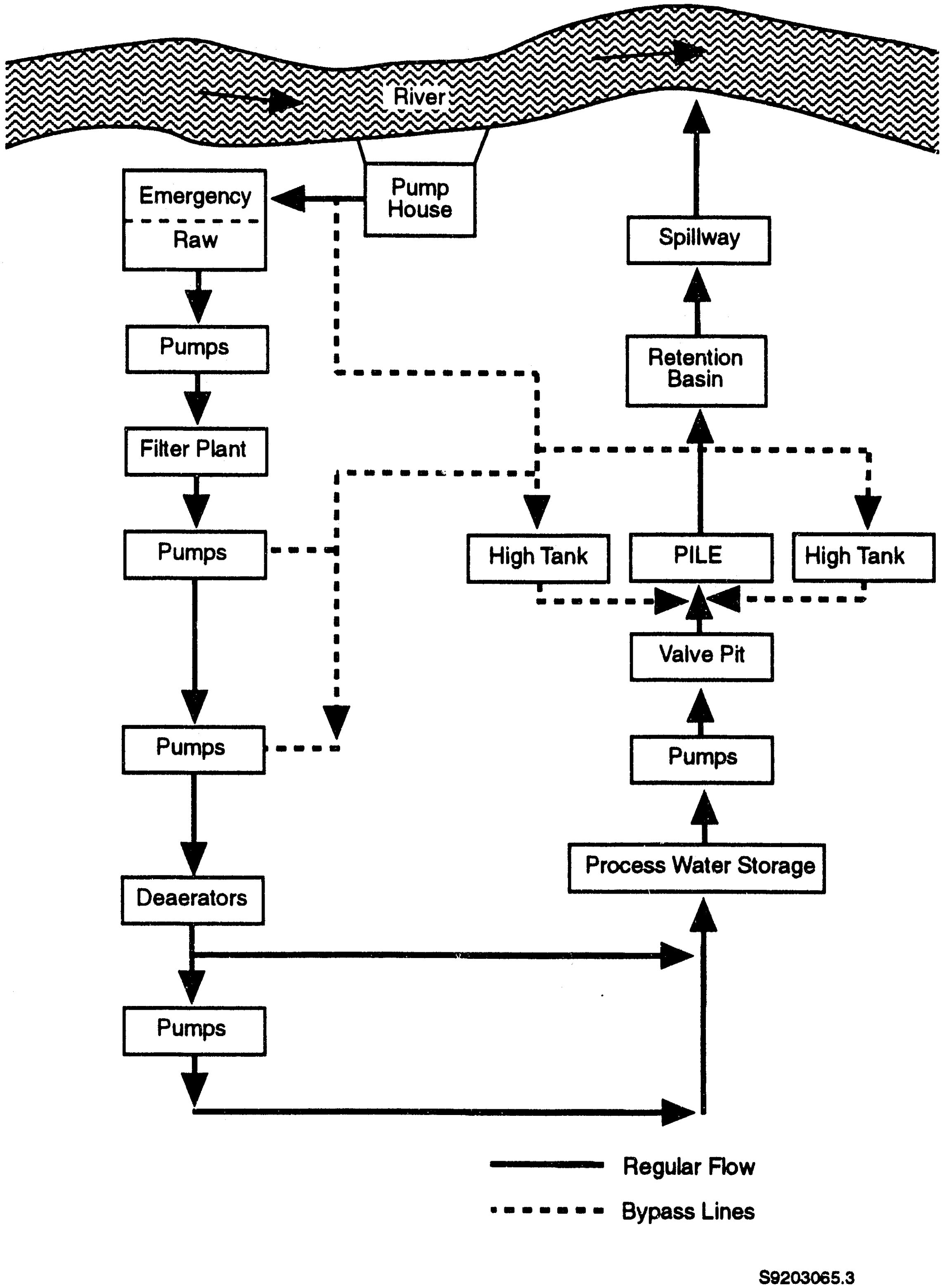


FIGURE 5.1. 100-D Area Water System (Ballinger and Hall 1991)

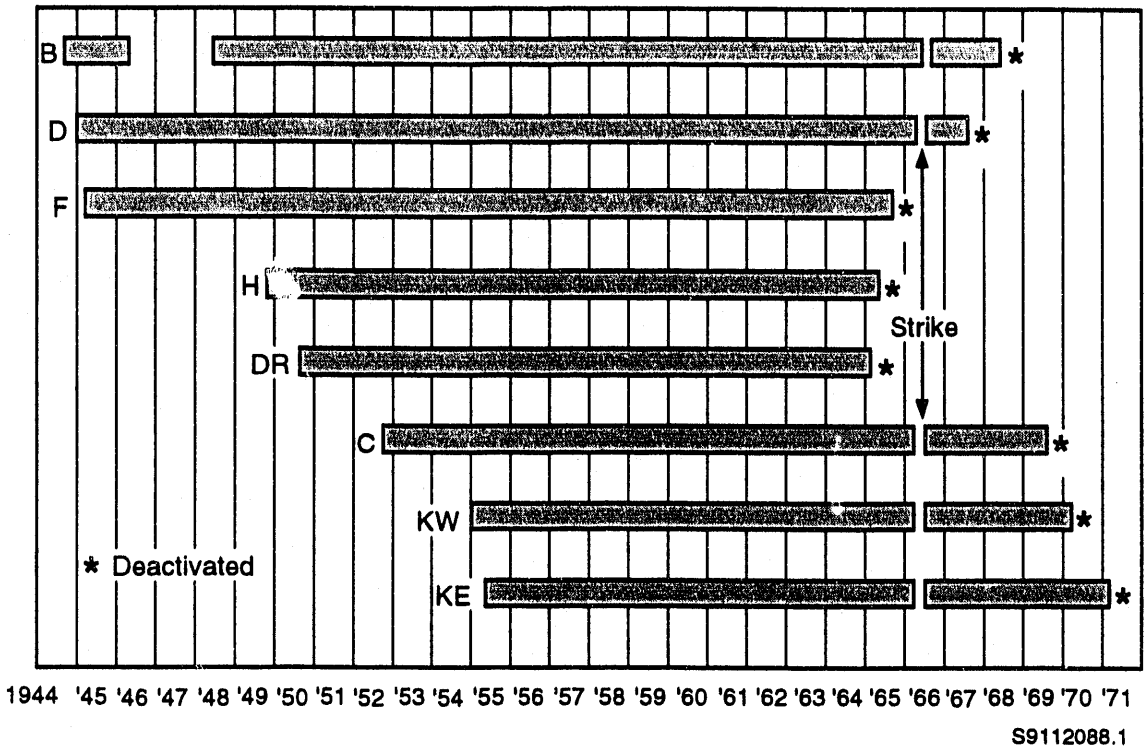


FIGURE 5.2. Operating Periods for the Once-Through-Cooled Hanford Production Reactors (based on Foster 1972)

100-KW (RM 381.8) and 100-KE (RM 381.4), came on line in January and April 1955, respectively. Because design power levels for older reactors were substantially increased and design power levels were high for C and K reactors, peak plutonium production and discharge of maximum amounts of radioactive effluent did not begin until about 1958.

In 1963, President Johnson ordered a large-scale reduction in plutonium production, and the Hanford reactors were scheduled for retirement. Between 1964 and *January 1971*, all eight once-through-cooled reactors were taken off line permanently (Figure 5.2). The first reactor to be shut down was 100-DR on December 30, 1964. Its closure was followed in mid-1965 by the closures of 100-H and 100-F. The remaining reactors were all down temporarily during July and August 1966 because of a labor strike on July 8. In June 1967, 100-D was taken off line, followed by 100-B in 1968, 100-C in April 1969, and 100-KW in February 1970. The last of the eight once-through-cooled reactors, 100-KE, was shut down permanently in January 1971 (Ballinger and Hall 1991).

5.2 ELEMENTS IN COLUMBIA RIVER WATER

During the early 1950s, scientists at the Hanford Site recognized that the isotopic composition of effluent water was not constant, but displayed a regular seasonal fluctuation and irregular daily fluctuations as well as the expected differences between reactors (Honstead 1954). During the early 1960s, studies at the Hanford Site investigated the presence of natural elements in the river water to determine the relative concentrations and their sources. These elements were of interest because of their activation during the passage of cooling water through the reactor pile. The elements of interest were sodium, copper, phosphorus, sulfur, manganese, arsenic, uranium, lanthanum, iron, cobalt, zinc, and scandium.

The reports of this work concluded that concentrations of elements depended on the relative volumes of water supplied by two separate drainage basins (Silker 1964). One basin in Canada includes the headwaters of the Columbia River and the Kootenai River basin, and the other is the combined drainage of the Pend Oreille and Spokane River watersheds in the United States. Both sources drain about 30,000 square miles and supply approximately equal amounts of water to the Columbia River until mid-May, when the Columbia and Kootenai rivers crest to contribute about 80% of the Columbia River flow at Grand Coulee Dam.

The following conclusions were reached regarding the relationship between the two drainage basin runoffs and the elemental concentrations in the raw river water: zinc and cobalt appeared to originate primarily in the Canadian area of the basin, and the changes in concentration closely parallel those in the upper Columbia River discharge hydrograph. Concentrations of sodium, uranium, sulfur, and phosphorus are lower in the Canadian area, causing a relative decrease in concentrations of these elements during the peak flow period (Silker 1964).

Concentrations of manganese, copper, arsenic, and *natural* uranium were from two to five times higher in Spokane River water than in the upstream segment of the Columbia River (Silker 1964). The increased concentration of these elements tends to correspond to peak flows from the Spokane River in late April. Lanthanum exhibited a similar late-April trend. Iron concentrations were variable and scandium was consistently low.

5.3 CHEMICAL ADDITIVES

Certain radionuclides in the reactor effluent originated from neutron activation of chemicals added to the process water. As the water was withdrawn from the river, *water-quality* variables (e.g., pH, turbidity, temperature, chemistry, bacteriology) were carefully monitored to determine the amounts of chemical compounds to be added. Because the natural pH of the river water *ranges from* 8.0 to 8.6, sulfuric acid (H_2SO_4) was added in large amounts to bring the water to a pH of 7.0, *which* was *the* desired *pH* for cooling water. From 3 to 10 parts per million (ppm) of alum [$Al_2(SO_4)_3 \cdot 18H_2O$] were added as a coagulant as soon as water was withdrawn from the river to chemically reduce certain elements that were present in the water as solids and colloids, such as arsenic, scandium, and uranium. Approximately 2 ppm sodium dichromate ($Na_2Cr_2O_7$) were added shortly before the water entered the reactor to inhibit corrosion of the aluminum tubing and fuel element jackets. An organic filter aid, Separan, was added occasionally in very small amounts just *before* filtration (Hall and Jerman 1960; Perkins 1961).

67 Two reports offered some estimates as to the percentage of radionuclides the various additives contributed to the effluent. Hall and Jerman (1960) concluded that many of the radionuclides found in reactor effluent water had their primary source in the river except for chromium-51, which was supplied by the sodium dichromate. This chemical also contributed *some* of the elemental sodium. Hall and Jerman further concluded that as much as 25% of the phosphorus-32 may have resulted from activation of the sulfuric acid.

Perkins (1961) concluded that nearly 100% of the chromium-51 and 25% of the sodium-24 were neutron-activation products of sodium dichromate. At least 40% of the phosphorus-32 was produced from the sulfur in the sulfuric acid and the alum. According to Perkins, impurities in the alum also produced 60% of the gallium-72, 50% of the samarium-153, and 25% of the iron-59. The contribution *of* all other radionuclides *due to* neutron activation of chemical additives was less than 10%.

5.4 PURGES

To dislodge and remove a film, *which contained radionuclides, that* built up on the surface of fuel elements and process tubing, purges were run on the average of about two to three times per month *for the group of eight reactors*. These purges were necessary because this film would occasionally become thick enough to partially restrict the flow of water through the tubing (Hall and Jerman 1960). During the purging process, a slurry of diatomaceous earth and process water was run through the tubes in the belief that the abrasive action of the slurry would dislodge the film.

Reports on the purging process written during the 1950s identified several radionuclides *whose concentrations in the effluent* were elevated by the diatomaceous earth slurry process. A report by Healy (1952) specifically *mentioned* copper-64, iron-59, and phosphorus-32 as being increased by the purging process. This finding was made by comparing the normal activity levels in cooling water entering the retention basin with those levels following purging. A later report by Koop (1957b) identified phosphorus-32 and zinc-65 concentrations being increased in the river because of purging. According to Koop, the concern regarding these two radionuclides was their uptake in *the flesh of* Columbia River whitefish, especially during the warm-water season of the river. This season extended from about the first of July to the first of November.

Based on tests conducted in 1955, a report by Koop (1956) recommended control measures for purging operations. These included a time limitation of 1 hour per purge, a maximum of 25 ppm of diatomaceous earth (100 ppm had been previously used), no more than one purge per 48-hour period (all reactors combined), and purges during reactor operations only on those days when the river temperature was less than 15°C. Purging while a reactor was operating, as opposed to being shut down, produced several times the activity level (net difference) in the effluent, based on analysis of samples from the retention basin (Healy 1952).

Another purging process involved the use of a chemical cleaner, Turco 4306-B, to remove radioactive scale from the surfaces of rear face reactor piping. The purpose of using this cleaner was to lower rates of radiation exposure for workers near the rear face of a reactor. Turco 4306-B, which is a chelating and reducing agent and a strong acid, was tested in September 1957; the results were reported by Koop (1957a). The cleaner was tested during reactor outage time using a concentration of 6 ounces of Turco per gallon of cooling water, heated to about 85°C, and pumped through reactor tubing and rear face *piping* of the reactor to *the retention* basin *system.* The flow rate was about 5% of normal reactor operation flow. Disposal of the cleaning solution was handled differently than the other purging process. *The usual practice was to divert the purged effluent to an inactive retention basin, allow time for decay, and then return it to the normal reactor effluent.*

Koop (1957a) stated that the concentrations of radionuclides from Turco purging were not significantly different from the normal reactor effluent samples, although two radionuclides, iron-59 and zinc-65, were found in higher concentrations in basin inlet samples, which contained cleaning solution, than in operating effluent. In the same report, Koop later stated that the radionuclides of concern, with respect to potential pollution, were iron-59, zinc-65, and neptunium-239. The recommended disposal was to release the spent cleaning solution to the river at as slow a rate as was practical.

Another study, reported by Perkins (1959), presented results of testing the efficiency of the Turco cleaning solution on process tubing and associated fuel element jackets. The report *presented* a detailed discussion of Turco purging effects within the reactor system, but *did* not provide much information on releases to the river.

78 5.5 *UNCONTROLLED AND* ACCIDENTAL RELEASES

Uncontrolled releases of radionuclides to the river occurred from retention basin leakage (shoreline springs). Accidental releases occurred as fuel element ruptures from the eight once-through-cooled reactors; the failure of a 300 Area waste pond dike; and the fuel element failure that occurred in the Plutonium Recycle Test Facility (PRTR). The shoreline releases occurred as river bank springs that were fed by retention basin leakage into the underlying soils. Fuel element ruptures were intermittent events that began in 1948 and increased in frequency as more reactors were added and power *levels increased. The failure of the 300 Area waste pond dike was a single event (October 1948) as was the fuel element failure in the PRTR (September 1965).*

5.5.1 Shoreline Releases

78 *Shoreline releases occurred during reactor operations by leaks transmitted through the ground water to the river. The earliest mention of shoreline releases is discussed in a memo dated November 26, 1945, from J. W. Healy to H. M. Parker (Healy 1945). The releases are described as warm springs or "areas" along the Columbia River beside the 107-F and 107-D retention basins. An area was described as only one spring or a general seepage from an area of several square feet. At 100-D, there were about 15 areas and at 100-F about 30 areas in the vicinity of the spillways. The spring-water temperature was comparable to that of the basins, indicating a relatively short transit time through the ground. However, Healy states that "...the activity was less than 1 [percent] of that in the basin indicating that the sodium (14.8 hrs.) and manganese (2.5 hrs.) may be adsorbed in the soil through which it passes..." The maximum spring-water activity appeared to occur beside the spillways with 100-F consistently yielding concentrations from five to seven times those at 100-D. The range of activity sampled 2 feet below the 100-F spillway, during October and November 1945, varied from 4.2×10^{-4} to 7.3×10^{-4} microcuries (µCi) per liter.*

By the late 1950s, the condition of the retention basins for B, C, D, and F reactors had raised concerns regarding the leakage of the basins contributing to shoreline releases to the river (Koop, McCormack, and Hall 1958). The concerns were the contamination of drinking water for workers at downstream reactors (more specifically, at reactors downstream of B, C, and D reactors--no reactor was downstream of F reactor) and the radionuclide uptake by aquatic life in the river. The bottom organisms along the shoreline area were food for whitefish and waterfowl, both of which were consumed by humans.

The report by Koop, McCormack, and Hall (1958) mentioned that the deterioration of the basins involved both surface and bottom leakage but that the release rates were not known. Although the shoreline releases were considered to be significant, some decontamination was assumed from filtration and ion exchange within the soil column. The authors also assumed that the soil between the basins and the river had limited capacity and that the activity level of the water emerging from the shoreline would eventually approach that of the basin effluent. According to the authors, this trend had been confirmed by the increase in the amount of radionuclides in ground water flowing into the 181-B forebay and approximately a twofold increase since 1955 in the radionuclide concentrations from river bank hot springs at the 100-F Area.

5.5.2 Fuel Element Ruptures

During reactor operations, the cladding (jacket) of individual fuel elements can fail and release fission products and uranium to the cooling water. McCormack and Schwendiman (1959) discuss two principal rupture types: 1) a severe rupture, usually a side rupture or fragmented element, and 2) a split or end-cap failure.

The first two fuel element ruptures occurred in 1948 followed by three more in 1950 (DeNeal 1965). Beginning in 1951, the number of ruptures per year increased significantly as shown in Table 5.1. Jerman, Koop, and Owen (1965) stated that severe ruptures resulted in a weight loss of about 150 grams per fuel element, while the other types of ruptures resulted in a weight loss of about 9 grams per fuel element. The authors did not state whether the weights included other materials *besides* uranium. They estimated that the average weight loss was 12 kilograms per year for the years from 1955 through 1958.

68 *The significant* fission products released during ruptures were strontium-89,90 and iodine-131 (McCormack and Schwendiman 1959; Jerman, Koop, and Owen 1965). McCormack and Schwendiman (1959) stated that ruptures contributed about 20% of the strontium-89,90 in the Columbia River at Pasco and about 4% of the gross fission product activity. Jerman, Koop, and Owen (1965) considered iodine-131 to be the most significant radionuclide. They estimated that 2400 grams of irradiated uranium containing 920 curies of iodine-131 were lost from the 97 ruptures in 1964. For comparison, they stated that about 500 kilograms of natural uranium in the cooling water passed through the eight reactors, creating about 800 curies of iodine-131.

TABLE 5.1. Fuel and Target Element Failures Removed from the Reactors (DeNeal 1965)

Calendar Year	Total Failures All Types
1948	2
1949	0
1950	3
1951	115[a]
1952	142
1953	93
1954	211
1955	242
1956	191
1957	201
1958	174
1959	71
1960	130
1961	86
1962	95
1963	68
1964	97
1965[b]	49
Total	1970

(a) Includes 13 lithium target elements.
(b) Through May 1965. Includes 17 thoria target elements.

As of 1965, the most severe rupture occurred on May 12, 1963 (Hall 1963; Jerman, Koop, and Owen 1965). The rupture occurred in one of the process tubes of the 100-KE reactor and involved a zircalloy-clad experimental fuel element. About 450 grams of uranium were lost, indicating a release of about 170 curies *of iodine-131* (Jerman, Koop, and Owen 1965).

5.5.3 300 Area Waste Pond Dike

A description of *the 300 Area waste* pond, its associated problems, and the dike failure that occurred on October 25, 1948, is presented in a report by Singlevich and Paas (1949). The following description of the pond and details of the dike failure are summarized from that report.

The pond covered an area of 490,000 square feet and was about 5 feet deep. The walls were constructed of crushed rock and earth; the bottom was earthen, through which waste solution continuously infiltrated. Estimates indicated that about 2 to 3 pounds of *unirradiated* uranium *wastes from fuels preparation and Hanford Laboratories facilities (Haney 1957)* were discharged daily into the pond from the 300 Area. However, this estimate neglected sources of uranium from other buildings. At the time of the report, exact quantities of uranium discharged into the pond were not known.

Following the failure of a weak point in the northwest corner of the dike, approximately 14.5 million gallons of waste solution were discharged into the river between 2:30 PM and 4:00 PM on October 25. The waste traveled about 1000 to 1500 feet over the ground to the river. Rough calculations indicated that about 12 to 60 pounds of uranium were included in the waste solution. River water samples were taken from the 300 Area down to Portland, Oregon, at strategic locations (500 samples). The maximum single result was 2280 disintegrations per minute per liter (dpm/L) of alpha activity about 30 yards downstream of the 300 Area. Trace quantities of uranium were found about 1 mile above Richland, and normal alpha activity was detected below Richland and at Portland.

78 *5.5.4* *<u>PRTR Fuel Element Failure</u>*

The PRTR was constructed in the 300 Area for use as part of a fuel cycle research effort to investigate the use of plutonium as a reactor fuel. The major function of the PRTR was the irradiation testing of plutonium-bearing fuel elements (Purcell 1966). The reactor was designed as a vertical pressure tube type and was heavy-water moderated and cooled. Construction began in March 1958. The reactor was initially started up on November 21, 1960, and operations began in March 1962 (Purcell 1966).

The Fuel Element Rupture Test Facility (FERTF) was a pressurized light-water-cooled loop occupying the center position in the PRTR. The FERTF had a separate cooling system and was used to test partially molten core fuel elements, including tests with elements having deliberate defects. On September 29, 1965, during the irradiation of an intentionally defected fuel *element, the FERTF pressure tube failed. The reactor was automatically shut down. The accident resulted in releases of radioactivity to the atmosphere and the Columbia River.*

Summaries of these releases are described in a two-part report by the Investigative Committee composed of BNW and Atomic Energy Commission (Richland, Washington) staff (PNL 1966a, 1966b). Liquid wastes were disposed of in onsite trenches and by releases to the river. Some of the contaminated liquids were transported in tankers to disposal trenches near the Chemical Separations Facilities (200 areas). Other onsite disposal of liquid wastes occurred at a temporary trench near the PRTR when contamination was detected in the secondary coolant and other normally contamination-free streams that were routed directly to the river (PNL 1966a). Releases to the river were monitored at Richland, Kennewick, and Pasco from September 29 through October 1. Estimates of releases of iodine-131 to the river ranged from 9 curies at Pasco to 20 curies at Richland. The iodine-133 releases were estimated at 55 curies at Richland (PNL 1966b).

5.6 BASIN RETENTION TIME

The purpose of retention basins was to hold reactor effluent until many of the shorter-lived radionuclides had decayed substantially before discharging effluent to the river. Retention time depended on the flow rate through the reactors and varied from one reactor to the next. In 1945, the optimum time was reported as 6 hours (Parker 1945).

By 1960, retention time had been reduced because of increased cooling-water discharge and varied from 30 minutes to about 3 hours. Based on this range of holdup times, activity levels in the effluent released to the river were reduced by a factor of two to three, but in no case were holdup times long enough to reduce the activity of those radionuclides of major interest by a significant amount. The radionuclides of major interest were identified as phosphorus-32, arsenic-76, zinc-65, chromium-51, and neptunium-239 (Hall and Jerman 1960).

A study of basin retention times was conducted in 1953 to provide data for calculating decay correction factors to determine more accurate values for beta particle activity *concentration* in the water leaving the basins. Results of this study were reported by Soldat and Quimby (1953). *Pilcher and Norton (1953) provided* a summary of basin retention times based on flow rate data for 100-B, 100-D, 100-DR, 100-H, and 100-F *reactors*.

5.7 EFFLUENT DISCHARGE TO RIVER

Effluent was discharged into the river from each reactor by gravity flow through a pipe 42 to 60 inches in diameter that was placed along the river bottom and ran from an open discharge structure (spillway) at the bank. The pipe or outfall line usually extended to the channel center and was buried for most of its length a few feet below the riverbed (Honstead, Healy, and Paas 1951). Thus, *to produce as much near-field diffusion as possible*, outfall lines discharged effluent at a point 300 to 700 feet from the reactor shore where the velocity of flow was faster.

There were two exceptions to this typical effluent discharge design. At the 100-D reactor, the river channel is divided by a mid-channel island, with the higher velocities occurring on the opposite side of the island. The outfall line for the combined 100-D and 100-DR effluents was extended along the near-channel bottom, over the island, and into the far channel to take advantage of faster flow velocities. The outfall line crossing the island was perforated with 1/2-inch holes every 20 feet to prevent air pockets in the line. This design allowed continuous venting of effluent water onto the island surface. The other exception was at 100-F, where the original line failed and was replaced in 1946 by a new line that extended only 300 feet from the *spillway* (Honstead, Healy, and Paas 1951). As a result, effluent was discharged about 200 to 250 feet from the shore into slower flow velocities. The resulting effluent plume hugged the reactor shoreline and produced elevated activity levels for some distance downstream.

Problems arose during seasons of high river flow because the hydraulic head differential between the discharge structure and the water-surface elevation decreased. This decrease *lowered* the discharge capacity of the line and *caused* the effluent basin to *divert effluent* into a bypass spillway that released into the river at the shoreline. Diversion of basin inflow to the bypass spillway was also common during power peaking and concurrent high flow rates through the reactors (Honstead 1954; Hall and Jerman 1960).

5.8 ACTIVITY LEVELS AND VARIABILITY OF RELEASES

According to a report by Parker (1954), contamination of the Columbia River by reactor effluent had been studied "with increasing intensity since the start of the Hanford operations." Parker stated that, at the time of the report, about 8000 *curies per day (Ci/day)* of radioactive material were released to the river. The radiochemical composition *varied* and *was* influenced by seasonal turbidity changes and modifications of water treatment. A brief discussion in Parker's report seems to indicate that calculations of river concentrations had been attempted, but that results were not as reliable as desired because 100% material balance was impossible. No specific details were provided on the calculation procedure.

56 A report by Hall and Jerman (1960) includes some tabulated data of the activity levels in effluent releases to the river. For the years 1957 through 1959, the tabulated data for each of the eight reactors include the monthly average cooling-water discharge, monthly average total beta releases (Ci/day), and monthly average releases (Ci/day) for phosphorus-32, arsenic-76, zinc-65, chromium-51, and neptunium-239. A monthly average release rate for total beta is shown in Figure 5.3. The cause of the unusually high monthly release rates that occurred in 1957 (Figure 5.3) is not known at this time; however, there are several possibilities. *Contributing factors could include* the initial use of Separan, which improved the efficiency of filter-bed backflushing; the disturbance of upstream riverbed sediments at the Priest Rapids Dam construction site *(construction on Priest Rapids Dam began July 9, 1956; low-head filling began in September 1959; reservoir filling was completed March 24, 1961); or the inflow of elemental manganese from the Spokane River watershed.* The most likely cause *of the high release rates* is thought to be the activation of elemental manganese from the Spokane River system, producing

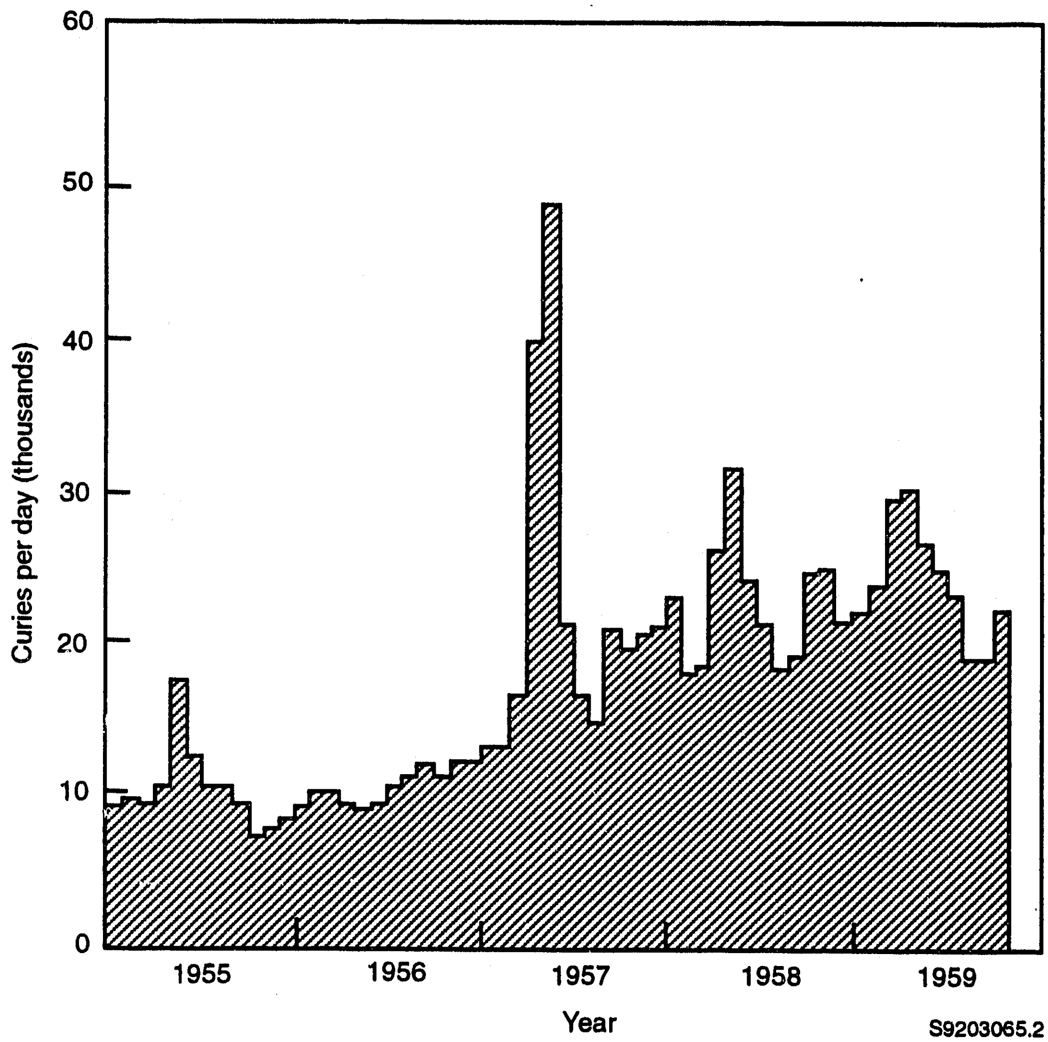


FIGURE 5.3. Monthly Average Radioactivity Release Rate *for Total Beta Activity* in Ci/day for Reactor Effluent at the Point of Release to the Columbia River (Hall and Jerman 1960)

manganese-56. According to Hall, there was a significantly higher level of elemental manganese in the Columbia River at that time.[a]

Bogan (1956) summarizes results of several earlier studies and provides some insight into the difficulty in correlating reactor power levels (total beta activity produced), river flow, and measured downstream beta activity.

(a) Personal communication to W. H. Walters from R. B. Hall, March 1992.

Bogan states that the results were both inconsistent and inconclusive. In some instances, higher values were found in the river than would be expected based on input calculations, and in another instance, the opposite was found.

6.0 COLUMBIA RIVER MONITORING AT HANFORD

The potential for contamination of the Columbia River as a result of Hanford operations was recognized even before construction of the first plutonium production reactors. Initial monitoring began at the Hanford Site in 1945 and was conducted by Site contractors. Since 1945, emphasis and detail of the monitoring programs have changed, as has the reporting frequency. Also, beginning about 1950, offsite (e.g., federal and state) agencies conducted monitoring programs and various studies at river locations downstream of Hanford, including the coastal areas. This section presents an overview of the river monitoring and topical studies conducted by Hanford contractors. Monitoring and topical studies conducted by offsite agencies are discussed in Section *9.0*.

79 The history of Columbia River monitoring is divided into three periods: *1945* through 1957, 1958 through 1971, and 1972 through 1990. These particular periods correspond reasonably well with 1) significant developments in analytical techniques that greatly enhanced the type of information generated by the monitoring programs, 2) programmatic modifications that resulted in changes in the rationale for and purposes of the programs, and 3) *sequential reactor shutdowns that resulted in significant reductions in contaminant loading to the river.*

6.1 *1945* THROUGH 1957

43 *The potential for contamination of the Columbia River water and fish, as a result of Hanford operations, was recognized before the first reactor (100-B) startup in September 1944. The earliest studies undertaken to determine the potential impact of radioactive effluent on Columbia River fish began at offsite laboratories (Foster 1972). Studies began at the University of Washington in 1943 using X-rays on fish and at the University of Chicago in 1945 where the uptake of some radionuclides by fish was investigated. Following the startup of the first three reactors (100-B, 100-D, and 100-F) by early 1945, initial monitoring of Columbia River water began in 1945 under wartime conditions and was conducted by Site contractors.*

80 *When the first Hanford reactors began operation in 1944, limits for the radioactive effluent released to the river were not known. According to Parker (1952), "It was elected to control the waters by the stipulation that the immersion dose rate at the point of release to the river should not exceed 100 mrep per 24 hours or 4.17 mrep per hour, the then existing conventional limit for external exposure." According to Parker, it was also recognized from the start that a realistic limit would have to be based on radiobiological consequences in the river, which at that time were completely unpredictable. Parker further stated that "...with the establishment of the original limit, such investigation programs as were possible in the stress of wartime conditions were initiated..." These programs continued to develop and become more comprehensive during the late 1940s and included water, sediment, and biological sampling.*

Columbia River water monitoring was initiated during 1945. The primary objective of the original surveillance efforts was only the detection of reactor-created radioisotopes, not their quantification. Shortly after the startup of the reactors, the need to not only detect but also measure the quantity of radionuclides in the river was recognized and routine sampling started.

8,44,76 Locations for routine Columbia River water sampling from *1945* through 1957 are shown in Table 6.1. Initially, the program included sampling locations at the 100-B, 100-D, and 100-F areas, the Hanford townsite, the 300 Area, and Richland. This scheme was quickly extended as far downstream as Pasco. During the late 1940s through 1957, the Columbia River monitoring program was expanded significantly, providing a large amount of data (primarily *total* beta activities) from several locations. *Total beta activity referred to in this report may actually be "total nonvolatile beta" because volatiles could have been driven off during sample processing and analysis.* Plate 1 illustrates water sampling locations used at various times *from* 1944 through 1957. Grab samples were collected at various times from upstream of the Hanford Site to the *areas near* Portland, Oregon, *and* Vancouver, Washington.

TABLE 6.1. Summary of Routine Locations for Sampling Columbia River Water, 1945 *Through* 1957

Location[(a)]	Year Sampled 1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
Columbia River													
Wills' Ranch	-[(b)]	-	-	-	x	x	x	x	x	x	x	x	x
Above 100-B	x	x	x	x	x	x	-	-	-	-	-	-	-
181-B	x	x	x	x	x	x	x	x	x	x	x	x	x
181-C	-	-	-	-	-	-	-	-	x	x	x	x	x
Allard Station	-	-	-	-	-	x	x	x	x	x	x	x	-
181 KW	-	-	-	-	-	-	-	-	-	-	x	x	x
181 KE		-	-	-	-	-	-	-	-	-	x	x	x
181-D	x	x	x	x	x	x	x	x	x	x	x	x	x
181-H	-	-	-	-	x	x	x	x	x	x	x	x	x
Below 100-H	-	-	-	-	-	x	x	x	x	x	x	x	x
181-F	x	x	x	x	x	x	x	x	x	x	x	x	x
Below 100-F	-	-	-	-	-	x	x	x	x	x	x	x	x
Foster's Ranch	-	-	-	-	x	x	x	-	-	-	-	-	-
Hanford S. Bank	x	x	x	x	x	x	x	x	x	x	x	x	x
Hanford Middle	-	x	x	x	x	x	x	x	x	x	-	-	-
Hanford N. Bank	x	x	x	x	x	x	x	x	x	x	-	-	-
300 Area	x	x	x	x	x	x	x	x	x	x	x	x	x
Byers Landing	-	-	-	-	-	-	-	-	x	x	x	x	x
Richland (Dock)	x	x	x	x	x	x	x	x	x	x	x	x	x
Kennewick Highlands	-	-	-	-	-	x	x	x	x	x	x	x	x
Pasco Pumping Station	-	-	-	-	-	-	-	-	-	x	x	x	x
Pasco Bridge													
Pasco	x	x	x	x	x	x	x	x	x	x	x	x	x
Kennewick	-	-	-	-	x	x	x	x	x	x	x	x	-
Sacajawea Park	-	-	-	-	-	-	x	x	x	x	x	x	x
McNary Dam - Below	-	-	-	-	-	-	x	x	x	x	x	x	x
McNary Pool	-	-	-	-	-	-	-	-	-	x	x	-	-
Paterson, WA	-	-	-	-	-	-	x	x	x	x	x	x	x
Arlington, OR	-	-	-	-	-	-	-	-	x	-	x	-	x
Mary Hill Ferry, OR	-	-	-	-	-	-	-	-	x	-	-	-	x
Celilo Falls, OR	-	-	-	-	-	-	-	-	x	-	-	-	x
The Dalles, OR	-	-	-	-	-	-	-	-	x	-	x	-	x
Hood River, OR	-	-	-	-	-	-	-	-	x	-	-	-	x
Cascade Locks, OR	-	-	-	-	-	-	-	-	x	-	-	-	-
Troutdale, OR	-	-	-	-	-	-	-	-	x	-	-	-	x
Stevenson, WA	-	-	-	-	-	-	-	x	x	-	-	-	x
Bonneville Dam, OR/WA	-	-	-	-	-	x	-	x	x	-	-	-	x
Portland, OR	-	-	-	-	-	-	-	x	x	-	x	-	-
Vancouver, WA	-	-	-	-	-	-	-	-	-	-	x	-	x
Yakima River													
Prosser	x	x	x	x	x	-	-	-	-	x	x	x	x
Horn	-	-	-	x	x	-	-	-	-	x	x	x	x
Mouth	-	-	-	x	x	-	x	x	x	x	x	x	x
Snake River													
Mouth	-	-	-	-	-	-	x	x	x	x	x	x	x

(a) For an idea of where water was sampled, see Plate 1 in a pocket in the back of this report.
(b) - indicates no samples collected.

In addition to the routine Columbia River water monitoring programs, comprehensive surveys were conducted to determine the plume dispersion of reactor effluents during the 1950s and early 1960s. Special studies, including extensive sampling, were conducted to determine the horizontal and vertical mixing characteristics of the Columbia River along the Hanford reach to better understand the fate of reactor-generated contaminants. These studies are discussed in Section *8.0* of this report.

Analytical capabilities were limited during the early years. Laboratory techniques were newly developed and improvements were constantly being made throughout the late 1940s and 1950s. Until the advent of gamma energy spectroscopy in 1957-1958, total alpha and total beta measurements were essentially the only data available. Five-hundred-milliliter (mL) samples were evaporated, leaving a sample residue that was then counted for total beta activity with a thin-window counter. Alpha activity was determined using a standard alpha counter. Detection levels were reported as being approximately 5×10^{-5} microcuries per liter (μCi/L) beta and 2 dpm/L alpha activity.

Monitoring of Columbia River sediment, or mud as it was referred to in the early days, was initiated in 1948. Sediment samples were routinely collected at various locations through 1957, as shown in Table 6.2. Sediment samples were collected from two points at each sampling location. The first was on shore, just above the water level, and the second was from the river bottom, approximately 5 feet into the river. Sediment sampling locations during the period *1948* through 1957 are presented in Plate 1 (in a pocket at the back of this report).

During this period, direct surveys of the sediment provided raw data indicative of contamination levels. In addition, gross beta results were typically reported for the sediment samples collected and analyzed by a laboratory.

As discussed earlier, before and during the early days of operations at Hanford, there was a great deal of interest and concern about the impact of discharging radioactive material into the Columbia River. Numerous special studies, both laboratory and field-oriented, were undertaken during the early days of Hanford operations. Columbia River fish, primarily whitefish, have been routinely sampled at Hanford since 1950. Whitefish were chosen for routine sampling because they were available year round and had some of the

TABLE 6.2. Summary of Routine Locations for Sampling Columbia River Sediment, 1948 *Through* 1957

Location[a]	Year Sampled									
	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
Columbia River										
Wills' Ranch	x	x	x	x	x	x	x	x	x	x
Allard Station	x	x	x	x	x	x	x	x	-[b]	-
100-H Area	x	x	x	x	x	x	x	x	x	x
Below 100-F	x	x	x	x	x	x	x	x	x	x
Hanford Ferry Landing	x	x	x	x	x	x	x	x	x	x
300 Area	x	x	x	x	x	x	x	x	x	x
Byers Landing	-	-	-	-	x	x	x	x	x	x
Richland (Dock)	x	x	x	x	x	x	x	x	x	x
Kennewick Highlands	-	-	x	x	x	x	x	x	x	x
Clover Island	-	-	-	-	x	-	-	-	-	-
Pasco Bridge										
Pasco	x	x	x	x	x	x	-	-	-	-
Kennewick	-	x	x	x	x	x	x	x	x	x
Sacajawea Park	-	-	-	x	x	x	x	x	x	x
McNary Dam	-	-	-	x	x	x	x	-	-	-
McNary Cold Springs										
South	-	-	-	-	-	x	-	-	-	-
Middle	-	-	-	-	-	x	-	-	-	-
North	-	-	-	-	-	x	-	-	-	-
McNary Pool	-	-	-	-	-	-	x	-	-	-
McNary Below Dam	-	-	-	-	-	-	x	x	x	-
Paterson	-	-	-	x	x	x	x	x	x	x
Yakima River										
Prosser	-	-	-	-	-	-	x	x	x	x
Horn	-	-	-	-	-	-	x	x	x	x
Snake River										
Mouth	-	-	-	x	x	x	x	x	x	x

(a) For an idea of where sediment was sampled, see Plate 1.
(b) - indicates no samples collected.

highest concentration factors.[a] Other species that have been monitored include trout, salmon, sucker, carp, bass, crappie, perch, squawfish, chiselmouth, chub, catfish, and sturgeon (e.g., Davis, Watson, and Palmiter 1956). Sampling locations were generally defined by area rather than specific site because of the mobility of the fish. These areas typically included sites upstream of operating facilities, sites directly downstream of operating reactors, and sites downstream of the Hanford Site at areas popular with local *fishermen*.

(a) J. P. Corley, personal communication to W. H. Walters, March 1992.

Routine monitoring results from various shellfish, primarily oysters, obtained from the marine environment near the mouth of the Columbia River are documented from 1953 through 1978. Willapa Bay, the major oyster-rearing area nearest the mouth of the Columbia River, was chosen as the primary sample collection site for oysters. As in the case of water samples, the analysis of fish and shellfish samples from 1944 through 1957 consisted of gross beta measurements.

6.2 1958 THROUGH 1971

By 1957, the Columbia River monitoring activities had developed into an extensive program of sampling river water and sediments at a number of locations downstream of Priest Rapids Dam (Wilson 1962). In addition, samples of various aquatic biota in the river were routinely taken, as were shellfish from coastal regions near the mouth of the river. During the late 1950s, the purpose of the Columbia River monitoring program changed from detection of Hanford-derived contaminants to quantification and dose evaluation. As a result, the monitoring program was modified to generate the optimum amount and type of river data for evaluating the potential radiation doses received by the public living near and using the Columbia River.

Routine river water sampling *from* 1958 through 1971 provided an indication of the burden of radioactive materials added to the river as a result of Hanford operations. Data obtained through the program were used in estimating doses that might have been received through the surface-water pathway. In addition, the sampling program provided insight on seasonal changes and long-term trends in the concentrations of radionuclides resulting, in part, from changes in operating procedures and practices. Routine monitoring also provided a mechanism for detecting and evaluating the effects of abnormal releases, such as slug ruptures and system purges.

The Columbia River monitoring program established in the early 1960s is the predecessor of today's Surface Environmental Surveillance Project (SESP) surface-water monitoring task. Sampling sites (see Plate 1) were selected to provide specific data. Upstream locations were established to determine background concentrations so the contribution of Hanford effluents could be distinguished from that of fallout from weapons tests. The first downstream points of water withdrawal for use as a public drinking-water supply were established as routine sample locations as well. Points farther downstream, such as Bonneville Dam and Vancouver, served as indicators of the amounts of radioactivity being discharged via the river into the Pacific Ocean or taken up within the river environment. Table 6.3 lists the Columbia River water sampling locations that were routinely monitored as part of the monitoring program during the years 1958 through 1971.

Sampling methods and equipment changed somewhat over the years. Grab samples were standard during the early years. Composite sampling was initiated later to provide better estimates of average radionuclide concentrations in the river at a given location over time. In addition, composite sampling provided some assurance that short-term elevated releases were not missed because of the sampling protocol and frequency. Continuous sampling systems

TABLE 6.3. Summary of Routine Locations for Sampling Columbia River Water, 1958 *Through* 1971

Location[a]	Year Sampled													
	1958[b]	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969[c]	1970	1971
Priest Rapids Dam	-[d]	-	-	-	-	-	-	-	x	x	x	x	-	-
Wills' Ranch	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Vernita Bridge	-	-	-	-	-	-	-	x	x	-	-	-	x	x
Vernita Ferry Landing	-	-	-	-	x	x	x	x	-	-	-	-	-	-
Hanford S. Bank	-	x	x	x	x	x	-	-	-	-	-	-	-	-
Ringold	-	-	-	-	-	-	-	x	x	x	x	-	-	-
300 Area	-	-	-	-	x	x	-	-	-	-	-	-	-	-
Richland Pumping Station	-	-	-	-	-	x	x	x	x	x	x	x	x	x
Richland (Dock)	-	x	-	-	x	-	-	-	-	-	-	-	-	-
Pasco Pumping Station	-	x	x	x	x	x	x	x	-	-	-	-	-	-
Pasco Bridge Pasco	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Sacajawea Park	-	x	-	-	-	-	-	-	-	-	-	-	-	-
McNary Dam - Below	-	x	-	-	-	-	x	x	x	x	x	x	x	-
Paterson, WA	-	x	-	-	-	-	-	-	-	-	-	-	-	-
The Dalles, OR	-	-	-	-	-	x	x	-	-	-	-	-	-	-
Hood River, OR	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Bonneville Dam, OR/WA	-	-	-	-	-	-	x	x	x	x	x	x	x	x
Vancouver, WA	-	x	x	x	x	x	-	-	-	-	-	-	-	-

(a) For an idea of where water was sampled, see Plate 1.
(b) Specific locations not provided. Assume similar to 1957 because concentrations reported for river "stretches" from the 100 Areas to Portland.
(c) Nonradiological parameters initiated (Vernita, 100-D, 100-F, 300 Area, Richland Pumping Station).
(d) - indicates no samples collected.

(filter/resin) were put into service in later years to increase the sample size sufficiently to detect radionuclides at very low concentrations. With the introduction of gamma energy spectroscopy in 1957, it became practical to obtain isotopic analyses of river water samples on a routine basis. Following this improvement in radiation detection capabilities, measurement of specific radionuclides became the norm. Table 6.4 summarizes the radionuclide analyses *for* 1958 through 1971.

57 For the 1958 through 1971 period, samples of Columbia River sediments were collected only in 1959. Routine sampling of the shoreline and surface river bottom sediments was discontinued in 1960, primarily because the data

TABLE 6.4. *Radionuclide* Analyses for River Water Samples, 1958 *Through* 1971

	Analyses								
Year	Total Alpha	Total Beta	Gamma[a] Scan	^{3}H[b]	^{32}P	^{90}Sr	^{131}I	^{239}Pu	U
1958	X	X	X	-[c]	X	X	-	-	X
1959	X	X	X	-	X	X	X	-	X
1960	X	X	X	-	X	X	X	-	X
1961	X	X	X	-	X	X	X	-	X
1962	X	X	X	-	X	X	X	-	X
1963	X	X	X	-	X	X	X	-	X
1964	X	X	X	-	X	X	X	-	X
1965	X	X	X	X	X	X	X	-	X
1966	X	X	X	X	X	X	X	-	X
1967	X	X	X	X	X	X	X	-	X
1968	X	X	X	X	X	X	X	-	X
1969	X	X	X	X	X	X	X	-	X
1970	X	X	X	X	X	X	X	X	X
1971	X	X	X	X	X	X	X	X	X

(a) Including primarily sodium-24, barium-140, scandium-46, chromium-51, manganese-56, copper-64, zinc-65, zirconium/niobium-95, iodine-131, cesium-137, and neptunium-239.
(b) From left to right, abbreviations in column headings stand for the following radionuclides: tritium, phosphorus-32, strontium-90, iodine-131, plutonium-239, and uranium *(refers to total uranium)*.
(c) - indicates *no analysis*.

were not useful in direct determination of doses.[a] Subsequent annual reports likewise were void of sediment sampling data. The sediment sampling locations for 1959, which was the last year of routine monitoring of activity levels in sediment, include the following:

- Wills' Ranch
- Hanford Ferry Landing
- 300 Area
- Byers Landing
- Richland (Dock)
- Pasco and Kennewick sides of the Pasco bridge
- Sacajawea Park
- below McNary Dam
- Paterson.

Special studies were conducted throughout this period, providing some indication of the levels of Hanford-derived radionuclides associated with Columbia River sediments. These studies are summarized in Section 9.5. Core samples were collected from behind McNary Dam on various occasions between 1958 and 1971.

As in the case of water samples, the advent of gamma energy spectroscopy provided the ability to generate radionuclide-specific data for the sediment samples collected. Core sampling investigations also included isotopic analysis.

The collection of fish from the Columbia River and shellfish from coastal areas near the mouth of the river continued to be an integral part of the Columbia River monitoring program from 1958 through 1971. As had been the case during earlier years, whitefish remained the primary species sampled. Sampling locations were again identified as areas along the river. Samples were typically collected from areas upstream of operating facilities, immediately downstream of the operating reactors, and downstream of Hanford at areas known to be frequented by the local fishermen.

Shellfish, primarily oysters, continued to be routinely collected throughout the years 1958 through 1971. Oysters reared in Willapa Bay were

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(a) Personal communication to W. H. Walters from J. K. Soldat and R. F. Foster, March 1992.

obtained from a commercial market in Portland, Oregon. Sample analysis included gamma scans, which provided radionuclide-specific data, with zinc-65 being of most interest.

6.3 1972 THROUGH 1990

The Columbia River monitoring program, as it evolved during the late 1950s and early 1960s, continued from 1972 to the present. As sampling and analytical techniques were improved, the program was modified, enhancing the quality and usefulness of the data obtained.

Samples of river water continued to be collected routinely from several locations from 1972 to the present. The primary emphasis of the Columbia River monitoring program since its restructuring in the early 1960s has been the evaluation of the potential dose to those persons using and/or consuming the river water. Following shutdown of the once-through-cooled production reactors, concentrations of radionuclides in the river water decreased significantly (Robertson et al. 1973). Levels of radionuclides fell to near detection limits relatively quickly at several locations. As a result, the more distant sample locations were gradually eliminated from the routine river water sampling network. Routine water sampling locations during the years 1972 through 1990 are listed in Table 6.5.

As was the case during the earlier periods, grab, composite, and continuous sampling systems were used for the collection of river water samples. Like sample collection methods, analytical procedures have undergone numerous improvements to provide greater sensitivities. Standard analytical procedures were not sensitive enough to detect the low concentrations of radionuclides present in the river water following the shutdown of the original reactors. Water sample analyses included gross alpha, gross beta, gamma scan, tritium, strontium-90, technetium-99, iodine-129, plutonium-239,240, and isotopic uranium.

With the shutdown of the original production reactors, direct discharges of large quantities of radionuclides into the river were eliminated. However,

TABLE 6.5. Summary of Routine Locations for Sampling Columbia River Water, 1972 *Through* 1990

Location[a]	Year Sampled																		
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Richland Pumping Station	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Vernita	x	x	x	x	x	x	x	-[b]	-	-	-	-	-	-	-	-	-	-	-
Bonneville Dam - River	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Below 181-N	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100-B Area - River	-	x	x	x	x	x	x	x	x	-	x	x	x	-	-	-	-	-	-
Hanford Powerline Crossing	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
300 Area	-	-	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Priest Rapids - River	-	-	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hanford Townsite - River	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-

(a) For an idea of where sediment was sampled, see Plate 1.
(b) - indicates no samples collected.

radionuclides were known to be present in the ground water beneath the Hanford Site and, in some cases, to be approaching and entering the river along the Hanford shoreline (Myers, Fix, and Raymond 1977).

Ground-water discharges or river bank springs have been sampled periodically over the years. Documentation of these monitoring activities, however, is not abundant and is typically contained in project files *(Freshley and Thorne 1992)*. Springs near the 300 Area retention basin and sewage leaching trenches were routinely sampled and analyzed for various biological, chemical, and radiological parameters. Springs along the 100-N Area resulting from disposal of liquid waste have been and are today monitored routinely (Rokkan 1988).

Springs located in the contaminated ground-water plumes from the 100-N Area, the 200 areas (emerging at the Hanford townsite), and the 300 Area have been sampled routinely since 1984. Special studies conducted in 1982-1983 and 1988 included sampling several contaminated springs along the Hanford reach (McCormack and Carlile 1984; Dirkes 1990). Analyses of spring samples were similar to those performed on the river water samples, and sampling results were consistent with those from nearby ground-water monitoring wells.

The routine collection of Columbia River sediment samples, discontinued in 1960, was reestablished in 1988. Initially, samples were collected from behind Priest Rapids Dam upstream of Hanford and behind McNary Dam downstream of Hanford. Subsequently, sediment sampling locations were established at the White Bluffs slough, the 100-F Area slough, the Hanford slough, and Richland. The routine sampling reestablished in 1988 consisted of collecting surface sediments using a clamshell-type sampling dredge designed to collect approximately the top 6 inches of sediment material. Sample analyses consisted of gamma scans, strontium-90, isotopic plutonium, and isotopic uranium.

Even before 1988, special studies were conducted at McNary Dam to investigate the content of radionuclides in the sediments and to observe how soon after the closure of the once-through-cooled reactors clean sediments were deposited on top of the radiologically contaminated sediment material (Robertson et al. 1973; Robertson and Fix 1977; Beasley et al. 1981; Beasley and Jennings 1984). In special studies, core samples were collected from the pool sediments behind McNary Dam (Robertson and Fix 1977).

The collection of various fish species continued into the period from 1972 through 1990. As in the past, whitefish was the primary species sought. The number and diversity of fish samples routinely collected and the associated radionuclide concentrations declined steadily over the years, following the decline of radioactivity in the river as a result of the shutdown of the reactors (Cushing et al. 1981). The primary constituents of concern in the river environment included strontium-90, tritium, and the gamma emitters.

The collection of oysters from Willapa Bay continued into the years following closure of the once-through-cooled reactors. The routine collection and analysis of oysters from Willapa Bay was discontinued in 1978 (Houston and Blumer 1978). Zinc-65 was still the radionuclide of concern, although its levels diminished following the reactor shutdown, as the remaining zinc-65 decayed.

From *1945* through 1957, reports that presented results of the environmental monitoring programs (including Columbia River monitoring) were issued at various intervals and under different titles by authors from Hanford Site contractors. Over the years, the frequency of the monitoring reports generally decreased. During the very early days of Hanford operations (January 1945 through August 1946), reports were issued weekly. Semimonthly reports were issued from September 1946 to May 1947. From June 1947 through the end of 1957, monthly environmental monitoring reports were issued; quarterly reports were also prepared from January 1947 through the end of 1957. An annual report was also prepared summarizing all the monitoring results for 1957.

Beginning in 1958, annual environmental monitoring reports were issued, providing improved documentation of the findings of the river monitoring program. Routine environmental monitoring data are available either within these reports or in a data appendix. In addition to the routine environmental monitoring reports, topical reports were issued presenting results of special studies of the river. Such studies were conducted to fill a particular need. The special studies are discussed in Sections *7.0* and 9.5. These studies primarily address investigations of river processes, as well as transport and distribution of radioactivity in the Hanford reach and, to a limited extent, downstream *to* the river mouth. This reporting system remains in place today.

7.0 SUMMARY OF RESULTS OF COLUMBIA RIVER MONITORING BY HANFORD CONTRACTORS

The amount of radioactivity entering the *Columbia* River varied from 1944 through 1971 in response to the startup and shutdown of various reactors, the operation of individual reactors at different power levels, reactor closures for maintenance and refueling, water treatment modifications, frequency and severity of fuel-cladding failures, and other operational features, as discussed in Section *5.0* of this report. As the number and power levels of the reactors increased, the amount of radioactivity discharged to the river increased. Consequently, radionuclide releases to the Columbia River were highest during the late 1950s through the early 1960s.

An extensive amount of data has been generated through the *Columbia River* monitoring programs and activities described in the previous section. Sample results generated as part of the routine surveillance programs have been reported periodically over the years in weekly, semimonthly, monthly, quarterly, and annual reports. To document the results of special investigations and sampling activities, topical reports generally were issued. In some cases, summary reports have contained data previously reported in periodic status reports.

An eight-volume set, A Compilation of Basic Data Relating to the Columbia River, was prepared by several staff members of the Hanford Atomic Products Operation under the direction of R. F. Foster in 1961 (Foster et al. 1961). Much of the raw data generated during the early years of Hanford *was* classified, but was made publicly available in 1962 as Volume 8 (under separate title) of this multivolume compilation (Soldat 1962b).

An entire book, Aquatic Bioenvironmental Studies: The Hanford Experience 1944-84, was dedicated to *summarizing* various studies conducted on the Columbia River and related to operations at Hanford (Becker 1990). This publication serves as an excellent reference on the history of Hanford, as well as providing extensive summaries of the data available through years of monitoring and study of the Columbia River ecosystem. While the book focuses primarily on the monitoring of biota and related laboratory studies, much information is also provided on the Hanford-derived contaminants and their behavior and fate in the river water and sediment. *This book is* considered a primary source of summary information regarding the surface-water (Columbia River) pathway, and *it* may be useful in evaluating the adequacy of monitoring data for the purpose of reconstructing potential doses during the HEDR Project.

The following sections provide brief summaries of the Columbia River monitoring data generated by Hanford contractor monitoring programs (as opposed to those of offsite agencies) during the years of Hanford operations.

7.1 WATER MONITORING DATA

During the early years of Hanford operations, until the advent of gamma energy spectroscopy in 1957, gross radioactivity in Columbia River water was measured only as total beta concentrations. Although total beta measurements in themselves are not directly useful in the determination of the potential doses, they are indicative of the contaminant loading to the river and serve to identify those years in which *radioactivity* concentrations in the river water as a result of Hanford operations were greatest. Figure 7.1 *presents* the *annual average* total beta concentrations in Columbia River water at Pasco for the years *1945* through *1971. The concentrations for the years from 1945 through 1963 are based on measurements. From 1964 through 1968, the concentrations are based on the number of operating reactors and ratios to phosphorus-32 and zinc-65. The concentrations for 1969 through 1971 are based on the number of reactor operating months.* Consistent with the effluent discharges to the river, *annual average* total beta levels in river water at Pasco were highest during the late 1950s and early 1960s.

The development of gamma energy spectroscopy in 1957 permitted the measurement of specific radionuclides in Columbia River water. Annual average radionuclide concentrations as reported (*before* 1971) in historical annual reports and as contained in the Hanford SESP database (since 1971) are provided in Tables 7.1 through 7.5 for the Richland Pumping Station, Pasco Pumping Station, McNary Dam, Bonneville Dam, and Vancouver water sampling locations for any of the years between 1957 and 1990 when data were collected at each site. Figures 7.2 through 7.5 graphically present the data included

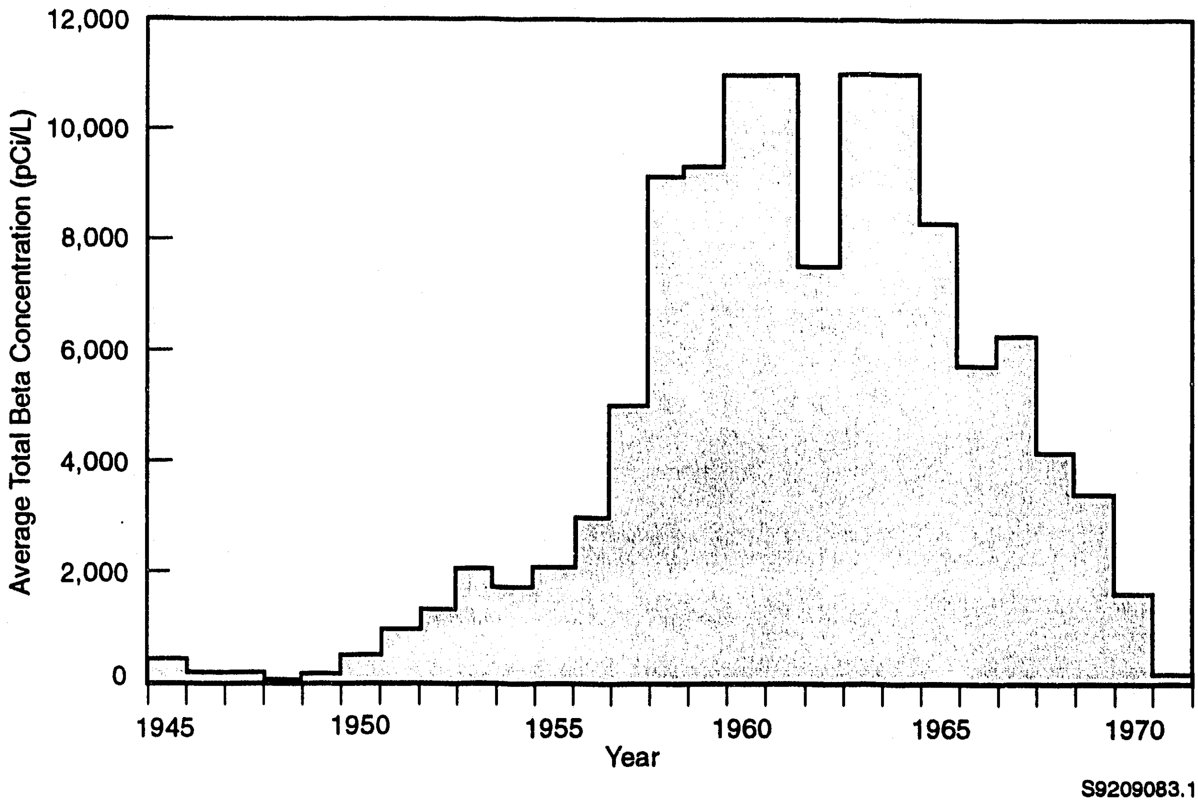


FIGURE 7.1. *Annual Average* Total Beta Concentrations in Columbia River Water at Pasco, Washington, 1945 *Through* 1971 (see *also* Table *10.14*)

in Tables 7.1 through 7.5. Apparent in the data is the decrease in radionuclide concentrations with increasing distance from the reactor discharge points and with time following the shutdown of the first of the reactors in December 1964. Radionuclide concentrations in river water rapidly declined to levels at or below detection limits following the closure of the last of the original reactors. As this occurred, the remote river water sampling effort gradually ceased, in accord with the decrease in *contamination to* levels *that* were no longer detectable or *significant for* dose evaluations.

7.2 SEDIMENT MONITORING DATA

Although they are not a direct contributor to dose, radionuclides in sediments may be resuspended during high river flows and reintroduced into the aquatic food chain, *at which time they* may subsequently contribute to

72 TABLE 7.1. Annual Average Radionuclide Concentrations in Columbia River Water at the Richland Pumping Station

Year(a)	Radionuclide Concentration (pCi/L) ^{3}H(b)	^{24}Na	^{32}P	^{46}Sc	^{51}Cr	^{56}Mn	^{65}Zn	^{76}As	^{90}Sr	^{131}I	^{137}Cs
1963	-(c)	3400	260	-	8800	-	380	1200	1	8	-
1964	-	3500	300	-	12000	-	450	1200	1	19	-
1965	-	3100	140	-	7000	-	180	1000	1	10	-
1966	-	2600	140	30	3600	290	200	420	1	18	-
1967	1500	2600	190	60	3200	520	220	400	1	8	-
1968	1700	2200	92	100	1500	250	86	320	0.6	7.4	-
1969	1900	1600	73	72	720	1000	72	310	0.5	4	-
1970	1100	900	28	43	300	100	34	130	<MDC(d)	<MDC	-
1971	779	43.9	22.1	-	127	-	18.1	11.2	0.844	1.64	10.4
1972	110	-	0.305	-	115	-	5.53	-	0.363	1.16	7.37
1973	623	-	-	-	42	-	7.17	-	0.334	1.01	2.22
1974	508	-	-	-	9.96	-	3.87	-	0.277	2.1	1.63
1975	373	-	-	-	10.3	-	3.6	-	-	0.647	2.79
1976	261	-	-	-	17.4	-	1.33	-	0.239	-	0.661
1977	585	-	-	-	27.2	-	2.75	-	0.321	-	0.783
1978	429	-	-	-	21.7	-	1.96	-	0.474	-	2.25
1979	355	-	-	-	16.1	-	-0.514	-	0.336	-	2.1
1980	265	-	-	-	1.72	-	1.39	-	0.195	-	0.413
1981	199	-	-	-	1.49	-	0.0305	-	0.23	-	0.176
1982	216	-	-	-	17.3	-	0.459	-	0.171	-1.34	0.211
1983	135	-	-	-	-	-	-0.746	-	0.29	-	0.153
1984	169	-	-	-	-	-	-0.639	-	0.169	-	0.0935
1985	152	-	-	-	-	-	0.0645	-	0.158	-	-0.105
1986	149	-	-	-	-	-	0.0295	-	0.16	-	0.347
1987	128	-	-	-	-	-	-0.261	-	0.131	-	-0.138
1988	135	-	-	-	-	-	-0.724	-	0.119	-	0.121
1989	128	-	-	-	-	-	0.204	-	0.0745	-	0.0594

(a) Data not collected before 1963 and in 1990.
(b) From left to right, abbreviations in column headings stand for the following radionuclides: tritium, sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, arsenic-76, strontium-90, iodine-131, and cesium-137.
(c) - means not determined.
(d) <MDC means below minimum detection concentration.

potential dose received by persons using the river. As in the case of river water, the analyses of sediment samples collected from *1948* through 1957 were limited to total beta measurements. However, direct surveys of the sediment material that provided *data on* raw count rate were also performed. Routine

TABLE 7.2. Annual Average Radionuclide Concentrations in Columbia River Water at the Pasco Pumping Station

Year[(a)]	Radionuclide Concentration (pCi/L)										
	^{3}H[(b)]	^{24}Na	^{32}P	^{46}Sc	^{51}Cr	^{56}Mn	^{65}Zn	^{76}As	^{90}Sr	^{131}I	^{137}Cs
1959	-[(c)]	1139	155.7	-	4209	-	206.2	1458.3	0.638	-	-
1960	-	1500	200	35	5600		300	1500	0.6	12	-
1961	-	1800	260	33	5700		340	1200	0.4	10	-
1962	-	1600	180	30	4300	87	220	470	0.7	6	-
1963	-	1600	190	-	6700	-	220	750	1	8	-
1964	-	1500	200	-	6800	-	240	670	1	12	-
1965	-	-	87	-	4100	-	160	-	-	7	-

(a) Data not collected before 1959 and after 1965.
(b) From left to right, abbreviations in column headings stand for the following radionuclides: tritium, sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, arsenic-76, strontium-90, iodine-131, and cesium-137.
(c) - means not determined.

TABLE 7.3. Annual Average Radionuclide Concentrations in Columbia River Water at McNary Dam

Year[(a)]	Radionuclide Concentration (pCi/L)										
	^{3}H[(b)]	^{24}Na	^{32}P	^{46}Sc	^{51}Cr	^{56}Mn	^{65}Zn	^{76}As	^{90}Sr	^{131}I	^{137}Cs
1964	-[(c)]	-	70.3	-	3478	-	76.5	-	-	6.7	-
1965	-	-	47.5	-	2264	-	67.6	-	-	3.9	-
1966	-	-	76.2	-	1849	-	61.0	-	-	7.1	-
1967	-	-	49.5	-	1748	-	82.2	-	-	4.7	-
1968	-	-	39.2	-	769	-	51.1	-	-	3.8	-
1969	-	-	33.0	-	333	-	44.2	-	-	2.6	-

(a) Data not collected before 1964 and after 1969.
(b) From left to right abbreviations in column headings stand for the following radionuclides: tritium, sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, arsenic-76, strontium-90, iodine-131, and cesium-137.
(c) - means not determined.

collection of sediment samples was discontinued in 1959, shortly after the capability to measure specific radionuclides became available.

Special studies of radionuclide concentrations in river sediments, primarily behind McNary Dam, were conducted during and after the shutdown *(1965-1971)* of the reactors (Nelson et al. 1966; Fisher 1971; Fix 1975; Robertson and Fix 1977). Five years after the shutdown of the final

TABLE 7.4. Annual Average Radionuclide Concentrations in Columbia River Water at Bonneville Dam

Year[a]	Radionuclide Concentration (pCi/L) ^{3}H[b]	^{24}Na	^{32}P	^{46}Sc	^{51}Cr	^{56}Mn	^{65}Zn	^{76}As	^{90}Sr	^{131}I	^{137}Cs
1964	-[c]	-	28	-	2400	-	63	-	-	5	-
1965	-	-	23	-	1700	-	70	-	-	3	-
1966	-	-	23	-	1300	-	43	-	-	3	-
1967	-	-	25	-	1400	-	62	-	-	3	-
1968	-	-	15	20	530	-	30	-	-	3.2	-
1969	-	-	14	-	240	-	25	-	-	-	-
1970	-	-	5	-	100	-	10	-	-	-	-
1971	-	-	-	2.6	-	-	5.9	-	-	-	-
1972	-	-	-	0.15	-	-	1.1	-	-	-	-
1973	-	-	-	-	-	-	8	-	-	-	-
1974	-	-	-	<MDC[d]	<MDC	-	<MDC	-	-	-	<MDC
1975	-	-	-	<MDC	<MDC	-	<MDC	-	-	-	<MDC

(a) Data not collected before 1964 or after 1975.
(b) From left to right, abbreviations in column headings stand for the following radionuclides: tritium, sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, arsenic-76, strontium-90, iodine-131, and cesium-137.
(c) - means not determined.
(d) <MDC means below minimum detection concentration.

TABLE 7.5. Annual Average Radionuclide Concentrations in Columbia River Water at Vancouver, Washington

Year[a]	Radionuclide Concentration (pCi/L) ^{3}H[b]	^{24}Na	^{32}P	^{46}Sc	^{51}Cr	^{56}Mn	^{65}Zn	^{76}As	^{90}Sr	^{131}I	^{137}Cs
1959	-[c]	-	31	-	2100	-	37	-	-	-	-
1960	-	-	41	18	2100	-	75	-	0.4	4	-
1961	-	-	68	24	2100	-	90	-	0.4	-	-
1962	-	-	38	20	1800	-	64	-	0.4	3	-
1963	-	-	30	-	2600	-	60	-	1	4	-
1964	-	-	50.3	-	3317	-	55.8	-	-	4.2	-

(a) Data not collected before 1959 and after 1964.
(b) From left to right, abbreviations in column headings stand for the following radionuclides: tritium, sodium-24, phosphorus-32, scandium-46, chromium-51, manganese-56, zinc-65, arsenic-76, strontium-90, iodine-131, and cesium-137.
(c) - means not determined.

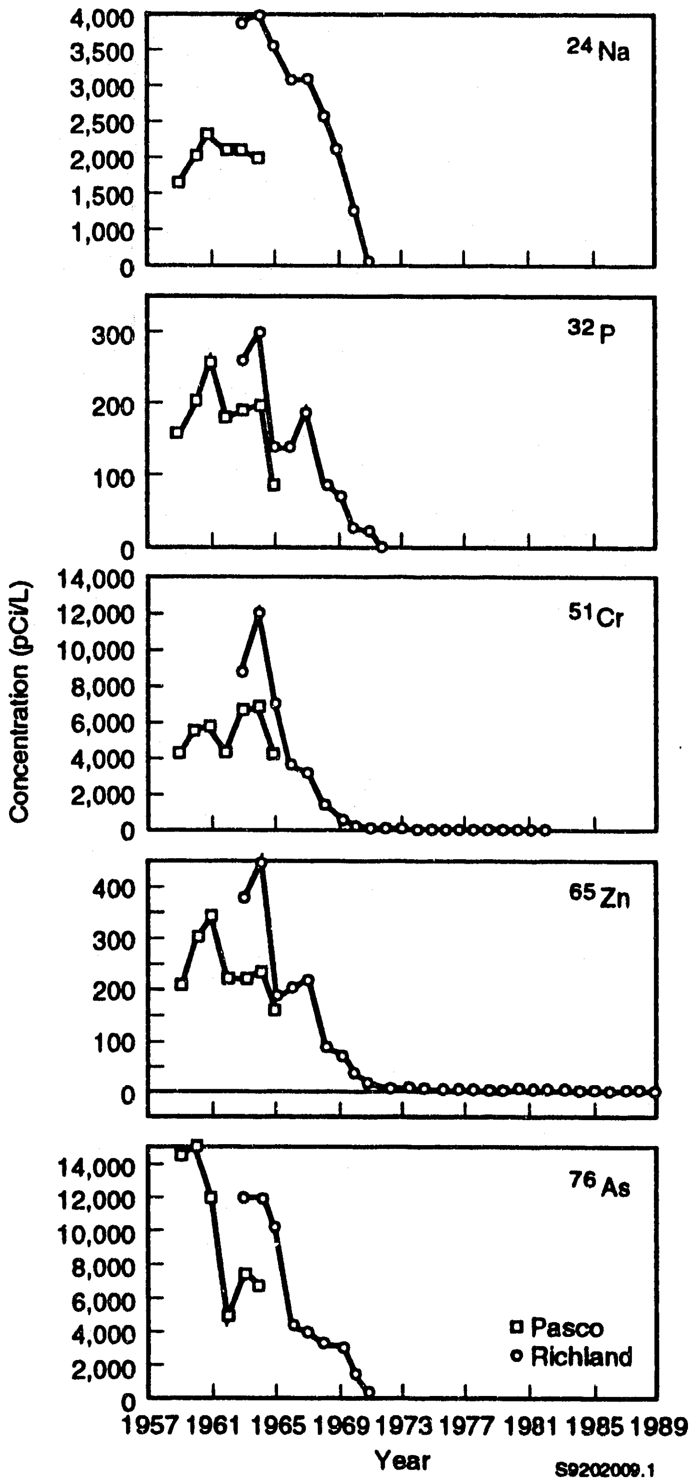


FIGURE 7.2. Annual Average Radionuclide Concentrations in Columbia River Water at the Richland *Pumping Station* and Pasco *Pumping* Station (for sodium-24, phosphorus-32, chromium-51, zinc-65, and arsenic-76)

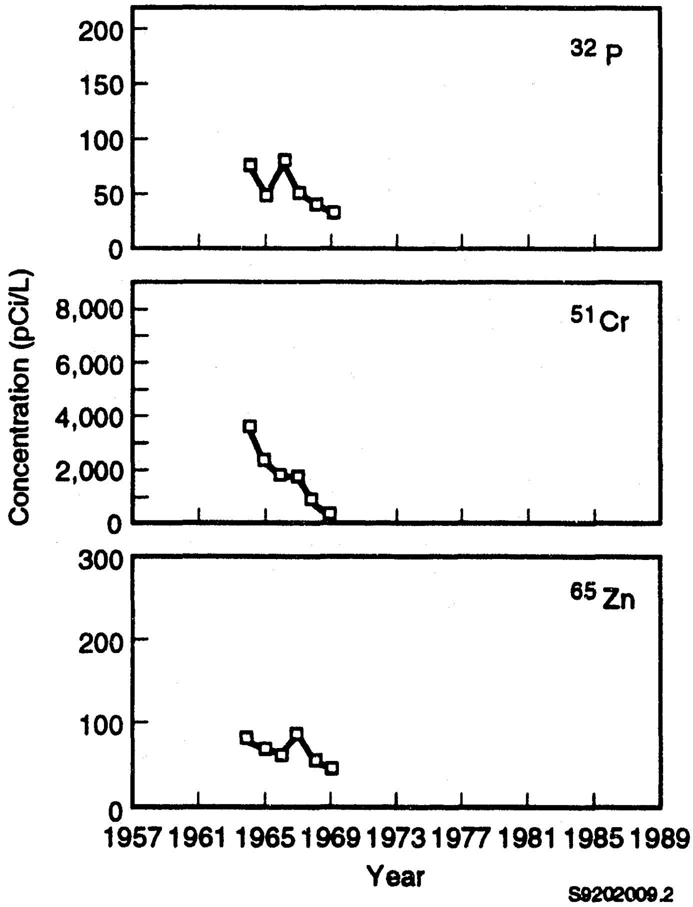


FIGURE 7.3. Annual Average Radionuclide Concentrations in Columbia River Water at McNary Dam (for phosphorus-32, chromium-51, and zinc-65)

once-through-cooled reactor, the short- and intermediate-lived radionuclides had decayed away. However, measurable concentrations of a few long-lived radionuclides remained in the deep sediments behind McNary Dam. Sediments free of Hanford-originated radionuclides covered the contaminated radionuclides behind McNary Dam at a rate of approximately 15 to 30 inches per year between 1971 and 1976 (Robertson and Fix 1977).

Sediment samples were also collected from The Dalles Dam and Bonneville Dam. Radionuclide concentrations in these sediments were lower than those observed in the McNary reservoir sediments. Radionuclide concentrations in sediment samples collected during 1976 were reported in disintegrations per

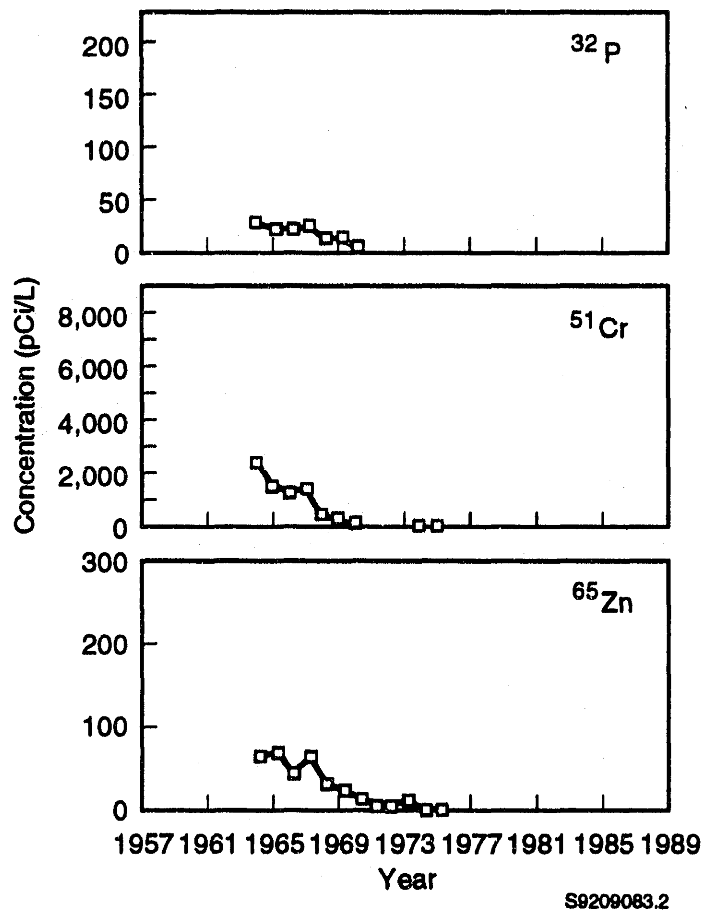


FIGURE 7.4. Annual Average Radionuclide Concentrations in Columbia River Water at Bonneville Dam (for phosphorus-32, chromium-51, and zinc-65)

minute per gram (dpm/g). Table 7.6 provides a comparison of radionuclide concentrations in sediment behind McNary Dam during 1971 and 1976.

7.3 BIOTA MONITORING DATA

Concern for the aquatic biota and the effects of the reactor effluent on the biota *was* expressed very early in the development of the Hanford Site, even before construction *began*. Numerous laboratory and field investigations *were* conducted over the years to investigate effects of reactor effluent on biota. Summaries of these studies have been documented, including discussion of the study results (Becker 1990). Consumption of fish contaminated with

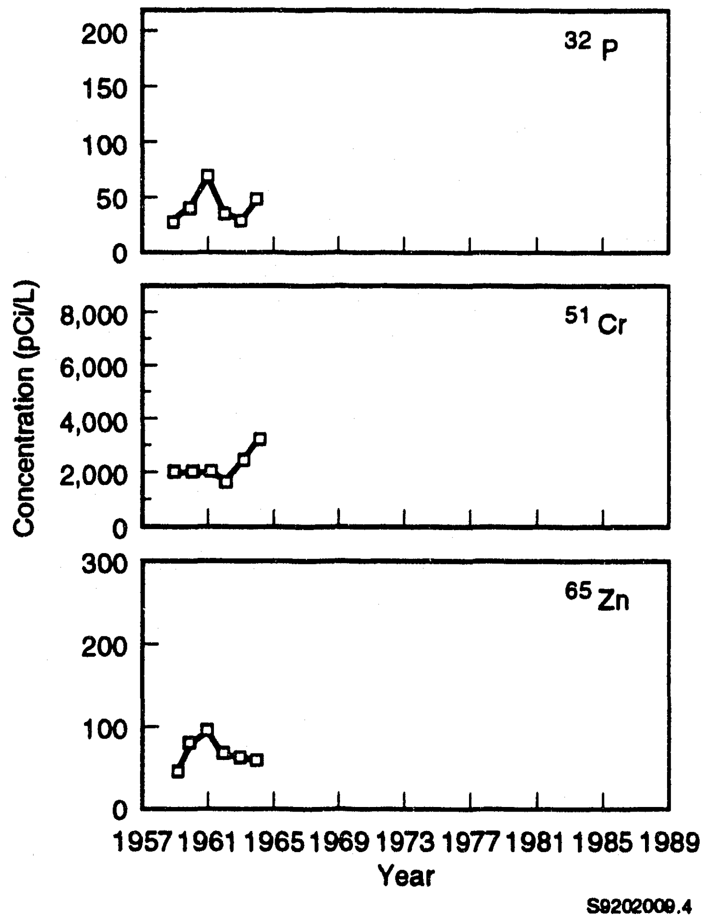


FIGURE 7.5. Annual Average Radionuclide Concentrations in Columbia River Water at Vancouver, Washington (for phosphorus-32, chromium-51, and zinc-65)

radionuclides from Hanford effluent was recognized as a primary pathway through which the public could be exposed to radionuclides originating at Hanford.

Phosphorus-32 and zinc-65 were the two radionuclides of concern in Columbia River fish because these isotopes accumulate significantly in the edible muscle tissue *of fish*. These two radionuclides *were estimated to contribute* more than 90% of the calculated dose resulting from the consumption of fish. Figures 7.6 and 7.7 indicate the monthly mean phosphorus-32 and zinc-65 concentrations in muscle tissue of whitefish collected at Ringold

TABLE 7.6. Radionuclide Concentrations in Surface Sediments in McNary Reservoir in 1971 and 1976 (from Robertson and Fix 1977)

Element	Typical Concentrations (dpm/g dry sediment)	
	April 1971	August 1976
Iron-55	1100	30 (est.)[a]
Zinc-65	240	0.14
Scandium-46	120	0.34
Cobalt-60	60	2.7
Europium-152,154	51	2.2
Manganese-54	25	0.32
Cesium-137	9	2.7
Plutonium-239,240	0.06	0.03

(a) Estimated using known ratio with cobalt-60.

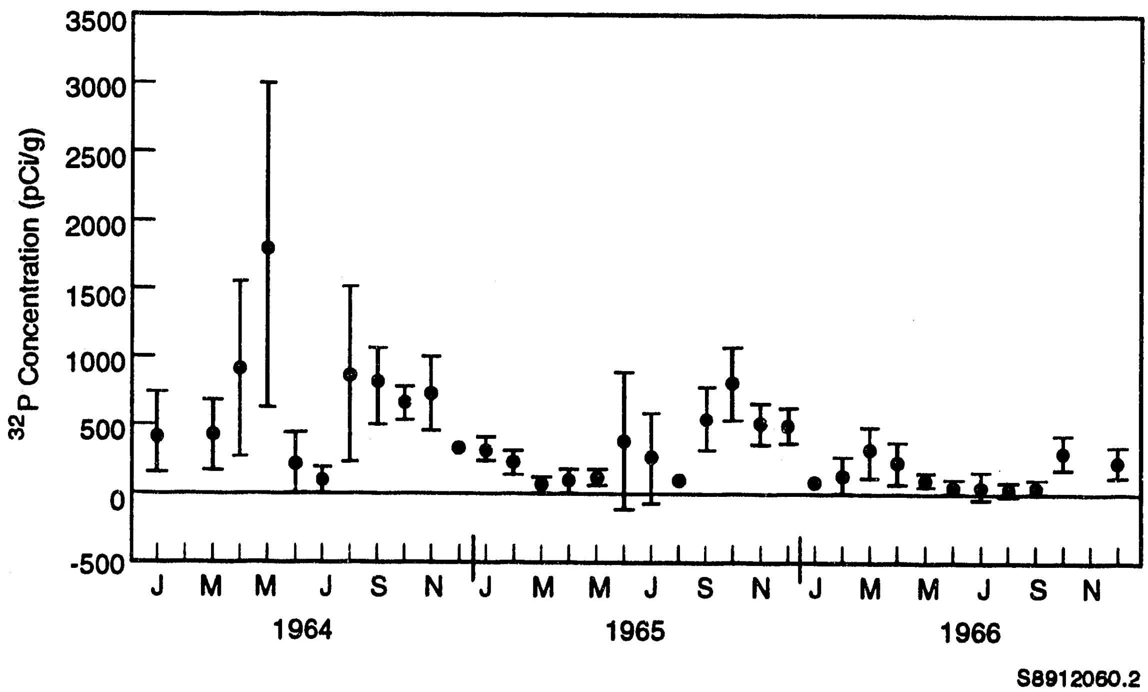
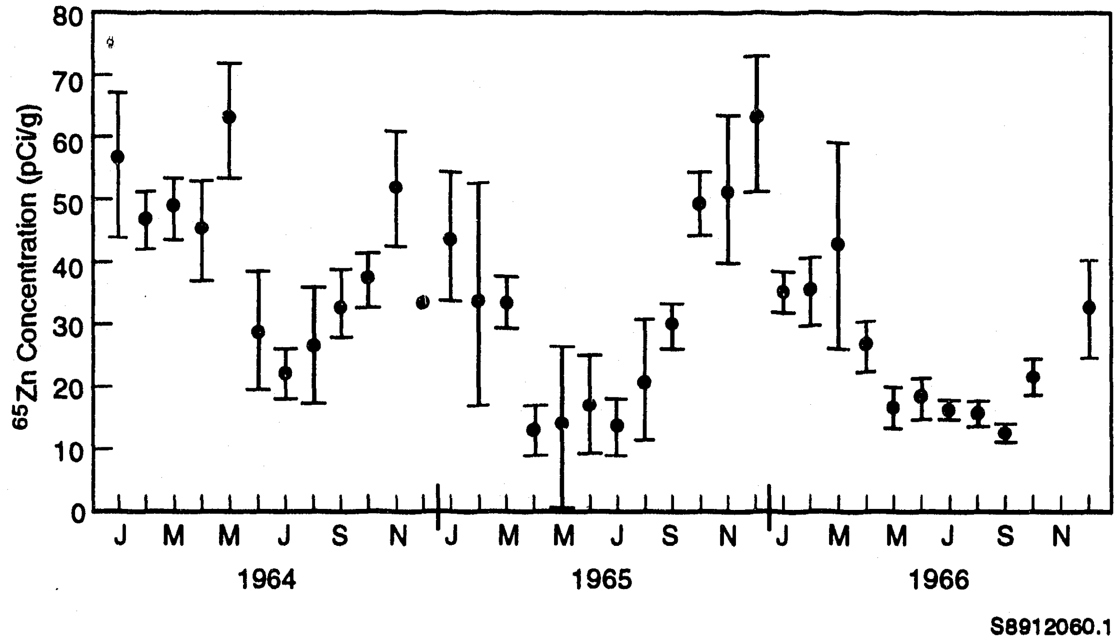


FIGURE 7.6. Monthly Mean Phosphorus-32 Concentrations in Columbia River Whitefish, 1964 *Through* 1966. *Data points without 90% confidence intervals are a single fish sample.*



<u>FIGURE 7.7</u>. Monthly Mean Zinc-65 Concentrations *(90% confidence intervals)* in Columbia River Whitefish, 1964 *Through* 1966

during the years 1964 through 1966. The 90% confidence interval is also provided in the figures. Data on whitefish are presented because their radionuclide concentrations indicate the highest levels observed in Columbia River sport fish. Concentrations in suckers were typically the highest for any large Columbia River fish (Davis et al. 1958). However, whitefish were thought to be more important from the standpoint of potential dose because sports fishermen harvest large numbers of these fish, as opposed to suckers, which are rarely eaten (Foster and Junkins 1960). *The report by Foster and Junkins (1960) also mentions steelhead trout, bass, salmon, crappie, and sturgeon, but they were not discussed in any detail.*

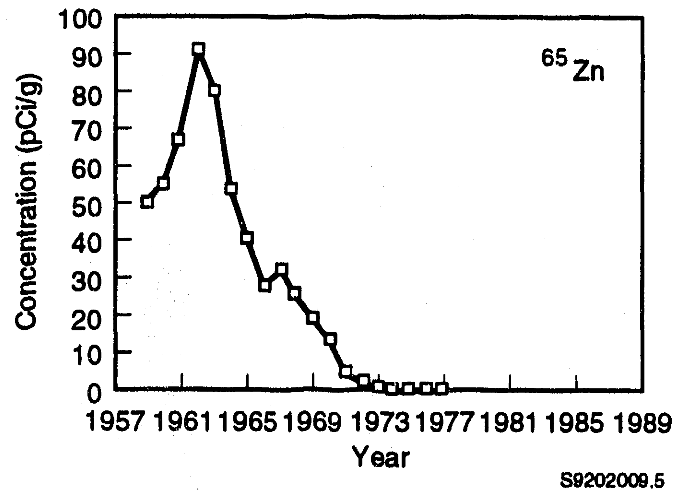
Various marine organisms that indicate the presence of Hanford-originated radionuclides have been collected routinely from areas near the mouth of the Columbia River. Oysters generally contained higher concentrations of zinc-65 than other marine organisms (Foster and Wilson 1964). Table 7.7 presents the radionuclide concentrations observed in Willapa Bay oysters for the years 1959 through 1977. *Monitoring* of oysters *for radioactivity* from Willapa Bay was discontinued during 1978 because

TABLE 7.7. Annual Average Radionuclide Concentrations in Willapa Bay Oysters, 1959 *Through* 1977

	Radionuclide Concentration (pCi/g)									
Year[(a)]	^{32}P[(b)]	^{40}K	^{46}Sc	^{51}Cr	^{58}Co	^{60}Co	^{65}Zn	^{90}Sr	^{131}I	^{137}Cs
1959	-[(c)]	-	-	-	-	-	51	-	-	-
1960	0.57	2.4	0.12	0.54	-	-	55	0.0032	<MDC[(d)]	<MDC
1961	1.7	1.4	0.11	0.59	-	-	67	-	<MDC	<MDC
1962	2.9	2.1	-	-	1.0	<MDC	91	-	-	0.34
1963	3.9	6.5	-	-	0.82	<MDC	80	-	-	0.31
1964	4.7	2.0	-	-	-	-	54	-	-	<MDC
1965	3.7	2.0	-	-	-	-	39	-	-	0.13
1966	3.0	2.1	-	-	-	-	28	-	-	0.10
1967	3.4	2.1	-	-	-	-	32	-	-	0.10
1968	1.9	2.2	-	-	-	-	25	-	-	0.10
1969	3.3	2.0	-	-	-	-	19	-	-	0.16
1970	0.61	1.9	-	-	-	-	13	-	-	0.04
1971	1.3	1.8	-	-	-	-	4.6	-	-	0.04
1972	-	1.7	-	-	-	-	1.7	-	-	0.025
1973	-	1.7	-	-	-	-	0.57	-	-	0.02
1974	-	1.6	-	<MDC	-	<MDC	0.14	-	-	<MDC
1975	-	1.7	-	-	-	-	<MDC	-	-	<MDC
1976	-	1.4	-	-	-	-	<0.08	-	-	<0.04
1977	-	1.4	-	-	-	-	<0.08	-	-	<0.04

(a) Data not collected before 1959 and after 1977.
(b) From left to right, abbreviations in column headings stand for the following radionuclides: phosphorus-32, potassium-40, scandium-46, chromium-51, cobalt-58, cobalt-60, zinc-65, strontium-90, iodine-131, and cesium-137.
(c) - means not determined.
(d) <MDC means below minimum detection concentration (no numerical values reported).

Hanford-originated radionuclides had declined to levels that were generally *below detection*. Figure 7.8 graphically displays the zinc-65 concentrations reported in the annual environmental reports. Evident from *Figure 7.8* is the relatively rapid decline in radionuclide concentrations following the shutdown of the once-through-cooled reactors.



<u>FIGURE 7.8</u>. *Mean Annual* Zinc-65 Concentrations in Willapa Bay Oysters, 1959 *Through* 1977

8.0 SPECIAL STUDIES AND SURVEYS AT HANFORD

This section discusses effluent plume dispersion and shoreline radiation surveys in the Hanford reach of the Columbia River. Plate 2 (in a pocket in the back of this report) will help the reader track the effluent plume and locate the areas surveyed at various times.

8.1 EFFLUENT PLUME DISPERSION

Monitoring of radioactivity in the Columbia River began in 1945 with routine sampling of river water for total gross beta activity. The sampling was conducted at areas near the operating reactors (initially 100-B, 100-D, and 100-F), the Hanford Ferry Landing, the 300 Area, Richland, and Pasco. The horn of the Yakima River was sampled for background levels. Sampling stations were added as more reactors came on line.

Early in the sampling program, scientists realized that radioactivity was not uniformly distributed across the channel and downstream. An early report by Turner (1947) stated that "there is not much mixing of this effluent by the time it reaches [the] Hanford [townsite]." Observations from 1947 indicate that the radioactive "channel" within the river appeared to hug the south bank (reactor shore).

By 1950, the pattern of effluent dispersion in the Hanford reach was well established. The centerline of the effluent plume from the 100-B reactor to Pasco is shown in Plate 2. Immediately below 100-B, the discharge point farthest upstream, the beta activity was confined to a narrow plume that gradually widened to about 400 feet in the 100-D Area (Paas and Singlevich 1950). At the 100-D Area, the high-velocity path of flow was directed toward the opposite shore to the north of 100-D Island. However, the maximum measured beta activity remained along the reactor shore. Although the activity became more diffuse toward the north shore, there were no indications of cross-channel mixing (Paas 1951a). The plume continued to hug the reactor shore between 100-H and 100-F, especially when high water elevations caused effluent to be discharged over a spillway directly into the river (Paas and Singlevich 1951b). Immediately downstream of the 100-F Area, the maximum zone of radioactivity tended to move directly toward the reactor side of the river (Paas and Singlevich 1950), even though the high-velocity flow was directed toward the opposite shore around an island at RM 366-367. It was assumed that the island forced the plume toward the reactor shore (Paas 1951b), but the maximum activity in this area may have actually been a consequence of the shortness of the outfall line at 100-F.

The maximum beta activity generally occurred near the Hanford Ferry Landing, possibly because all reactors were contributing at this point. By the time it reached this point, the plume was about 5 miles long and 500 feet wide. Downstream of the Hanford Ferry Landing the mixing across the river was better, although the plume could still be discerned along the shore at Richland (Honstead, Healy, and Paas 1951).

The plume distribution in the river was confirmed by ferro-floc dispersion studies conducted in September 1950 and April 1951. Deep red ferro-floc sludge from the sedimentation basins was released to the river and used as a tracer. Aerial photography indicated that the plume formed a narrow band that persisted for 6 to 10 miles downstream from the release point (Rostenbach 1956).

In 1949 and again in 1951, special studies were conducted to determine the effects of the Yakima River confluence on the plume pathway. Results indicated that the Yakima River water diluted the radioactivity by as much as a factor of two along the west shore and forced the higher radioactivity levels toward the east (Pasco) shore. These effects persisted for at least 7 miles downstream (Paas and Singlevich 1951a).

Radioactivity distribution studies in the McNary reservoir in 1954 indicated little cross-sectional variation. The maximum beta activity was located in the middle of the river, while minimum concentrations fluctuated between the Washington and Oregon shorelines (Paas 1954).

Only one significant plume dispersion study was carried out below the reactor areas. Tracer dye was released into the river from the 300 Area in August 1961, October 1961, and January 1962. Aerial photography and water samples were used to define the plume distribution (Backman 1962, 1963). The objectives were to determine whether complete mixing occurred by the time the dye reached Pasco and to identify the dispersion configuration for low flow conditions.

All three tracer tests produced similar results. For each test, the dye tended to remain near the 300 Area shore, and the plume passed directly over the location of the Richland Pumping Station intake. At this point the plume was almost 3 miles long. Downstream of the proposed pumping station, the plume moved east of the fourth island but left pools of dye along the west shore. More mixing was observed off the downstream tip of the island than at any other location. Lateral dispersion was almost complete by the time the plume reached Pasco. Vertical sampling indicated there were no variations in dye concentration except within about 300 feet of the release point, suggesting that vertical dispersion was complete within a much shorter mixing length.

All raw data collected during downstream dispersion studies undertaken before 1960 were compiled in a section of a rather large monitoring report (Soldat 1962a). The data include river velocity profiles, ferro-floc distributions, radioactivity density profiles, and the results of early dye tests.

8.2 SHORELINE RADIATION SURVEYS

The earliest information on a shoreline radiation survey was reported by Paas (1953). A survey of 100-D Island, using portable instruments, showed readings ranging from 500 counts *per* minute to 5000 counts *per* minute around the island perimeter; readings of 35 millireps per hour (mrep/h) (1 rep = 0.93 rad) were measured at locations adjacent to the point where the 100-D outfall discharged effluent. These readings were not related to any unit area. Beta activity in island mud was 0.2 *microcurie per gram* (μCi/g), but no alpha particle emissions were detected in the mud (Paas 1953). The locations of the shoreline radiation surveys are shown in Plate 2.

8.2.1 Survey of 1959

A shoreline survey was conducted during March and April of 1959 to correlate a new sensitive scintillator for the measurement of gamma dose rates from reactor effluent in the Columbia River. The river discharge was approximately in the range of 100,000 to 125,000 cfs. Survey results were reported by McConiga and Rising (1959).

The survey combined scintillator readings with pulse pencil and portable instrument readings taken along the river from 1.5 miles upstream of the reactors to about 57 miles downstream. Gamma pulse pencils, in sets of five, were placed 3 feet above the ground on stakes on both shorelines at each survey river mile beginning at 1.5 miles above the reactors to 20 miles downstream of that point. From the 20-mile point, pencils were placed at each mile on alternate shores. At least one group of pencils was placed on each island, but the exact locations were not described.

Scintillator measurements *taken from a* boat over effluent bubbles varied from 0.6 to 1.8 milliroentgens per hour (mR/h) to a maximum of 2.5 mR/h with the scintillator held outside the boat. At 6 miles below the reactors, dose rates decreased to about 0.06 mR/h through the boat and 0.1 mR/h outside the boat. Shoreline readings from the pencils indicated a dose rate of 0.1 mR/h to Richland and on some islands. A reading of 15 mR/h was measured on 100-D Island. The Pasco pumping plant and Sacajawea Park recorded 0.022 mR/h and 0.018 mR/h, respectively. Background was about 0.018 mR/h according to the authors.

8.2.2 Survey of 1961-1962

During 1961 and 1962, three surveys were conducted to determine average exposure rates on beaches and islands for 33 locations between Ringold and Richland (McConnon 1962). (Sampling locations are shown on Plate 2.) The locations were chosen for their attractiveness to swimmers, sunbathers, and boaters. The surveys were conducted in July 1961, early October 1961, and late March 1962. The river discharge at the time of the July survey was approximately 175,000 cfs following a June peak of approximately 500,000 cfs. By October, the discharge was reduced to 60,000 cfs, and by the end of March, the discharge was about 50,000 cfs. Measurements were taken in approximately the same areas during the first two surveys. For the third survey, measurements were repeated from Ringold to the 300 Area, but emphasis was placed on areas opposite Richland.

Four types of radiation detection instruments were used: 1) a portable Geiger-Müller (GM) detector for extent and intensity of contamination, 2) a 40-liter ionization chamber for extremely low exposure rates, 3) a 5-inch plastic scintillation detector for exposure rates in boats, and 4) small "pencil" ionization chambers for measuring integrated exposure rates over a 1-week period per location. The small pencil instruments were used both on the shoreline and in the water. At shoreline locations, they were placed at ground level and 3 feet above ground to measure exposure from either lying or standing on the beach. Pencils were also submerged in 4 to 8 feet of water about 10 to 15 feet offshore to estimate exposure rates from swimming.

The July results showed beach activity levels from about 200 counts *per* minute to a maximum of 800 counts *per* minute (portable GM detectors). The highest readings were on the upper half of Island Z; however, there was not a consistent decrease downstream near Richland. The contamination was not associated with scattered particles but seemed to be spread uniformly over the surveyed surfaces. The pencil results indicated ground-level rates ranging from 0.06 to 0.19 mR/h with levels at the 3-foot height being about half the ground values. Pencil instruments submerged offshore indicated a range from 0.05 to 0.09 mR/h. The 40-liter chamber showed exposure rates slightly higher than the pencil instruments and a lack of any distinct change downstream near Richland (McConnon 1962).

During the October survey, measurements were taken on beaches that had been submerged during the July survey; the rates were significantly higher. The GM detector recorded measurements as high as 5000 counts *per* minute. The 40-liter chamber measured a maximum value of 1.1 mR/h. The pencil range at ground level was from 0.06 to 0.21 mR/h, with the exposure rate in water about twice that in July. There was no significant decrease downstream near Richland (McConnon 1962).

The March survey focused more on the shorelines from the 300 Area to Richland. The measurements taken with the GM detectors and the 40-liter chamber indicated no substantial increase in exposure over the October survey. Sand samples from five locations were analyzed for the contributing radionuclides. The major contributors were zinc-65 and chromium-51 in approximately equal amounts, with neptunium-239 and lanthanum-140 contributing to a lesser degree.

8.2.3 Shoreline Surveys Reported in 1966

Two shoreline surveys were reported in 1966. (Sampling locations are shown on Plate 2.) The first survey included specific locations from Vernita Ferry Landing (upstream of the reactors) to Sacajawea Park at the Snake River confluence. The second survey was of the reactor areas and extended from the 100-B reactor (RM 384) to White Bluffs (RM 370).

Vernita Ferry Landing to Sacajawea Park Survey

This survey, reported by Grande (1966), is dated January 31, 1966, but may have been conducted sometime in 1965. No specific survey date is mentioned in the report. However, most of the report is concerned with a comparison between counting instruments.

For each site along the shoreline, gamma activity measurements were taken at the beach surface and at elevations of 3 feet and 5 feet above the surface. At each site, three locations were chosen: 1) near the maximum flood level, 2) the maximum weekly flow level, and 3) the water line existing at the time of measurement.

Based on the initial GM detector survey of the general areas in question, the highest readings were measured at the river side of the Hanford *slough* and the north shore of the old Hanford Ferry Landing (Plate 2). Readings taken from mossy rocks at these locations ranged from 1000 to 3000 counts *per* minute with a maximum of 15,000 counts *per* minute. The readings remained in this range from the reactor locations to the 300 Area but decreased downstream from that point to 250 counts *per* minute at Richland and 150 counts *per* minute at the Finley lagoon (opposite the Snake River confluence).

Counting rate normally decreased rapidly with increasing distance and height from the shoreline, except for one location. At a point in the Hanford slough, the activity level increased from 150 counts *per* minute at the surface to 400 counts *per* minute at heights of 3 to 5 feet. This *increase is attributed to* improved geometry for the gamma radiation originating at the shoreline and river.

Vegetation that received irrigation water from the river at least once per year showed a significant concentration of radionuclides (200 to 1000 counts *per* minute). Readings at the water edge at Ringold ranged from 1000 to 3500 counts *per* minute.

The major contributor to exposure rates was zinc-65, with small additional contributions from sodium-24 and chromium-51. Accumulations of radionuclides were found mainly in algae, among the rocks, and on native shoreline vegetation (Grande 1966).

<u>Reactor Areas Survey</u>

This second survey, reported by Lodge (1966), was conducted in March and April 1966. This extensive GM detector survey extended from the 100-B reactor (RM 384) to White Bluffs (about RM 370). The reactor farthest downstream, 100-F, is at RM 369 (Plate 2). Measurements were made at the water line, the daily water elevation, and the annual high-water mark of 44 locations on the reactor shore, 25 far-shore locations, and 12 island locations. For comparison purposes, an aerial survey *(overflight)*, using a sodium iodide scintillation crystal, was conducted concurrently with the GM detector survey.

The objectives of the survey were to determine shoreline radiological conditions, check instrumentation, and determine major contributing radionuclides (Lodge 1966). Radioactivity levels were highest at the water line on the islands opposite and below the 100-D Area. Maximum shoreline readings were observed along the reactor side of the river just below the 100-K Area and again below the 100-N Area. On the far shore, background levels were measured as far downstream as the 100-D Area. Between the 100-D Area and White Bluffs, the readings increased, with the highest at the bluffs. The maximum spot activity level was 78,000 counts *per* minute at the downstream end of 100-D Island, and a maximum shoreline level of 12,000 counts *per* minute was found on the next island downstream (Island E). The locations of these maxima are most likely the result of leaks from the combined 100-D and 100-DR perforated outfall line extending across 100-D Island. For the reactor shoreline, the water-line maximum levels ranged from 100 to 4000 counts *per* minute; the daily wet-line maxima ranged from 100 to 1000 counts *per* minute; the annual high-water maxima ranged from 100 to 350 counts *per* minute. The major contributing radionuclides were zinc-65; chromium-51; manganese-54,56; and scandium-46.

8.2.4 Post-Reactor-Shutdown Surveys

Two shoreline radiation surveys were conducted after the shutdown of the eight once-through-cooled reactors. The purpose of these surveys was to assess the association of radionuclides with sediments in the river system. The first of these two surveys was reported in 1975 and included a detailed aerial radiation survey flown March 26 and April 28, 1974. The survey also included analysis of sediment samples from the shoreline, island, and slough areas shown in the aerial surveys to have the highest activity levels and analysis of sediment cores from Priest Rapids (background) and McNary dams (Fix 1975). The aerial survey was conducted along the Hanford reach, from the vicinity of the Vernita Bridge to several miles below the Snake River confluence. An additional aerial survey was included for several miles downstream of McNary Dam.

The highest activity levels were found along the slough north of the old Hanford townsite and in the slough between 100-D and 100-H reactors. Radiation levels in the slough north of the old townsite included 0.022 mR/h (maximum survey reading) from cobalt-60 and 0.001 mR/h from cesium-137. Radiation levels in the slough between 100-D and 100-H were 0.014 mR/h from cobalt-60 and 0.003 mR/h from cesium-137. Similar activity levels were measured along the 100-F *Area* slough and on the islands upstream of the 300 Area downriver to those adjacent to Columbia Park. The radiation levels were highly variable and indicate no decrease in activity downstream.

A 22-inch-long core taken somewhere along the reactor shore at Hanford indicated that the primary radionuclides contributing to exposure rates were cobalt-60, cesium-137, and europium-152. Also present were manganese-54, cobalt-58, zinc-65, ruthenium-106, cesium-134, cerium-144, and europium-154.

Analysis of cores from McNary reservoir showed that the maximum activity was from europium-152, cobalt-60, and zinc-65, with contributions from scandium-46, manganese-54, and cesium-137.

The second post-shutdown survey was conducted during the spring and summer months of 1979 and reported by Sula (1980). The survey area included shorelines and islands between the uppermost point of reactor discharge (100-B) and the confluence of the Snake River, almost a 60-mile length of river. From these measurements, three basic types of contamination were identified: 1) a uniform layer of contamination over the entire area, 2) areas of higher contamination referred to as "contamination deposits," and 3) discrete particles containing cobalt-60.

Uniformly distributed contamination consisted of a constant level of radiation, slightly higher than background, that extended from 100-B to the Snake River. The average exposure rate was 11 ± 3 microroentgens per hour (μR/hr); the background radiation level was 7 ± 1 μR/hr. This slightly higher exposure rate was attributed to cobalt-60 and europium-152 everywhere, with cesium-137 contributing at the 100-N Area and on the Hanford townsite peninsula. There was no downstream decrease in activity levels.

Contamination deposits, exhibiting exposure rates that were significantly higher than the uniform contamination rate, were located throughout the reach. Ninety-two areas exhibited exposure rates exceeding 25 μR/hr. These areas were attributed to the presence of contaminated sediments that had been concentrated by river processes. The areas ranged from a few square meters to several thousand square meters, usually in dense vegetation. The highest contamination deposits were at the White Bluffs slough area (40 μR/hr), the Hanford townsite peninsula (45 μR/hr), and the island at RM 344 near the 300 Area (38 μR/hr). The remaining contamination deposits were in the 25- to 30-μR/h range and appeared to be evenly distributed over the survey area. Samples of soil and vegetation indicated that the radionuclides in the deposits consisted of a mixture of cobalt-60, cesium-137, and europium-152 in approximately equal proportions.

Discrete particles of contamination containing cobalt-60 were found along the river, with the highest concentrations on the group of islands between 100-D and Locke Island. Locations with the greatest number of particles were the island at RM 375 (below 100-D Island); the 100-F Area flood plain; and the islands at RM 367, RM 353, and RM 350. The particles tended to decrease in number downstream and were found both in flat, rocky, unvegetated areas and above the daily high-water level. The particles were metallic flakes, possibly fragments of stellite valve and pump components used in production reactors. Fourteen particles were recovered and found to contain from 1.7 to 24 μCi of cobalt-60.

8.3 DOWNRIVER TRAVEL TIMES

In 1955, Hanford scientists began studies to determine downstream travel times of reactor effluent released to the Columbia River. The primary reason for the studies, according to the initial report on the studies (Soldat 1956), was the problem of evaluating the hazards resulting from the discharge of radioactive effluent and the subsequent consumption of river water in cities downstream of Hanford. Knowledge of travel time was required to establish decay correction factors for river water samples collected for monitoring and to determine what sampling times at downstream locations would represent specific Hanford operating conditions.

The initial approach to determining these travel times was to use a system of river surface floats with the objective of measuring the minimum travel time to various points downstream for a range of river discharges. The tests were confined to the reach from the reactors to Pasco. Two types of floats, rod floats and cork floats, were used. In either case, most of the float was submerged just below the surface to reduce the effect of wind. Beginning in April 1955 and ending in August 1955, intermittent tests were conducted for river discharges ranging from 86,000 to 360,000 cfs. The study results provided a minimum travel time to the Pasco-Kennewick area of 22.4 hours at 90,000 cfs and 11.2 hours at 360,000 cfs. Because of the backwater effects of the McNary reservoir, these travel times were *longer* than those possible under the free-flow conditions that existed until dam construction.

During the next 5 to 6 years, the travel times were slightly refined to provide more detail and improved graphical presentation of the information

(Soldat 1962a). Comparisons were made between data collected by the U.S. Army Corps of Engineers and by Hanford contractors; data were also compared with results from a mathematical equation used to calculate flow times.

During 1964, studies were conducted to determine downriver flow times from the reactors to any point downstream as far as Astoria, Oregon (Nelson, Perkins, and Haushild 1966). These studies used two tracer methods to determine the travel times. One method used the decay of sodium-24 (15.0 hours) as an index of travel time to various points downstream. The other method, which was used simultaneously, measured the time required for a "peak" of iodine-131 activity to reach the locations. Measurements were made during January and July 1964. The results were tabulated (Table 8.1) from the reactors to Vancouver, Washington, for low, intermediate, and high discharges to the Columbia River and from the reactors to Astoria, Oregon, for very high discharges to the river.

TABLE 8.1. Travel Times of Peak Concentrations in the Columbia River *from* 100-D Reactor (RM 377.6) to Various Downstream Points, Measured During July 1964

		Low Discharge		Intermediate Discharge		High Discharge		Very High Discharge	
Downstream Point	River Mile	Time (days)	Discharge (cfs x 10^3)	Time (days)	Discharge (cfs x 10^3)	Time (days)	Discharge (cfs x 10^3)	Time (days)	Discharge (cfs x 10^3)
Pasco	330	1.0[a]	65	0.67	173	0.48[a]	309	0.43[a]	432
Finley	324	1.6	66	---	---	---	---	---	---
Umatilla	290	6.0	89	2.6	222[b]	1.7	560[b]	1.3	624[b]
Biggs	208	7.9	95	---	---	---	---	---	---
The Dalles	191	9.5	102	4.6	209	2.5	577	2.3	627
Hood River	170	10.7	105	---	---	---	---	---	---
Vancouver	107	14.6	108	7.2	192[c]	3.7	585[c]	3.6	627[c]
Astoria	14	---	---	---	---	---	---	5.7	657

(a) Estimated from Soldat (1962a).
(b) Includes Snake and Walla Walla rivers.
(c) Upstream of Willamette River.

9.0 MONITORING AND STUDIES BY OFFSITE AGENCIES

Reports regarding Columbia River and coastal area contamination by Hanford reactor releases have been produced by state and federal agencies with specific interests in the river. These agencies included the states of Washington and Oregon and their state universities with marine science programs and laboratories (University of Washington and Oregon State University). Two federal agencies provided radiological data and information for the Columbia River system: the USGS and the USPHS under the U.S. Department of Health, Education, and Welfare. The USGS conducted a lengthy and comprehensive study of sediment and radionuclide transport in cooperation with Hanford Site contractors. The USPHS conducted a water-quality sampling program to obtain a database for evaluating the effects of McNary Dam on the Columbia River. Results of this program also include data on radioactive effluent releases from Hanford. Although the USPHS program was called a water-quality study, a significant number of biota samples were collected and analyzed for activity levels.

9.1 STATE OF WASHINGTON

During 1961 and 1962 and 1969 through 1976, samples of biota, water, and sediment were analyzed for concentrations of certain radionuclides. Biota considered were clams, oysters, and crabs. Samples were collected at several locations along the Columbia River and the Washington coast.

A radiological surveillance was conducted from September 1961 to April 1962 by the Washington Department of Health (1962) for statewide river systems. Only gross gamma and gross beta measurements were made, and no specific radionuclides were identified.

Reports by Mooney (1970, 1972, 1974, 1975, 1976) present the results of radiation surveillances. These reports present results of a continuing program documenting the significant reduction of radioactivity levels in the Columbia River during the systematic shutdown of the original Hanford production reactors. The radionuclides considered were zinc-65, chromium-51, phosphorus-32, and scandium-46. Most of the concentrations were relatively low (i.e., below a certain detection level or not analyzed). This was true for both the water column and the biota (e.g., oysters, salmon, halibut).

From 1977 through 1987, water column and sediment samples were analyzed for tritium, strontium-90, and some gamma emitters. The samples were collected from two locations: the Hanford Site and the Columbia River in the vicinity of the Trojan Nuclear Plant. For the gamma emitters, concentrations *either were generally* below specific detection levels or were not analyzed. The primary radionuclides in the river were tritium and strontium-90. The report by Mooney (1977) shows a range of less than 200 to 430 picocuries per liter (pCi/L) of tritium for the Columbia River at Richland for the months of April, May, and June 1977. A strontium-90 composite for the same period at Richland was 0.23 pCi/L. Tritium activity for the Columbia River at Longview, Washington, varied from less than 200 to 410 pCi/L. Similar results were documented for the years up through 1987. The results were listed in tables and presented graphically. However, the description of methods used is incomplete.

9.2 UNIVERSITY OF WASHINGTON

Reports from the University of Washington were published from 1960 through 1970. Radionuclide concentrations were determined for the water column, sediment, and several species of biota. Zinc-65 was the primary isotope considered. Others were chromium-51, phosphorus-32, scandium-46, potassium-40, and several others to a very limited extent. The sample locations were the coastal areas of Washington and Oregon, including Puget Sound. Specific locations were North Head (just north of the Columbia River mouth), Willapa Bay, and Hood Canal, all in Washington.

No regular monthly or yearly monitoring programs were carried out by the University of Washington. Although all the studies were conducted by the Laboratory of Radiation Biology and *the Department of Oceanography*, each has its own small and restricted data set. Radionuclide concentrations in the water column and sediment were determined primarily to support analysis of various species of biota (e.g., plankton, shellfish).

Studies of radioactivity in plankton were conducted from 1961 through 1963 and reported by Seymour,[a] Seymour and Lewis (1964), and Lewis and Seymour (1965). The sampling locations were along the Washington and Oregon coastlines and Puget Sound. The radionuclides of primary interest were zinc-65 and chromium-51. Seymour[a] reported the range of zinc-65 concentration in plankton sampled in 1961 to be from 6 to 980 *picocuries per gram (pCi/g)* dry weight. Seymour and Lewis (1964) reported maximum concentrations of zinc-65 in plankton as ranging from 110 to 1300 pCi/g dry weight.

Naidu (1963) reported on zinc-65 concentrations in Willapa Bay oysters based on samples gathered during February, April, May, and June 1963. Concentrations of zinc-65 ranged from 450 to 618 pCi/g dry weight. The corresponding range for Willapa Bay plankton ranged from 33.8 to 448 pCi/g dry weight. Concentrations in the mud ranged from 2.69 to 7.49 pCi/g dry weight. The data analysis and discussion present a reasonably complete assessment of zinc-65 in Willapa Bay for the short period of sampling.

Isakson (1969) studied phosphorus-32 activity in biota at North Head on the Washington coast near the mouth of the Columbia River. The sampling period was from October 1965 to September 1966. Most of the data are presented graphically for tissue from clams, mussels, barnacles, anemones, and algae. The data analysis and discussion present a detailed assessment of phosphorus-32 activity for this location.

The most significant publication from the University of Washington is a text edited by Pruter and Alverson (1972), The Columbia River Estuary and Adjacent Pacific Ocean Waters. *The book editors were from the National Marine Fisheries Service (U.S. Department of Commerce). Many of the reports are from the University of Washington and Oregon State University. Others are from the National Marine Fisheries Service, Battelle Memorial Institute, and the USGS.* The text contains 34 papers on the biological and chemical characteristics of the estuary and coastal areas, including several papers on sediment; most of the information concerns biological studies. Nine of the papers

(a) Progress report prepared by A. H. Seymour, 1961, Laboratory of Radiation Biology, University of Washington, Seattle, Washington.

(Chapters 25-33) deal with radionuclides in the estuary and coastal system. The primary radionuclides investigated are zinc-65, chromium-51, scandium-46, and phosphorus-32. Only six of the papers contain data of potential use for estimating dose. Most of the concentrations are associated with biota from the estuary bottom and coastal shelf, although some water column and sediment concentrations are presented. The reported studies cover the period from 1960 to 1969. The most important contributions are the *analyses* and discussions of the Columbia River estuarine and coastal area processes and how they distribute radioactivity.

9.3 STATE OF OREGON

The Health Division of the Oregon State *Board of Health* initiated a study in June 1961 to identify and monitor the activity levels of neutron activation and fission product radionuclides in the lower Columbia River and Oregon coastal areas. The primary concern was the continual release to the Columbia River of radionuclides in the cooling water effluent of the Hanford reactors. The objective of the study was to determine the extent of the distribution of the radionuclides and their uptake by biological organisms and sediments. The work was supported by a contract with the Division of Radiological Health of the USPHS, with supporting funds from the Oregon State Board of Health. When the contract expired on July 31, 1967, the Oregon State Board of Health continued to maintain the program to serve three purposes: 1) to establish a continuous background of radiological data to be used in assessing radioactivity from future nuclear power installations on the lower Columbia River, 2) to monitor the changes in levels of radioactivity resulting from reactor shutdowns at Hanford, and 3) to provide a basis for *evaluating* radionuclide intake of individuals consuming fish, shellfish, and other Columbia River foods containing radioactivity.

The state's original upstream sampling location was the John Day Dam site (RM 215.6), but its use was discontinued in November 1963 because of filling operations and construction extending downstream from the dam (Figure 9.1). After 1963, The Dalles Dam (RM 191.5) was the upstream sampling location. The other Columbia River locations, in downstream order, were

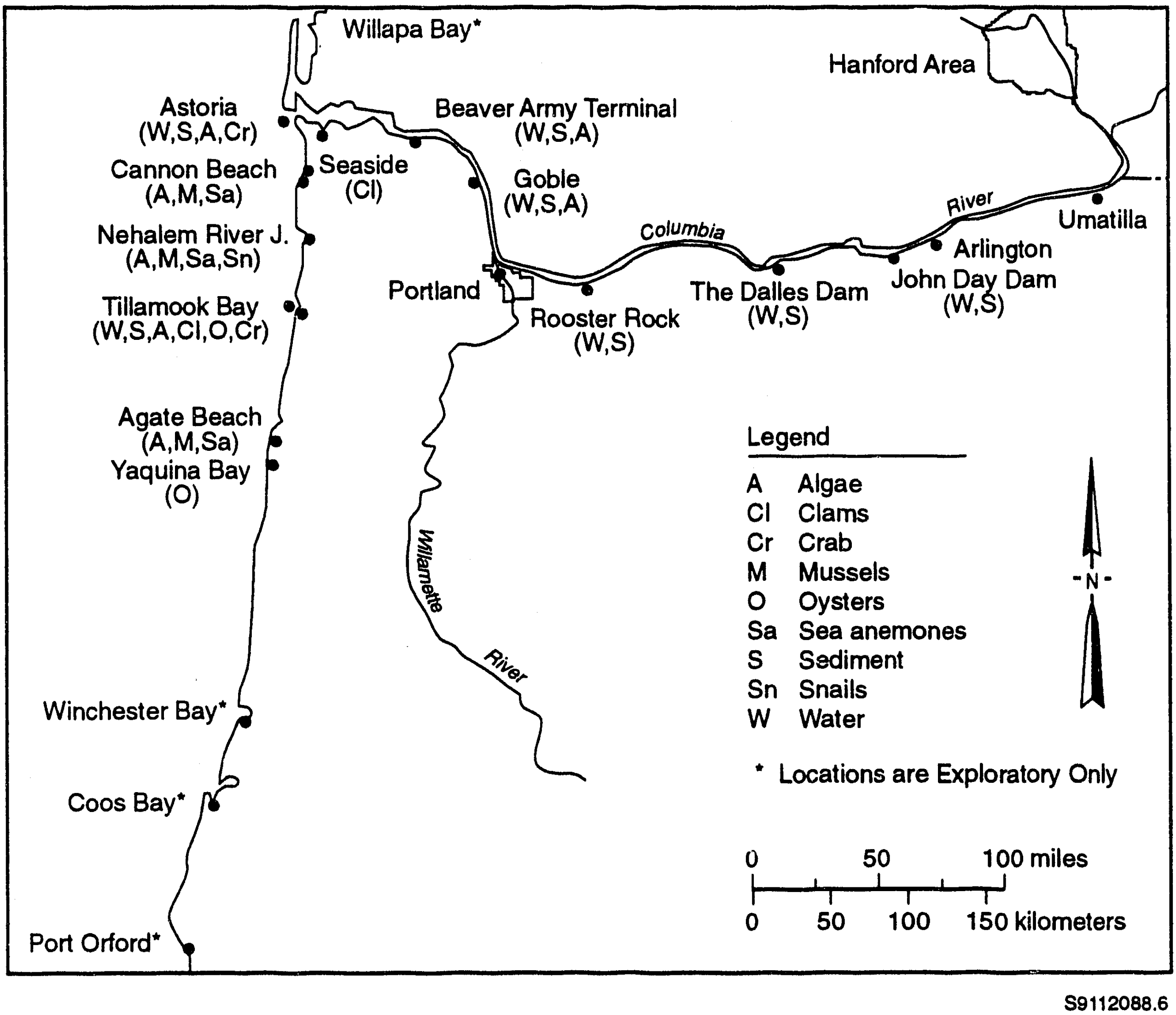


FIGURE 9.1. Columbia River and Coastal Sampling Locations for 1961 *Through* 1967 Studies by the State of Oregon (Toombs and Cutler 1968)

Rooster Rock State Park (RM 128.4), Goble (RM 74.0), Beaver Army Terminal (RM 53.6), and Astoria (RM 13.7), all in Oregon.

Oregon coastal locations (in miles below the mouth of the Columbia River) were Seaside (28 miles), Cannon Beach (35 miles), Nehalem River jetty (50 miles), Tillamook Bay (62 miles), Agate Beach-Yaquina Bay (140 miles), and Coos Bay (260 miles). The river and coastal locations *and* the type of sampling conducted at each are mapped in Figure 9.1.

The results of the study are documented in reports by Toombs and Cutler (1968) and Toombs and Paris (1978). The 1968 report, covering the period from 1961 to 1967, states that 10 radionuclides were detected using gamma spectrometry and radiochemical procedures. Zinc-65, chromium-51, and phosphorus-32 were of special concern because of their abundance and biological significance. The highest levels were found in sediments and algae. The most widely distributed radionuclide, zinc-65, was found in significant concentrations, especially in edible shellfish. Activity levels of zinc-65 and chromium-51 in water and sediment from the Columbia River for 1962 through 1967 are shown in Table 9.1. Activity levels of zinc-65 in water, sediment, and shellfish from Oregon coast locations for 1962 through 1967 are shown in Table 9.2.

From 1967 to 1977, studies continued much as they had been conducted from 1961 to 1967, except for special studies conducted in the vicinity of Tillamook Bay in 1970 and 1971 because of the potential for exposure of coastal residents through seafood. The locations and type of sampling are shown in Figure 9.2.

Radiological data were also reported in a set of data tables in a surveillance report for selected rivers in Oregon (Oregon State Department of Human Resources 1985). The surveillance covered from 1961 to 1983 for the Columbia, Snake, Willamette, and Klamath rivers, and the coastal river system.

For the Columbia River, six monitoring stations were used (McNary Dam, The Dalles Dam, Rooster Rock, Cascade Locks, Beaver Army Terminal, and Astoria). The stations were not always monitored over the entire period; the sampling frequency was usually quarterly for each year, but sometimes less frequent. Water, sediment, and algae were sampled. The surveillance measured gross alpha, gross beta, tritium, phosphorus-32, zinc-65, and chromium-51. However, not all samples were analyzed for each radionuclide, as shown by numerous NA (not analyzed) notations in the data tables. This pattern may indicate a selective sample analysis at each location, as the notations are not consistent for any radionuclide.

TABLE 9.1. Range of Yearly Concentrations of Zinc-65 and Chromium-51 at Columbia River Locations for 1962 Through 1967. Activity levels are in pCi/L for water and in pCi/g (wet or drained weight) for sediment and algae. Number of samples is shown in parentheses.

	Range of Yearly Concentrations					
	Zinc-65			Chromium-51		
Location	Water	Sediment	Algae	Water	Sediment	Algae
John Day Dam						
1962-1963	<35-81 (5)	1.2- 82.1 (9)	-[a]	2550-5280 (5)	-	-
1963-1965	<35 (2)	2.5- 6.7 (2)	-	5790-10303 (2)	-	-
The Dalles Dam						
1963-1965	-	0.7 (1)	-	-	-	-
1965-1967	<35-144 (8)	0.9-116.5 (8)	-	837-3700 (8)	13.4-149.9 (8)	-
Rooster Rock						
1962-1963	<35-74 (4)	0.2- 1.4 (4)	-	1670-3240 (4)	-	-
1963-1965	<35-135 (22)	0.7- 36.0 (22)	-	725-5760 (22)	-	-
1965-1967	<21-407 (24)	0.5- 31.3 (24)	-	<100-2520 (24)	4.4- 50.8 (24)	-
Goble						
1962-1963	<35 (5)	5.2-230.0 (4)	-	930-1780 (5)	-	-
1963-1965	<35-51 (23)	1.2- 99.6 (23)	18.7-225.0 (16)	350-5400 (23)	-	-
1965-1967	<21-78 (24)	0.9-127.1 (24)	18.7-340.7 (14)	<100-1830 (24)	4.6-195.1 (24)	298.1-349.7 (14)
Beaver Army Terminal						
1962-1963	<35-131 (7)	2.2-128.0 (6)	-	1300-2620 (5)	-	-
1963-1965	<35-81 (23)	3.4-128.0 (21)	36.1-137.9 (16)	<100-4670 (23)	-	-
1965-1967	<21-100 (24)	0.4-164.8 (24)	9.4- 65.0 (6)	<80-2184 (24)	4.6- 90.1 (24)	247.5-398.9 (6)
Astoria						
1962-1963	<35 (7)	62.9 (1)	9.1-208.0 (10)	600-2250 (7)	-	-
1963-1965	<35-37 (23)	1.5- 52.8 (19)	7.3- 82.7 (14)	<100-2720 (23)	-	-
1965-1957	<21-60 (24)	1.9- 85.6 (23)	8.3- 48.9 (7)	<100-1390 (24)	10.1-552.9 (23)	239.0-304.2 (7)

(a) - indicates no sampling.

TABLE 9.2. Range of Yearly Concentrations of Zinc-65 at Oregon Coast Locations for 1962 Through 1967. Activity levels are in pCi/L for water and in pCi/g (wet or drained weight) for sediment and shellfish. Number of samples is shown in parentheses.

	Range of Yearly Concentrations						
Location	Water	Sediment	Clams (Razor)	Clams (Soft Shell)	Crabs (Dungeness)	Mussels	Oysters
Seaside Beach							
1962-1963	-[a]	-	5.4-36.2 (3)	-	-	-	-
1963-1965			12.6-23.8 (3)	-	-	-	-
1965-1967			7.7- 9.4 (3)	-	-	-	-
Cannon Beach							
1962-1963	-	-	-	-	-	18.3-32.5 (3)	-
1963-1965	-	-	-	-	-	20.0-28.8 (2)	-
1965-1967	-	-	-	-	-	12.9-21.8 (2)	-
Nehalem River Jetty							
1962-1963	-	-	-	-	-	10.1-32.0 (4)	-
1963-1965	-	-	-	-	-	17.1-20.2 (3)	-
1965-1967	-	-	-	-	-	12.8-21.4 (2)	-
Tillamook Bay							
1962-1963	<35 (7)	0.1-0.9 (17)	-	0.4-5.3 (16)	10.0-27.4 (12)	-	7.1-37.0 (13)
1963-1965[b]	<35 (22)	0.1-0.5 (19)	-	0.9-5.3 (21)	9.4-16.1 (21)	-	9.6-23.4 (23)
1965-1967	<21-<35 (24)	<0.1-0.6 (22)	-	0.4-4.0 (18)	4.7-9.3 (20)	-	5.0-21.6 (23)
Yaquina Bay							
1962-1963	-	-	-	-	13.9 (1)	4.9 (1)	3.2 (1)
1963-1965	-	-	-	-	-	5.0-5.1 (2)	2.3-3.3 (2)
1965-1967	-	-	-	-	2.2 (1)	2.1-3.9 (2)	1.1-2.0 (2)

(a) - indicates no sampling.
(b) For 1963-1965, gross beta activity levels in water ranged from 53 to 820 pCi/L.

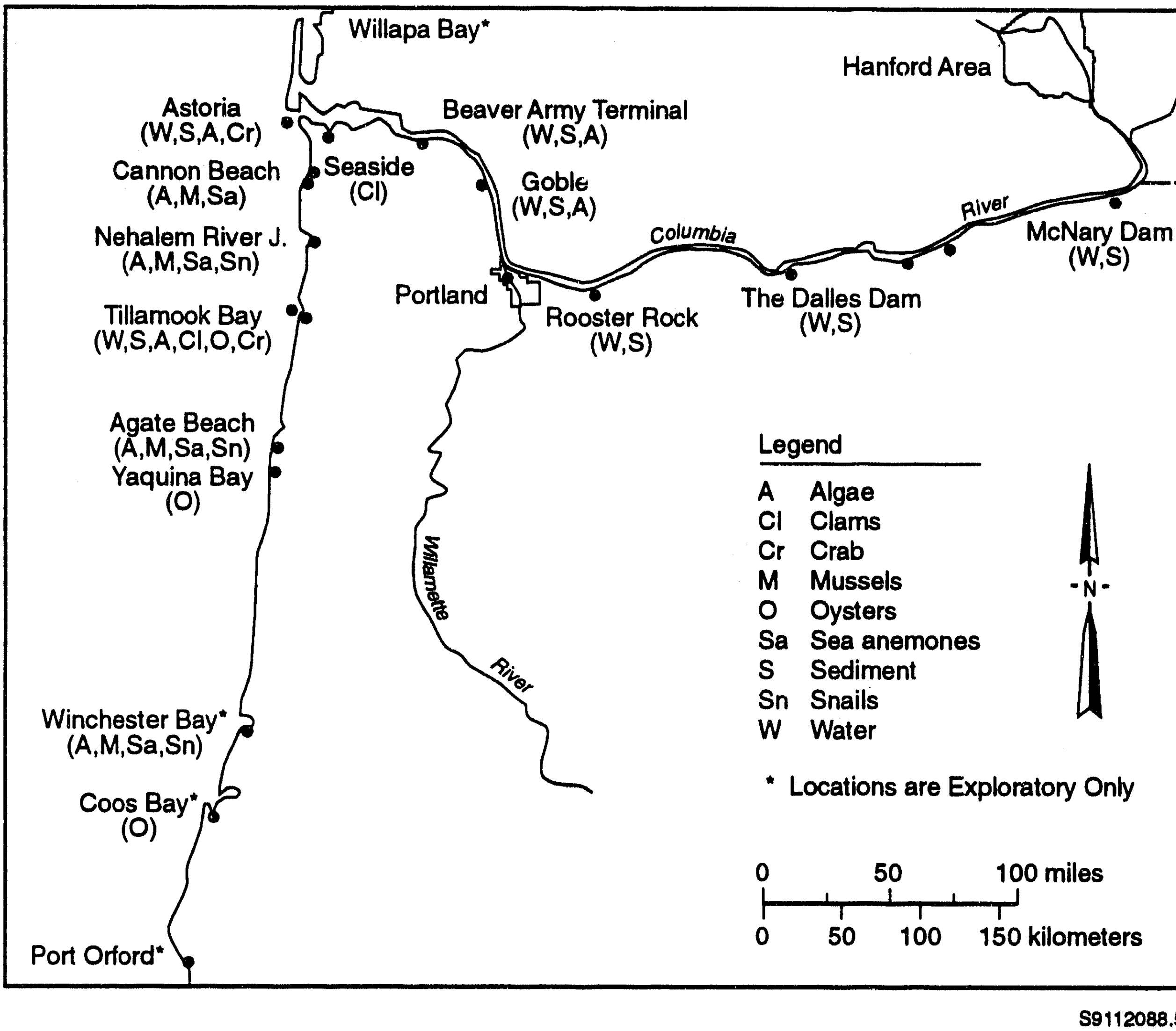


FIGURE 9.2. Columbia River and Coastal Sampling Locations for 1967 *Through* 1977 Studies by the State of Oregon (Toombs and Paris 1978)

9.4 OREGON STATE UNIVERSITY

Oregon State University did not conduct lengthy continuous monitoring programs, and therefore, no large or comprehensive databases were developed. Potentially useful data are found in small quantities, usually concerned with one type of fish or shellfish or with a particular location or phenomenon. Most of the reports and field programs represent limited or individual studies; many supported student dissertation work. In addition to dissertations, these studies also resulted in a number of journal articles and symposium proceedings. The basic purposes of the studies varied. There was a considerable amount of interest in the dispersion of the Columbia River plume along the coastal areas and seaward. Coupled with the plume dispersion was the affinity of certain commercial fishes for radionuclides. In at least one case, a secondary objective was to use the uptake of radionuclides to differentiate salmon of Asiatic stock from those of North American stock. Determining the decrease of radioactivity in fish and benthic marine life with distance from the river mouth was another objective.

For this review and discussion, the reports were grouped into two general locations: the Columbia River and estuary, and the coastline with adjacent ocean areas. Within these two basic groups, the reports and articles are separated into specific subjects for review purposes.

9.4.1 Columbia River and Estuary

There were several studies of Columbia River water, sediment, and the association of sediment with radionuclides, excluding the biological regime of the river. The studies extended as far upstream as The Dalles Dam and downstream to the river mouth, with most of the work being conducted in the estuary. The major radionuclides investigated were chromium-51 and zinc-65 over the period from 1963 to 1968. The study objectives were, collectively, to test methods of radionuclide measurement in water and sediment, to determine the chemistry of chromium-51 in river water (including its relationship with salinity), to identify the association of zinc-65 with sediment, and to determine the forms (dissolved or particulate) of chromium-51 and zinc-65 in transport. Most of the data are displayed in graphic form, with very few actual data points listed. The importance of these reports is in the study of specific processes and testing equipment. Reports and dissertations listing data or information of potential use for estimating dose are those by Cutshall and Osterberg (1964); Forster and Guthrie (1968); Hanson (1967); Jennings (1966); and Larsen, Renfro, and Forster (1968).

The studies investigating the uptake of radionuclides by biota were primarily concerned with using the presence of radionuclides to attain a better understanding of the physical, chemical, and biological phenomena taking place (radionuclide transfer through the food web), plus the effects of the Hanford production reactors being shut down. The radionuclides in question were zinc-65, chromium-51, and, to a lesser extent, scandium-46 and manganese-54. The period of sampling extends intermittently from 1963 to 1971. Data in the reports are mostly presented in graphical form. Tabulated data that may be useful are sparse. The biota investigated included algae, rooted vegetation, various freshwater fish, crab, and starry flounder. Reports providing potentially useful data are by Johnson, Cutshall, and Osterberg (1966) and Renfro (1966).

9.4.2 Coastal and Ocean

Studies in the coastal zone and adjacent ocean areas investigated the directional movement and areal extent of the Columbia River plume and its effect on the food web. Radionuclides of interest were zinc-65 and chromium-51, with some interest in manganese-54 and certain radionuclides derived from fallout (from sources other than Hanford). The *study* period extends from 1961 to 1970. A majority of the field studies focused on radionuclide concentrations in biota, with limited emphasis on water column concentrations and sediment. The decrease in activity levels with distance from the river mouth and coastal areas was of interest. Many of the species of biota sampled were noncommercial (e.g., starfish, and others). The samples were gathered from various distances seaward along the coastal shelf and used as "tracers" for the various radionuclides.

Columbia River Plume

The dispersion of the Columbia River plume was studied using chromium-51 and salinity as tracers (Frederick 1967a, 1967b). Water samples were collected at the surface along Washington and Oregon coastal areas and analyzed for salinity and concentrations of chromium-51. The salinity and chromium-51 concentrations were then used to define the direction of dispersion of the winter and summer plumes, as shown in Figures 9.3 and 9.4, respectively. Within the boundary of the sampling pattern, the winter plume tended to hug the Washington coast and the summer plume dispersed along the Oregon coast in a slightly seaward direction.

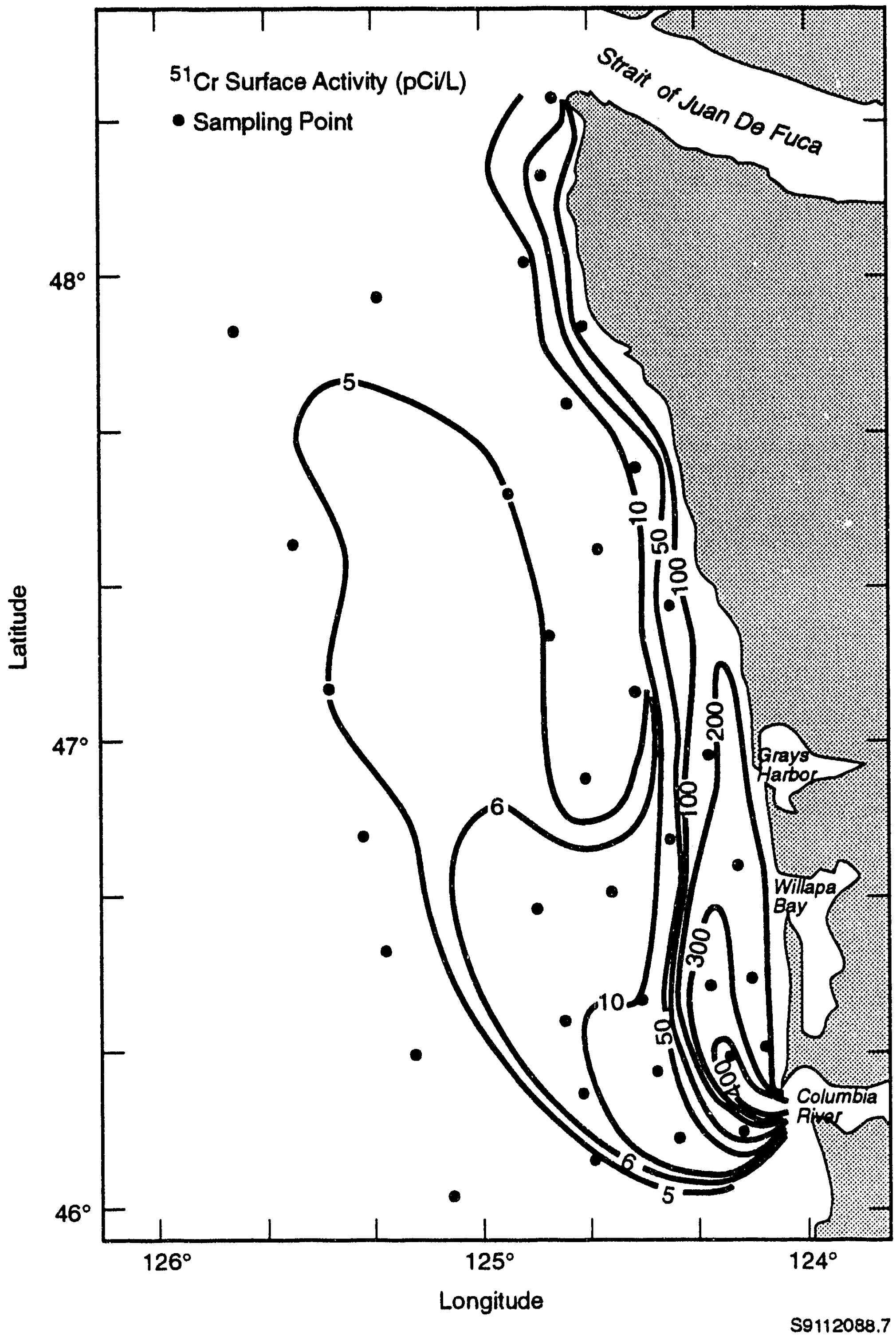


FIGURE 9.3. Winter Plume Pattern of February 1966 Based on Chromium-51 Activity (Frederick 1967b)

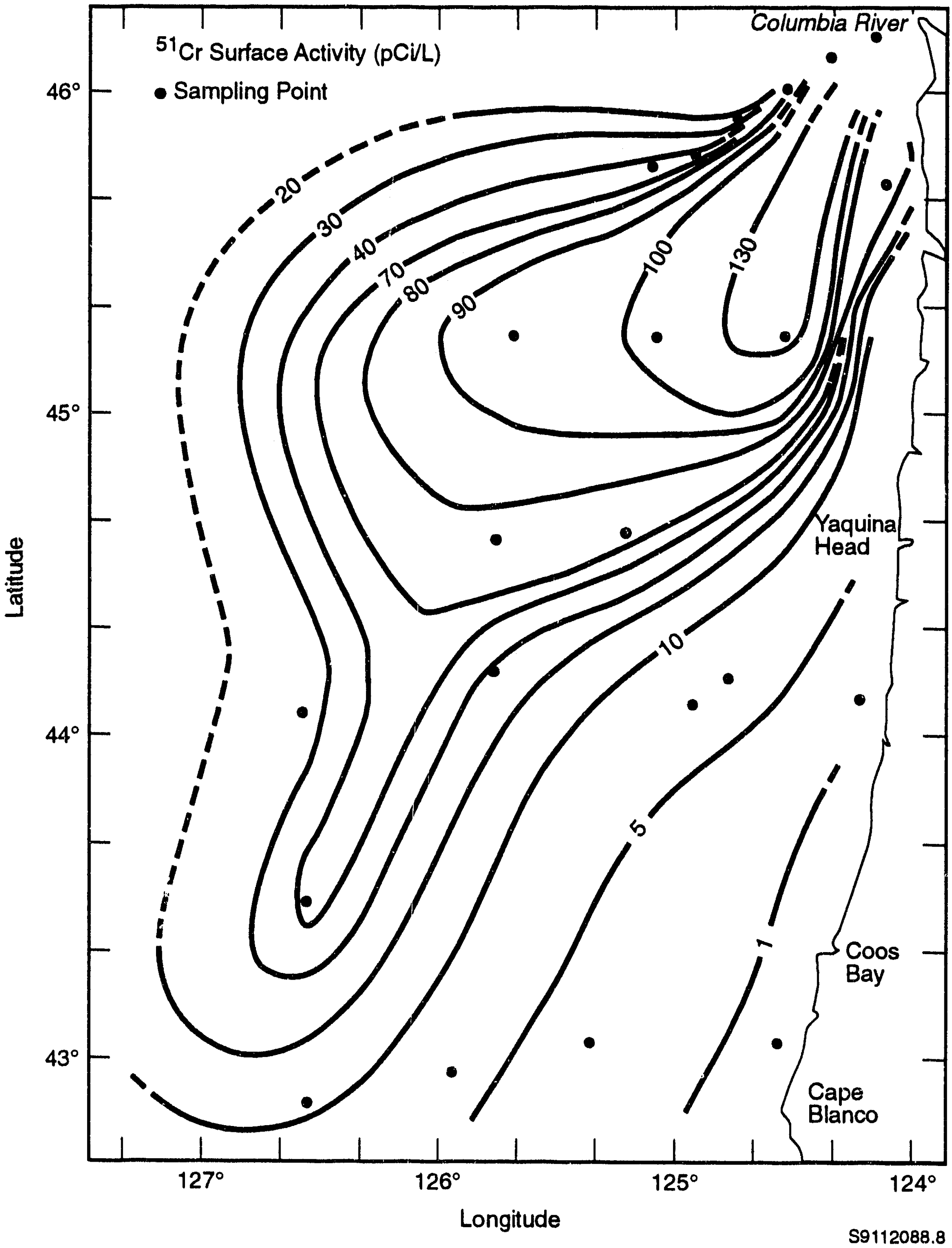


FIGURE 9.4. Summer Plume Pattern of June 1965 Based on Chromium-51 Activity (Frederick 1967a)

A subsequent study by Pearcy and Forster (1968) analyzed the concentration of zinc-65 in biota (pelagic animals) relative to the plume boundaries. Samples of biota and water were collected near the surface to about a 5-meter (16.4-foot) depth. Results indicated that concentrations in the biota roughly corresponded to those in the plume water; that is, concentrations in both were higher near the origin of the plume at the mouth of the river.

Three earlier studies used zinc-65 in various species of biota to evaluate the decrease in radioactivity with distance from the mouth of the Columbia River (Osterberg 1962; Pearcy and Osterberg 1963; Mellinger 1966). Osterberg's (1962) results indicated that zinc-65 is a reasonably good tracer for the Columbia River plume, and a significant amount of information regarding radionuclide content of marine biota off the Oregon coast is provided in the report. The other two reports evaluate much smaller data sets.

Radionuclide Concentrations in Tuna and Salmon

A study of radioactivity in tuna livers was reported by Pearcy (1966) and Pearcy and Osterberg (1967). The radionuclides identified were zinc-65 and manganese-54. The study period was from 1962 to 1966, with sampling locations extending from offshore northern Oregon southward to Baja California. Data tabulated by Pearcy and Osterberg (1967) indicate that, for the northern Oregon area, the ranges of zinc-65 concentrations in pCi/g of liver ash were 283 to 1050 pCi/g in 1963, 224 to 733 pCi/g in 1965, and 159 to 1067 pCi/g in 1966. For the southern Oregon area, the zinc-65 concentrations were 39.8 to 133 pCi/g in 1963 and 320 to 729 pCi/g in 1964. The one 1964 sample from the Baja California coast yielded a concentration of 46.4 pCi/g. The concentrations of manganese-54 were much lower, ranging from 3.6 to 88.6 pCi/g in all areas considered.

Radioactivity in Pacific salmon was studied during 1964 and 1965. The initial findings were reported by Kujala (1966), followed by brief reports by Kujala and Forster (1968) and Forster and Loeffel (1968). The study by Kujala (1966) analyzed salmon for zinc-65 and manganese-54 at 10 locations from Bristol Bay, Alaska, to Eureka, California. The range of concentrations for zinc-65 (in pCi/g dry weight) in chinook salmon was from 1.77 (Bristol Bay, Alaska) to 81.87 (Eureka, California). For sockeye salmon, the range was 0.86

(Bristol Bay, Alaska) to 5.52 (Barkley Sound, Canada). Sockeye salmon were not caught south of Canada. For coho salmon, the range was 3.61 (Cook Inlet, Alaska) to 59.28 (Depoe Bay, Oregon). All values were reported as averages for each location. The concentrations of manganese-54 were much *lower*, with a maximum average for all salmon of 8.8 pCi/g dry weight.

The concentrations of zinc-65 in a "tagged" salmon study by Forster and Loeffel (1968) were given for two locations on Vancouver Island, Canada, and three locations off the coast of Alaska. Zinc-65 concentrations for the Vancouver Island salmon ranged from 339 to 518 pCi/g of ash; for the Alaska locations, from 7.3 to 450 pCi/g.

9.5 U.S. GEOLOGICAL SURVEY

During the early 1960s, the USGS *began* a series of studies to investigate the role of river sediment in the uptake and transport of radionuclides. The work was conducted in collaboration with the U.S. Atomic Energy Commission (USAEC) and Hanford Site contractors. The length of river involved extended from the vicinity of Pasco to Longview, Washington, just upstream of the Columbia River estuary. The overall objective of the studies was to determine quantitatively, to the extent possible, the transport and disposition of Hanford radionuclides in and along the Columbia River. Specific studies addressed the uptake and release of radionuclides by river sediment, the transport rates of certain radionuclides, and the inventory of radionuclides in riverbed sediments. This effort followed initial studies conducted at Hanford during the 1950s. The field work for the cooperative studies began in 1962 and continued intermittently to 1966. Preliminary reports were prepared during the 1960s by the USGS and General Electric Company until 1964 and by Pacific Northwest Laboratory after 1964. The final results were not published until the early 1970s.

9.5.1 Initial Studies at Hanford

During 1956 and 1957, an attempt was made to assess the magnitude of radionuclide uptake by sediment between the reactors and McNary Dam. The results of this effort were reported by Nielsen and Perkins (1957). Quantities of certain radionuclides in reactor effluent were measured at the reactors and downstream in an attempt to obtain an estimate of sediment uptake along the Hanford reach. Each reactor basin was sampled for a period of 2 to 3 days in November 1956 and March 1957. The river at Pasco was sampled daily starting 1 day later to allow for travel time. In the first 50 miles below the reactor outfalls, about half of the sodium-24 and copper-64; two-fifths of the arsenic-76; one-third of the phosphorus-32, zinc-65, and neptunium-239; and one-fifth of the chromium-51 were lost. The authors assumed that the net reduction in activity levels, after allowances for travel time (decay), resulted from uptake by sediment.

Nielsen and Perkins also conducted a depletion study for the reach between Pasco and Vancouver. Concentrations of phosphorus-32, chromium-51, zinc-65, and neptunium-239 were measured in samples from *12* stations during 3 days in January 1957. Depletion of phosphorus-32 and chromium-51 averaged 15%, while depletion for zinc-65 was 65%.

The general conclusion drawn from these studies was that accumulation in sediment may account for a large part of the depletion of radionuclides from the water column, although Nielsen and Perkins' results were only representative of the conditions during sampling. Also, the conclusion that zinc-65 and chromium-51 were the major radionuclides in river sediments was based on one sample taken from behind McNary Dam. That sample contained 357×10^{-6} μCi/g of zinc-65, 87×10^{-6} μCi/g of chromium-51, and 5×10^{-6} μCi/g of cobalt-60.

9.5.2 U.S. Geological Survey Cooperative Studies

The results of these studies were first published in several Hanford documents and USGS open-file reports. These were mostly progress reports that included discussions of results to date and supporting data. The final results were published in a series of USGS professional papers that included all data from field sampling tabulated in appendixes.

Interim Hanford and USGS Reports

The first progress report presented preliminary results on the inventory of radionuclides in the river and the processes of sorption and release of radionuclides by sediment (Nelson, Perkins, and Nielsen 1964). The radionuclides of importance were zinc-65, chromium-51, scandium-46, cobalt-60, and manganese-54. Although the study team realized that core sampling was the most direct way to obtain an inventory of streambed radionuclides, they also knew that hundreds of samples would be required for a comprehensive survey. Therefore, an alternative approach was agreed upon that involved sampling water and sediment (suspended and bed material) at specific locations.

Beginning in July 1962 and continuing until September 1963, water, suspended sediment, and surficial streambed samples were collected several times per week at the highway bridges at Pasco, Hood River, and Vancouver. All water samples for a 2-week sampling period were composited and filtered, and the water and colloids were analyzed for cross-sectional and vertical variations in radionuclide concentration. Transport rates calculated for chromium-51 and zinc-65 at Pasco and Vancouver indicated that up to 30% of the chromium-51 was lost to decay and very little tended to adsorb to sediment. However, much of the zinc-65 was taken up by sediment, and its resuspension during high river discharges (spring runoff) yielded higher than usual zinc-65 concentrations at Vancouver in May.

Analysis of the radionuclides associated with sediment particle sizes indicated that chromium-51 and scandium-46 were present in the finer sizes, while cobalt-60 and zinc-65 were more prevalent in the coarse fractions because of the presence of organic material. Studies were then conducted to determine the ionic form of certain radionuclides in reactor effluent and river water. Zinc-65, scandium-46, and manganese-54 were all determined to be predominantly cationic, and all associated freely with sediment downstream of McNary Dam. Chromium-51 was principally anionic in behavior, although a later article by Nelson et al. (1966) concluded that both hexavalent (anionic) and trivalent (cationic) forms of chromium occurred in the river and that chromium-51 in the cationic trivalent form was easily adsorbed by sediment.

The progress of radionuclide transport studies was reported by Nelson (1965). This report *discussed* the riverbed characteristics where sediment deposition would be expected to accumulate, such as behind dams, in slack-water areas along the river, and others. Nelson calculated the zinc-65 inventory from the reactor area to the Snake River to be about 1500 curies.

This calculation was based on an estimate of zinc-65 concentration in coarse sand and gravel of 70 curies per square mile (Ci/mi^2) and an assumption that the extent of all types of deposition areas was reasonably estimated.

Nelson also investigated the uptake of radionuclides by biota. Algae scraped from rocks downstream of Pasco showed substantial concentrations of zinc-65 (21,800 dpm/g) and chromium-51 (78,000 dpm/g). The role of biota was not included in Nelson's calculations, based on the assumption that the biota did not amount to much volumetrically.

Results of the first year's sampling were presented in an open-file report of the USGS (Haushild et al. 1966). The report contained a compilation and analysis of all data collected during the 15-month sampling period. Data were presented for radionuclide, sediment, and water measurements at Pasco, Hood River, and Vancouver, and at stations near the mouths of the Snake and Willamette rivers. The radionuclides analyzed were sodium-24, scandium-46, chromium-51, manganese-54, cobalt-60, copper-64, zinc-65, zirconium/niobium-95, ruthenium/rhodium-103, lanthanum-140, cerium-141, and neptunium-239.

The report also discussed a special study, conducted during 2 days in March 1964, which indicated that radionuclide concentrations measured during the morning sampling period were 15% lower than the average concentration for 1 day because of significant diurnal fluctuations (hydropeaking) in discharge from Priest Rapids Dam. Differences in concentration values resulted from increases and decreases in travel time, which affected the decay of radionuclides between the reactors and Pasco. Variation in hydropeaking discharge would also modify the degree of dilution. These effects were particularly significant at low flow.

Estimates of the total quantity of radionuclides transported past each station indicated that approximately 277,000 curies were transported past Vancouver from January 1963 through September 1963. Chromium-51 was by far the largest volume (95%), with zinc-65 at 3%, and other radionuclides at 2%. Discharge of radionuclides in solution was highest during late winter and early spring, except for chromium-51. Maximum levels for chromium-51 were recorded for July through September. According to Haushild et al. (1966), these maxima either were anomalous or indicated a change in the practices controlling the addition of sodium dichromate to the reactor cooling water. The 277,000 curies transported past Vancouver represented about 77% of the total transported past Pasco. Decay was assumed to have reduced the Vancouver activity levels by about 19%; the remainder was assumed to have been retained in the riverbed. The authors recommended that future work investigate the variation in storage under changing hydrologic and hydraulic river conditions.

The second year of field work was carried out from January 1964 to January 1965. The first reported results came out in June 1965 (Perkins, Nelson, and Haushild 1965). The radionuclides considered in the study were scandium-46, chromium-51, manganese-54, cobalt-58, cobalt-60, zinc-65, zirconium/niobium-95, ruthenium-106, antimony-124, and barium-140. Water samples were collected weekly at the highway bridge locations at Pasco and Vancouver, but less frequently at Hood River. From analysis of these samples, the sorption and transport of radionuclides with suspended sediment, the uptake of radionuclides by sediment (water column depletion), and the riverbed inventory (Pasco to Vancouver) were investigated. The radionuclides that tended to stay in solution were chromium-51, ruthenium-106, antimony-124, and barium-140. Those associated with sediments were scandium-46, manganese-54, cobalt-58, cobalt-60, zinc-65, and zirconium/niobium-95. Perkins, Nelson, and Haushild (1965) concluded that about 75% of the depletion occurred upstream of Hood River, probably behind McNary Dam.

Based on the data from the January 1964 to January 1965 sampling year, another report was prepared by Nelson et al. (1966). They used the January 1964 to January 1965 data, together with data from supplementary sampling, to determine depletion, deposition, scouring, and inventories of radionuclides and to estimate where and by what materials the radionuclides were held. Data from the 1962-1963 sampling year were not included. The radionuclides considered were scandium-46, chromium-51, manganese-54, cobalt-58, iron-59, cobalt-60, zinc-65, zirconium/niobium-95, ruthenium/rhodium-106, antimony-124, cesium-137, and barium/lanthanum-140. The reach of river considered was from Pasco to Vancouver.

Percentage depletion was computed for each month and a radionuclide inventory estimated based on the assumption that radionuclide deposition for prior years was similar to that observed for 1964. The inventory calculated for the reach between Pasco and Vancouver was 11,000 to 38,000 curies. Of this total, 90% was zinc-65 and chromium-51.

Based on radionuclide concentrations in effluent and river water, the depletion, inventory, and amount of zinc-65 scoured (resuspended) *were calculated for* the reach from the reactors to McNary Dam. An average water column depletion of about 65% indicated a deposition of 5500 curies of zinc-65 in the reach. It was estimated that 30% of this was scoured and transported downstream during the spring discharge of 1964. These results were based on weekly samples taken from May to October 1964, but were assumed to be representative for the entire year.

A special study *began in May 1965* that investigated the scouring of sediment from behind McNary Dam during high river discharges. Weekly sampling at the highway bridge at Umatilla (just downstream of the dam) was added to the sampling program. To quantify the amount of scour, ratios of zinc-65 (associated primarily with sediment) to chromium-51 (primarily in solution) in reactor effluent were compared with ratios in river water. Results indicated that the ratio of zinc-65 to chromium-51 increased by a factor of five during the high discharge period.

In 1969, Nelson and Haushild reported on an attempt to estimate the radionuclide inventory in bed sediments from the reach between the reactors and McNary Dam (Nelson and Haushild 1969). Two estimation methods were used. The first method was *used* to determine the radionuclide concentrations in different bed sediments and estimate the extent of these sediment types within the reach. The second method was to use radionuclide data for Pasco and Umatilla to calculate the amount of radionuclides deposited behind McNary Dam. Both methods were based on the assumption of quasi-equilibrium between the river and the radionuclide input from the reactors, such that the number of curies of each radionuclide added to the streambed in a year balanced those lost by radioactive decay. This assumption of constant input of specific radionuclides from the source is invalid. Results *indicated* that about 16,230 to 17,300 curies were contained in the bed sediments between the reactors and McNary Dam. From the bed sampling method, it was estimated that 1430 curies were stored between the reactors and Pasco, and *that* an additional 14,800 curies were *stored* between Pasco and the dam. The radionuclide discharge data, which were valid only for that length of reach between Pasco and the dam, yielded an estimate of 17,300 curies.

USGS Professional Papers

The final reported results were published in 1973 and 1975 (Glenn 1973; Haushild et al. 1973; Hubbell and Glenn 1973; Haushild, Dempster, and Stevens 1975). According to these authors, the major radionuclides were zinc-65, chromium-51, manganese-54, scandium-46, and cobalt-60. A number of other radionuclides were discussed, but the reports indicate that these other radionuclides contributed only a very small percentage of the radioactivity in the river.

The report by Glenn (1973) presents the results of a detailed study of riverbed sediments and the five major radionuclides sampled at nine locations from Pasco to the Columbia River estuary. The sampling period was April 21 to May 12, 1966. Radionuclide levels in sediment were related to cation-exchange capacity, and some rudimentary models were proposed. A considerable amount of information on sediment particle size and mineralogy is presented *(Glenn 1973)*. Although the reported results do not include data useful for dose calculations, the report does present a discussion of river sediment processes that is very useful for conceptualizing the water-sediment-contaminant complex.

Haushild et al. (1973) reported on the study of radionuclide transport from Pasco to Vancouver. The sampling period was from January 1964 to September 1966. The three sampling locations were Pasco, Umatilla, and Vancouver. Samples were obtained three to four times per month and analyzed for both solute and particulate concentrations of the radionuclides of interest. The results are listed in an extensive set of tables in the report appendix *(Haushild et al. 1973)*. These water column concentrations were used to estimate radionuclide transport rates for eight radionuclides originating in the Hanford reactors. For 1964 *through* 1966, the combined discharges averaged 9190 curies per week at Pasco and 6630 curies per week at Vancouver. The approximate order of their abundance and the average percentage of the combined discharge were chromium-51 (96.4%), zinc-65 (2.5%), scandium-46 (0.5%), iron-59 (0.2%), antimony-124 (>0.1%), manganese-54 (>0.1%), cobalt-58 (<0.1%), and cobalt-60 (<0.1%).

A study of the radionuclide content of bed sediments (including core samples) from the Columbia River estuary was reported by Hubbell and Glenn (1973). Many measurements of gross gamma radiation were taken in situ at river cross sections spaced several miles apart. The cross sections began upstream at RM 64 and ended near the *river* mouth at RM 2. These measurements were used in inferring concentrations of individual radionuclides based on a few core samples that were counted in a laboratory. The results were used to calculate a rough estimate of the radionuclide inventory for the entire length of river sampled. The estimated total number of curies was 8700, with zinc-65 contributing 2100 curies (24%), chromium-51 contributing 5300 curies (61%), and the remainder divided about equally among scandium-46, manganese-54, cobalt-60, ruthenium-106, and zirconium/niobium-95. The results of the gamma measurements and core sample analysis are tabulated in the report appendix *(Hubbell and Glenn 1973)*.

The final project report (Haushild, Dempster, and Stevens 1975) presents the results of bed sediment analysis and inventory calculations for the Columbia River from the Hanford reactors to Longview, Washington, below Bonneville Dam. A radionuclide inventory was computed for individual reaches and for the entire length under study. For 1965, the total radionuclide inventory was 37,000 curies, of which 60% was chromium-51 and 34% was zinc-65. The *report* appendix lists radionuclide concentrations and particle-size distributions of surficial-sediment samples and gross gamma count rates of in situ sediment from the McNary reservoir to Longview, Washington. Also included are tables of core sample analysis results for reservoirs behind McNary, The Dalles, and Bonneville dams.

9.6 U.S. PUBLIC HEALTH SERVICE

Planning for this sampling program began in 1950 with meetings *attended by* USPHS staff, the USAEC, General Electric Company (Hanford), and the Columbia River Advisory Group. The purpose of the program was to develop a water-quality database for determining what effects dams would have on the Columbia River. (Several dams were either proposed or under construction at that time.) Also, the database was to be used to evaluate the effect of radioactive effluent releases from Hanford on the normal stream purification factors. The study began in 1951 and continued into 1953. The results were published in a report by Robeck, Henderson, and Palange (1954).

The principal study area was from Priest Rapids at RM 400, just upstream of the Hanford reactors, to Paterson, Washington, at RM 278 and below McNary Dam. The program was initiated on July 23, 1951, when a few samples were collected for chemical analysis. Sampling for the complete chemical, biological, bacteriological, and radiological program began on September 26, 1951, and continued into March 1953. Brief surveys were also conducted at other areas both upstream and downstream of Hanford. The downstream areas were the Bonneville reservoir; the area immediately upstream of Portland, Oregon; and the mouth of the Columbia River.

Ranges for sampling cross sections of the Columbia River were established in each study area and identified by river miles above the mouth of the river. Biological samples were generally collected in shallow water near the shorelines. Water samples were taken at three to ten points across the cross section; this was eventually standardized to five points at most locations. Water samples were collected four times *per* week. The ranges above and within the Hanford Site were sampled twice *per* month; those below the Site were sampled weekly. Biological samples were collected mostly at semimonthly or monthly intervals. All radiological results were presented as gross beta activity densities. Maximum and average gross beta activities for various types of samples at RM 362, several miles below the reactors, are shown in Table 9.3. Other fish caught and analyzed for gross beta activity included salmon, carp, chub, squawfish, bass, sunfish, crappie, and sculpin.

TABLE 9.3. Maximum and Average Gross Beta Activities at River Mile 362. Activity levels are in pCi/L for water and in pCi/g for biota.

Sample Type	Maximum	Average
Water	19	6
Plankton	80,000	20,000
Filamentous algae	13,000	6,000
Caddisfly larvae	10,000	7,000
Juvenile fish (shiners)	9,000	1,300
Adult fish (suckers)		
Bone	5,000	1,200
Muscle	1,100	300

Activity levels were also determined for a limited number of bottom mud samples collected at RM 191 (The Dalles, Oregon), RM 167 (Hood River, Oregon), and RM 150 (Bonneville reservoir). Gross beta activity varied from 13 to 210 x 10^{-7} μCi/g. Alpha activity varied from 1.8 to 5.9 x 10^{-7} μCi/g.

The well-written USPHS report *(Robeck, Henderson, and Palange 1954)* presents a considerable amount of field and laboratory data. All sampling and laboratory procedures are described and sample calculations are included. The data tables are easy to read and are listed in the appendixes. Many of the results are presented graphically. A graphical comparison between Hanford Site data and USPHS results (at RM 362) for gross beta activity levels in river water and juvenile fish (shiners) indicates that USPHS results were approximately 1.5 to 2 times higher than Hanford Site data. The numerical values of the Hanford data are not listed in the report, but both sets of results are described as being representative of a cross-section location near the west shore (i.e., on the reactor side of the river). The data listed in this report will provide an independent database for comparison with Hanford monitoring results for the period 1951 *through* 1953. The year 1953 is probably the best for comparison purposes because of an extensive sampling program conducted downstream of McNary Dam.

10.0 SCREENING CALCULATIONS OF RADIATION DOSE AT VARIOUS DOWNSTREAM LOCATIONS FOR SEVERAL YEARS

A set of screening dose estimates for maximally and typically exposed individuals was prepared to provide a scoping estimate of possible radiation doses to individuals along the Columbia River that resulted from aquatic releases of Hanford-originated radionuclides. The basis of these estimates *is* the environmental monitoring data described in Sections *7.0* and *9.0* of this report. Estimates are provided here, by major exposure pathway and radionuclide, for five representative locations along the Columbia River for the years 1964 through 1966. The five locations are illustrated in Figure 10.1.

The choice of the 1964 through 1966 period for these screening dose estimates was based on several factors. First, before the 1960s, it was not easy to discriminate among the various radionuclides represented by gross beta measurements, so it was important to select a period in the 1960s. Second, data from various sources were available for the specific years selected.

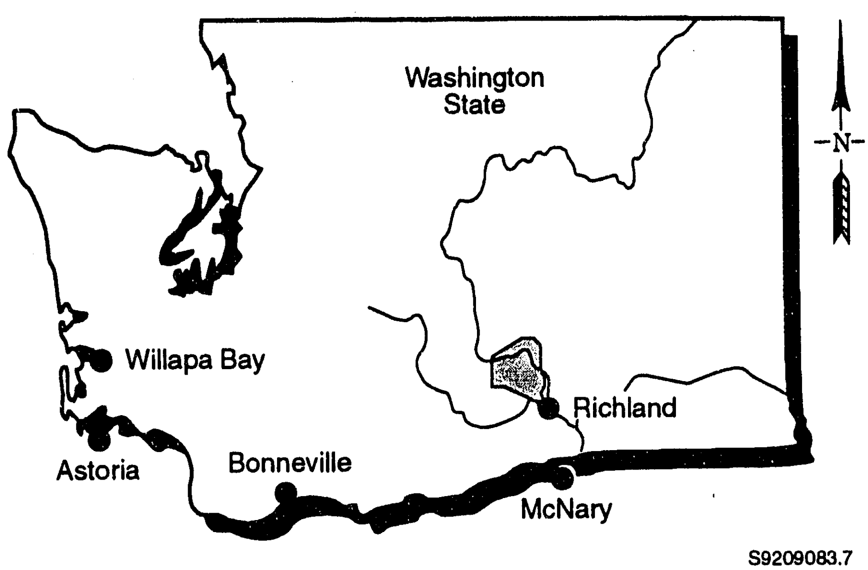


FIGURE 10.1. *Representative Locations Used for Dose Estimates*

Third, the selected period is of interest because it includes a year, 1964, when all reactors were operating and years when some reactors were shut down (see Figure 5.2).

10.1 RADIONUCLIDE CONCENTRATIONS IN RIVER WATER

The literature and databases summarized in Sections *7.0* and *9.0* of this report provided information on the radionuclide content of *Columbia* River water. Monitoring was routinely performed at a few locations along the river; these monitoring points provide the most consistent and coherent set of available data. The Hanford monitoring database was queried for all samples, and the data for the Richland Pumping Station, McNary Dam, and Bonneville Dam were summarized into annual means. Data were selected for the years 1964, 1965, and 1966 to match other available sources. Data for Astoria, Oregon, for the same period are available from the Oregon State Board of Health (Toombs and Cutler 1968). Data for all radionuclides reported for the selected years are presented in Table 10.1. For Richland and the McNary reservoir, the data are shown with annual mean values derived from the monthly numbers used in HEDR Phase I calculations, as reported by Richmond and Walters (1991). In some instances, the Phase I data appear to be more complete than the monitoring data, because these values reflect Phase I modeling calculations based on effluent monitoring data and are not environmental monitoring data per se.

The radionuclide concentration values in Table 10.1 show predictable behavior; the concentration uniformly decreases with increasing distance downstream. This is most noticeable in the short-lived radionuclides, such as sodium-24, neptunium-239, or iodine-131. It is less apparent in longer-lived radionuclides, such as chromium-51 or zinc-65, for which most of the decrease can be attributed to dilution by inflowing tributaries or to uptake by and deposition in bed sediments.

Gaps in the data are noticeable; not all radionuclides are reported for all years or locations. Extrapolation was used temporally, but not spatially, to calculate dose estimates. Thus, for any one location, if a concentration of a radionuclide was reported for 1 or 2 years but not at another time,

TABLE 10.1. Annual Mean Radionuclide Concentrations at Various Locations in Columbia River Water

Location/ Radionuclide	Radionuclide Concentrations (pCi/L) 1964	1965	1966
Richland[(a)]			
Sodium-24	3500/3600	3100/3100	2600/2600
Phosphorus-32	300/170	140/120	140/140
Scandium-46	-/-[(b)]	-/-	30/-
Chromium-51	12000/8900	7000/5200	2600/3500
Manganese-56	-/2800	-/-	290/-
Copper-64	-/5100	-/770	-/1400
Zinc-65	450/250	180/240	200/210
Arsenic-76	1200/1200	1000/1100	420/740
Strontium-90	1/-	1/-	1/-
Iodine-131	19/-	10/-	18/-
Neptunium-239	-/2100	-/1200	-/880
McNary[(a)]			
Sodium-24	-/150	-/-	-/-
Phosphorus-32	70/80	50/60	80/80
Chromium-51	3500/4100	2300/2500	1850/1850
Copper-64	-/20	-/-	-/-
Zinc-65	77/77	68/75	61/62
Iodine-131	6.7/-	3.9/-	7.1/-
Neptunium-239	-/470	-/300	-/190
Bonneville[(c)]			
Phosphorus-32	28	23	23
Chromium-51	2400	1700	1300
Zinc-65	63	70	43
Iodine-131	5	3	3
Astoria[(d)]			
Phosphorus-32	-	18	11
Chromium-51	1500	930	1600
Zinc-65	<35	<35	<35
Zirconium/Niobium-95	<13	<13	<13
Ruthenium-103,106	<10	<10	<10

(a) Information on the left *of* / from Hanford Monitoring Database; on the right from Richmond and Walters (1991).
(b) Dashes (-) indicate no data available.
(c) Source: Hanford Monitoring Database.
(d) Source: Toombs and Cutler (1968).

the highest value reported was used as an estimate of the missing value. This conservative assumption was made to ascertain whether radionuclides that were not monitored could have made significant contributions to dose in the other years. Additionally, the larger of the two values was used in all calculations as an additional conservative measure.

Because the HEDR Phase I report (Richmond and Walters 1991) was one of the sources of information for the analysis, the input concentrations in this screening study are compatible with the Phase I inputs (well within a factor of two). The inputs for the Richland location are also generally compatible (within factors of two to four) with the concentrations used in the HEDR "dominant radionuclides" study (Napier 1991).

10.2 RADIONUCLIDE CONCENTRATIONS IN AQUATIC BIOTA

Large amounts of data are available for fish in the Hanford reach of the Columbia River and immediately downstream. Many of these data were used in HEDR Phase I dose calculations. However, monitoring data for biota are much more limited for areas below McNary Dam. Available data for biota in the Columbia River estuary near Astoria, Oregon, are presented in Table 10.2, for the same period as the water data in Table 10.1. The data are much more limited than the data from the Hanford reach, and only a few radionuclides and a few species are represented. Measurements of Pacific coastal biota relevant to the selected locations are summarized in Table 10.3. Because the North Head area is at the mouth of the Columbia River across from Astoria, data from North Head were used in the calculation to represent the Astoria area.

32 Essentially no data are available on radionuclide concentrations on salmon returning from the Pacific Ocean to the Columbia River to spawn (Section 9.4.2). This is partly because runs of salmon in the Columbia were greatly depleted by the mid-1960s (Becker 1985) and partly because the concentrations of Hanford-originated radionuclides in the salmon tended to be lower than in the resident fish (Jaquish and Bryce 1989). However, the limited data *provided* in *Kujala (1966)* indicate that Hanford-related *radionuclides* in Pacific salmon increased near the mouth of the Columbia. The

TABLE 10.2. Radionuclide Concentrations in Selected Monitored Biota in the Columbia River Estuary at Astoria

Biota/Radionuclide	Radionuclide Concentrations (pCi/kg) 1964	1965	1966
Flounder[a]			
Zinc-65	19,000	17,000	14,000
Sculpin (incl. bone)[a]			
Zinc-65	10,000	9,400	7,400
Crab Muscle[b]			
Zinc-65	37,000	37,000	37,000
Manganese-54	20	20	20
Chromium-51	300	300	300
Freshwater Clams[c]			
Zinc-65	-	250	250
Manganese-54	-	17	17
Cobalt-60	-	1	1

(a) Annual averages reported by Renfro, Forster, and Osterberg (1972).
(b) *From* Tennant and Forster (1969).
(c) *From* Johnson, Cutshall, and Osterberg (1966).
- *indicates no data collected.*

concentrations of zinc-65 and manganese-54 in salmon caught off the Oregon coast near Astoria and Depoe Bay approached those calculated for *resident fish* in the river at the Astoria location. The entry in Table 10.3 for herring indicates that concentrations in the salmon were essentially the same as in their primary food supply. Because many of the radionuclides of interest are obtained mainly from food-web uptake (Poston and Klopfer 1986) and because the salmon do not eat significantly once they enter the river (Poston and Klopfer

TABLE 10.3. Reported Average Radionuclide Concentrations in Selected Pacific Coastal and Ocean Biota

Biota-Location/Radionuclide	Radionuclide Concentrations (pCi/kg)					
	1963	1964	1965	1966	1967	1968
Mussels-North Head[a]						
Zinc-65	120,000	-	-	-	38,000	24,000
Mussels-Westport[a]						
Zinc-65	52,000	-	-	10,000[b]	13,000[c]	10,000
Dover Sole-Ocean[d]						
Chromium-51	-	100	-	-	-	-
Zinc-65	-	200	-	-	-	-
Oysters-Willapa Bay[e]						
Zinc-65	100,000[f]	62,000	52,000	-	-	-
Chinook Salmon-Astoria[g]						
Manganese-54	-	8	-	-	-	-
Zinc-65	-	10,000	-	-	-	-
Coho Salmon-Depoe Bay[g]						
Manganese-54	-	170	-	-	-	-
Zinc-65	-	12,000	-	-	-	-
Herring-Depoe Bay[g]						
Manganese-54	-	44	-	-	-	-
Zinc-65	-	10,000	-	-	-	-

(a) Seymour (1970).
(b) Mellinger (1966).
(c) Larsen (1970).
(d) Jonsson and Seymour (1965).
(e) Seymour (1966).
(f) Naidu (1963).
(g) Kujala (1966).
- indicates no data collected.

1986), their river-entry concentration has been assumed in this analysis to remain essentially constant as the fish migrate upstream past Astoria to Bonneville.

Although it is often an oversimplification, the concentration of radionuclides in fish can be related to the concentrations of those radionuclides in water by means of a bioaccumulation factor (pCi/kg of fish per pCi/L of water). For this screening analysis, the bioaccumulation factors developed for Phase I were used where available. Because the HEDR Phase I model used actual distributions based on the numerous available measurements of zinc-65 and phosphorus-32 in fish (PNL 1991), bioaccumulation factors for these and for the radionuclides not considered in Phase I were taken from analyses specific to Hanford and the Columbia River (ERDA 1975). The values used are shown in Table 10.4. The values used represent an average bioaccumulation across numerous species commonly caught and eaten. Each of these values is discussed below.

13,46,84 *The bioaccumulation factors used in this report are intended to represent uptake over a variety of game fish commonly caught and eaten in the vicinity of the Hanford Site. An exhaustive review of the literature was not performed in the selection of these values, but they are derived from Hanford water and fish monitoring data described in Section 7.0 and an assumed dietary breakdown of types of fish. Detailed and defensible selection of appropriate bioaccumulation factors, or equivalent methods, for each fish type will be established following TSP definition of the level of detail required for complete modeling of the river.*

TABLE 10.4. Freshwater Fish Bioaccumulation Factors *and Water Treatment Cleanup Factors* Used in this Analysis

Element	Bioaccumulation Factor	*Water Treatment Cleanup Factor*[a]
Arsenic	200.0[b]	*0.7*
Chromium	5.0[b]	*1.0*
Cobalt	330.0[c]	*0.2*
Copper	10.0[b]	*1.0*
Iodine	15.0[c]	*0.8*
Manganese	70.0[b]	*0.5*
Neptunium	25.0[b]	*0.7*
Phosphorus	170.0[c]	*0.4*
Ruthenium	10.0[c]	*0.5*
Scandium	2.0[c]	*0.3*
Sodium	1.0[b]	*0.9*
Strontium	30.0[c]	*0.2*
Zinc	64.0[c]	*0.4*
Zirconium	330.0[c]	*0.7*

(a) Napier et al. 1988.
(b) HEDR Phase I input (PNL 1991).
(c) ERDA (1975).

The bioaccumulation factor for arsenic-76 is based on measurements from the Hanford reach of the Columbia River in 1961. This factor is based on measurements from 28 fish caught between April and December. The calculated bioaccumulation ranged from 30 to 910, with a mean of about 200. For reference, the current default used in Hanford Site-related dose calculations is 300. The radiation *dosimetry* software system, GENII, was used for these calculations (Napier et al. 1988).

The bioaccumulation factor for cobalt-60 is taken from the *Energy Research and Development Administration* (ERDA 1975), based on Hanford conditions. Recommendations for cobalt-60 range from 27 to 320, based on water conditions. The value currently recommended by Poston and Klopfer (1986) is 330 for mesotropic systems (such as the Columbia River). The current GENII default is also 330.

The factor for chromium-51 is based on Hanford data from 1961. The data indicate that most fish in the Columbia River at that time were below the detection limit for chromium-51. These data provide a range of 0.8 to 5. The value of 5 was conservatively chosen at the top of the range. The current GENII default is 20.

Copper-64 has a half-life of only 12.8 hours. As a toxic metal, it would be expected to accumulate in the liver, not flesh. Hanford data indicate a value of <10 for copper-64. The value for stable copper is much higher; the GENII default is 2500.

Literature recommendations for iodine-131 bioaccumulation range from 15 (Thompson et al. 1972) to 40 (Vanderploeg et al. 1975). A value of 15 was derived for Hanford (ERDA 1975). The current GENII default is 50, derived from Poston and Klopfer's (1986) recommendation for iodine-129.

Manganese-56 has only a 2.6-hour half-life. Published values for stable or long-lived manganese reach as high as 1000. Vanderploeg et al. (1975) developed a relationship, derived from filtered Columbia River data by Silker (1964). Poston[a] suggests a value of no more than 70 for unfiltered water.

(a) Personal communication to B. A. Napier from T. M. Poston, May 1990.

The current GENII default is based on Poston and Klopfer's (1986) generic recommendation of 400.

Sodium-24 has a short half-life compared with its biological turnover time. This suggests a value of 1.0, based on rapid isotopic distribution within fish tissue fluids. Longer-lived sodium is homostatically regulated and independent of water sodium concentrations. A generic value of 70 is used as a default in GENII.

The bioaccumulation factor for neptunium-239 is based on Hanford measurements. Data from 1961 range from a minimum of about 4 to a maximum of about 40. A seasonally weighted average of 25 was used. For longer-lived neptunium, Poston and Klopfer (1986) recommend values of 50 for *piscivorous* species, 250 for planktivorous species, and 2500 for bottom feeders. The current GENII default is 500, based on this recommendation.

Actual fish monitoring data were used in Phase I calculations for phosphorus-32. The reported values of bioaccumulation range from 20 to 100,000. Many studies have reported on the Columbia River (e.g., Foster, Soldat, and Essig 1966). Soldat derived a recommended value of 170 for the Columbia River (ERDA 1975). The current GENII default for unspecified rivers is 1500 (Poston and Klopfer 1986).

Few data exist to defend a bioaccumulation value for ruthenium-106. The reported values range from 0.1 to 170. Thompson et al. (1972) recommend 10, which was used by ERDA (1975) for the Columbia River. The current GENII default is 100.

Most sources indicate a bioaccumulation factor for stable scandium of between 20 and 104. The scandium-46 value used by ERDA (1975) was 2. Poston and Klopfer (1986) indicate that this may be a reasonable value for the Columbia River. The current GENII default is 100. A sensitivity analysis for scandium-46 indicates that even using a value of 100, the dose from scandium-46 varies by only a factor of four; most exposure to scandium-46 comes from pathways other than fish. This 50-fold increase of the scandium-46 bioaccumulation factor would result in less than a 1% change in the total dose to the maximally exposed individual.[a]

Bioaccumulation of strontium-90 is directly proportional to the amount of stable calcium in water. The bioaccumulation factor can range over three to four orders of magnitude. The value recommended by Poston and Klopfer (1986) for generic freshwaters is 50; this is the GENII default. The value of 30 used in the analysis is from ERDA (1975); this is not significantly different.

Bioaccumulation for zinc-65 can range from 100 to 2500. Values reported for the Columbia River range from 4 to 40, with single values of 132 and 155 (Poston and Klopfer 1986). The current GENII default is 500. The value of 64 used in ERDA (1975) approximates the results of using *data for* 1964 *through* 1966 in Phase I. Therefore, a value of 64 was used in this analysis.

Zirconium-95 bioaccumulation ranges from 40 to 460 in freshwater (Poston and Klopfer 1986). Poston and Klopfer recommend a value of 200. The default in GENII is 200. The ERDA (1975) value of 330 for the Columbia River is near the upper end of the range.

10.3 EXPOSURE SCENARIOS AND PATHWAYS USED IN SCREENING CALCULATIONS

Humans living along the river may have been exposed to radionuclides carried in the water, deposited in the sediments, accumulated in fish and other aquatic foods, and irrigated onto soils and crops. For any one of these pathways, a wide range of exposures may have occurred to different individuals, depending on their habits and activities. For the purpose of screening the possible magnitude of exposures to individuals in the population, two basic "types" of individuals were postulated. The first is a "maximally exposed" individual, who would have relatively large exposures from each of the pathways; the second is a more "typical" individual, whose exposures would be more representative of the average population. The parameters used in the calculation for the maximally exposed individual are shown in Table 10.5, and those for the typical individual are shown in Table 10.6.

(a) See Section 10.3 of this report for discussion of maximally exposed individual.

85 TABLE 10.5. Exposure Pathway Parameters Assumed for Maximally Exposed Individuals

Pathway	Assumed Value	Notes
External Exposure		
Boating	500 h/yr	
Swimming	100 h/yr	
Shoreline	500 h/yr	
Irrigated Soil	4000 h/yr	Richland/McNary/Bonneville only
Drinking Water Consumption		
Drinking Water	730 L/yr	River locations only; HEDOP[a] default
Treatment	*No*/Yes	
Aquatic Food Consumption		
Resident Fish	40 kg/yr	Considered at all locations
Anadromous Fish	100 kg/yr	Astoria/Bonneville only
Crabs	20 kg/yr	Astoria only
Mussels	20 kg/yr	Astoria only
Clams	20 kg/yr	Astoria only
Oysters	20 kg/yr	Willapa Bay only
Holdup Times	None	Consumed same day as caught
Irrigation		Richland/McNary only
Irrigation Rate	40 in./yr	
Foliar Interception Fraction	0.25	Sprinkler irrigation
Vegetable Diet		HEDOP[a] defaults
Milk Diet		HEDOP[a] defaults
Inhalation		
Resuspension Mass Loading	$100\ \mu g/m^3$[b]	
Exposure	8760 h/yr	

(a) Hanford Environmental Dose Overview Panel (McCormack, Ramsdell, and Napier 1984).
(b) Micrograms per cubic meter.

The external exposure pathways are those for which the individual would merely have been in a location where radioactive contamination was present to receive a dose of external radiation. These include boating in contaminated water, swimming in contaminated water, standing along a shoreline where

85 TABLE 10.6. Exposure Pathway Parameters Assumed for Typical Individuals

Pathway	Assumed Value	Notes
External Exposure		
Boating	5 h/yr	HEDOP[a] default
Swimming	10 h/yr	HEDOP[a] default
Shoreline	17 h/yr	HEDOP[a] default
Irrigated Soil	100 h/yr	4 h/weekend in summer on lawns; Richland/McNary
Drinking Water Consumption		
Consumption	440 L/yr	River locations only; HEDOP[a] default
Treatment	*No*/Yes	
Aquatic Food Consumption		
Resident Fish	1 kg/yr	
Anadromous Fish	5 kg/yr	Astoria/Bonneville only
Crabs	2 kg/yr	Astoria only
Mussels	2 kg/yr	Astoria only
Clams	2 kg/yr	Astoria only
Oysters	2 kg/yr	Willapa Bay only
Holdup Times	None	Consumed same day as caught
Irrigation		Not used (except lawns)
Inhalation		
Resuspension Mass Loading	10 $\mu g/m^3$[b]	
Exposure	8760 h/yr	

(a) Hanford Environmental Dose Overview Panel (McCormack, Ramsdell, and Napier 1984).
(b) Micrograms per cubic meter.

radionuclides were *associated* with the sediments, or standing in fields or lawns irrigated with the contaminated water. The major determinant of the dose received was the concentration in the water or soils and the amount of time spent there. Irrigation is assumed only for areas upstream of Bonneville Dam in these calculations.

For the drinking-water pathway, it was assumed that the individual consumed water taken from the Columbia River. This pathway is applicable only along the river, because salt water precludes drinking from the ocean bays. In these analyses, all water has been assumed to be treated prior to consumption. The drinking water cleanup factors known to be applicable to the Richland and Pasco alum flocculation cleanup processes have been used for all locations. Only the amount of water consumed has been allowed to vary.

The assumed *consumption* rates of nonmigratory fish, salmon, and shellfish are given in Tables 10.5 and 10.6. These values are somewhat arbitrary, but are believed to be reasonable estimates for maximal and typical consumers, respectively. Although some groups may consume more than the quantities shown, their doses may be derived from direct multiples of those presented. An example of this is presented in Section 10.5.

Irrigation with water taken from the Columbia River below Hanford would not have been a pathway of exposure for many people. Most irrigation water in the area was and is taken either from the Columbia River upstream at Grand Coulee Dam or from tributary streams. The largest area irrigated with downstream water during the period of reactor operations was the Riverview area near Pasco, Washington. A few thousand people were directly affected in the Riverview area. The assumed irrigation rate of 40 inches per year is typical for Columbia Basin farming practices (McCormack, Ramsdell, and Napier 1984). Consumption rates used in the calculations are those of the Hanford Environmental Dose Overview Panel (McCormack, Ramsdell, and Napier 1984).

Inhalation was a secondary pathway, but one that may have resulted from dust blowing off irrigated land. People are assumed to have been exposed to this source all year.

The pathways and parameters selected for the maximally exposed individual for this screening analysis are consistent with the HEDR "dominant radionuclides" study (Napier 1991). This screening analysis extends the dominant radionuclides report by the addition of the typical individual.

10.4 EXPOSURE PATHWAY MODELS

The calculations were performed using the publicly available GENII computer software system (Napier et al. 1988). The GENII system is composed of seven linked computer programs and their associated data libraries. The computer programs are of three types: user interfaces, internal and external dose factor generators, and environmental dosimetry programs. All steps of code development have been documented.

10.5 DOSE RESULTS

Doses estimated for the maximally exposed individual at five locations for the period 1964 through 1966 are summarized in Table 10.7. The table presents the total estimated annual dose in *milli*rem *(mrem)*, the radionuclide or radionuclides that contributed the largest percentage of the total dose, and the

40,47,85 TABLE 10.7. Summary of Annual Doses from Columbia River Pathways for the Maximally Exposed Individual

	Effective Dose Equivalent (mrem)		
Location/Detail	1964	1965	1966
Richland	160	100	82
Dominant Radionuclide/%	Arsenic-76/34% Zinc-65/25%	Arsenic-76/49% Zinc-65/21%	Arsenic-76/40% Zinc-65/22%
Dominant Pathway/%	Fish/86%	Fish/89%	Fish/87%
Untreated Drinking Water	25	15	12
McNary	17	14	14
Dominant Radionuclide/%	Zinc-65/39% Phosphorus-32/39%	Zinc-65/46% Phosphorus-32/36%	Phosphorus-32/48% Zinc-65/39%
Dominant Pathway/%	Fish/64%	Fish/64%	Fish/65%
Untreated Drinking Water	3.1	2.3	2.0
Bonneville (with salmon)	21	21	20
Dominant Radionuclide/%	Zinc-65/90%	Zinc-65/90%	Zinc-65/90%
Dominant Pathway/%	Fish/95%	Fish/95%	Fish/95%
Untreated Drinking Water	1.2	1.2	0.8
Astoria (with salmon)	40	40	40
Dominant Radionuclide/%	Zinc-65/93%	Zinc-65/93%	Zinc-65/93%
Dominant Pathway/%	Fish + Seafood/99%	Fish + Seafood/99%	Fish + Seafood/99%
Untreated Drinking Water	0.8	0.7	0.7
Willapa Bay	16	13	13
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%
Dominant Pathway/%	Oysters/100%	Oysters/100%	Oysters/100%

exposure pathway that contributed the largest percentage of the total dose. As indicated in the table, the most important exposure pathway was consumption of nonmigratory (resident) fish. The radionuclides contributing most to dose varied slightly with distance downstream. At Richland, the most important radionuclides were arsenic-76 and zinc-65, with a significant contribution also from phosphorus-32. At locations farther downstream, the relative importance of zinc-65 increased and that of the other radionuclides decreased. This change is a direct result of the radioactive decay of the shorter-lived materials. The calculated doses also decreased as distance downstream increased, reflecting the decay and dilution of the radionuclides listed in Table 10.1. However, the dose increases slightly at Bonneville with the addition of the salmon pathway and at Astoria with the addition of shellfish. Details relating to these additional pathways are shown in Tables 10.8 and 10.9. *Doses to individual organs, with contributing radionuclides, are shown in Table 10.10.*

The total doses reported include contributions from the external pathways of swimming, boating, and exposure to contaminated soils and sediments, as well as internal doses from drinking water, eating fish, and eating irrigated foods. The notation "fish" in Table 10.7 represents nonmigratory freshwater fish. The notation "seafood" includes crabs, mussels, and freshwater clams, as well as salmon. In Tables 10.8 and 10.9, the notation "standard pathways" includes the external pathways plus ingestion of resident fish.

The doses reported in Table 10.7 reflect an assumed consumption rate of 40 *kilograms per year (kg/yr)* of resident fish. However, concerns have been expressed that a few individuals may have subsisted on a diet consisting almost entirely of fish. For the extreme case of an individual eating 1 *kilogram per day (kg/d)* of fish, a total effective dose of about 1.3 rem/yr may be derived for the year 1964 at Richland. This is probably an upper bound, because a significant fraction of this dose is caused by short-lived radionuclides (e.g., arsenic-76); the decay that occurs between catching and eating the fish has not been accounted for in this calculation.

48 The doses estimated for typical individuals at the five locations for the period 1964 through 1966 are summarized in Table 10.*11*. *Details of organ dose*

40,47 TABLE *10.8*. Detail of Annual Doses Reported in Table 10.7 for *the Maximally Exposed Individual at* Bonneville

	Effective Dose *Equivalent (mrem)*		
	1964	1965	1966
Standard Pathways	*5.1*	*5.0*	*3.7*
Dominant Radionuclide/%	Zinc-65/55%	Zinc-65/64%	Zinc-65/51%
Dominant Pathway/%	Fish/93%	Fish/93%	Fish/94%
Salmon	*16*	*16*	*16*
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%

40,47 TABLE *10.9*. Detail of Annual Doses Reported in Table 10.7 for *the Maximally Exposed Individual at* Astoria

	Effective Dose *Equivalent (mrem)*		
	1964	1965	1966
Standard Pathways	*4.4*	*4.3*	*4.0*
Dominant Radionuclide/%	Zinc-65/41%	Zinc-65/42%	Zinc-65/45%
Dominant Pathway/%	Fish/90%	Fish/90%	Fish/90%
Crab/Mussel/Clams	*20*	*20*	*20*
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%
Salmon	*16*	*16*	*16*
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%

are provided in Table 10.12. Because the typical individual *was assumed to have* eaten very *small quantities of* fish, the doses were dominated by the drinking-water pathway. From 70% to 80% of the dose estimated for the typical individual *results from* drinking water derived from the Columbia River. The cities of Richland, Pasco, and Kennewick were and are the main users of Columbia River water for public drinking supplies. A few small towns downstream of these cities also use the Columbia River as a source of water. Because the drinking-water pathway dominated, the spectrum of important radionuclides was slightly different from that for the maximally exposed individual: arsenic-76, neptunium-239, and zinc-65 were important in the regions nearest Hanford. As the short-lived arsenic-76 and neptunium-239 decayed, the zinc-65 and phosphorus-32 remained at the downstream locations.

40.47 TABLE 10.10. *Organ Doses from Columbia River Pathways for the Maximally Exposed Individual*

Location/Organ[a]	Dose (mrem)		
	1964	1965	1966
Richland			
EDE	160 As, Zn[b]	100 As, Zn	82 As, Zn
RBM	150 P, Zn	75 P, Zn	70 P, Zn
GI-LLI	700 As, Np	530 As	380 As
Thyroid	120 I, Zn	65 I	95 I
McNary			
EDE	17 Zn, P	14 Zn, P	14 P, Zn
RBM	32 P	26 P	30 P
GI-LLI	53 Np, P	39 P, Np	37 P, Np
Thyroid	34 I	23 I	35 I
Bonneville (without salmon)			
EDE	5.1 Zn	5.0 Zn	3.7 Zn
RBM	9.2 P, Zn	8.6 P	7.3 P
GI-LLI	9.1 Np, P	8.5 P, Np	7.0 P, Np
Thyroid	12 I	8.3 I	7.4 I
Astoria (without salmon or seafood)			
EDE	4.4 Zn, P	4.3 Zn, P	4.0 Zn
RBM	5.8 P, Zn	5.8 P, Zn	4.4 P
GI-LLI	1.3 Zn, P	13 Zn, P	11 Zn, P
Thyroid	1.5 Zn	1.5 Zn	1.4 Zn
Salmon (Bonneville and Astoria)			
EDE	16 Zn	16 Zn	16 Zn
RBM	20 Zn	20 Zn	20 Zn
GI-LLI	22 Zn	22 Zn	22 Zn
Thyroid	14 Zn	14 Zn	14 Zn
Clams/Crabs/Mussels (Astoria)			
EDE	20 Zn	20 Zn	20 Zn
RBM	25 Zn	25 Zn	25 Zn
GI-LLI	27 Zn	27 Zn	27 Zn
Thyroid	18 Zn	18 Zn	18 Zn
Willapa Bay (oysters)			
EDE	16 Zn	13 Zn	13 Zn
RBM	20 Zn	17 Zn	17 Zn
GI-LLI	22 Zn	18 Zn	18 Zn
Thyroid	14 Zn	12 Zn	12 Zn

(a) For organs, EDE = effective dose equivalent, RBM = red bone marrow, GI-LLI = gastrointestinal tract - lower large intestine.
(b) Radionuclides that together add up to over 50% of the dose to this organ; Zn = zinc-65, P = phosphorus-32, I = iodine-131, Np = neptunium-239, and As = arsenic-76.

40,47,85 <u>TABLE *10.11*</u>. Summary of Annual Doses from Columbia River Pathways for the Typical Individual

Location/Detail	Effective Dose Equivalent (mrem) 1964	1965	1966
Richland	7.8	5.1	4.2
Dominant Radionuclide/%	Arsenic-76/26% Neptunium-239/22% Zinc-65/19%	Arsenic-76/35% Neptunium-239/20%	Arsenic-76/29% Sodium-24/18% Neptunium-239/17%
Dominant Pathway/%	D. Water/72%	D. Water/68%	D. Water/70%
Untreated Drinking Water	15	9.0	7.5
McNary	1.0	0.8	0.7
Dominant Radionuclide/%	Neptunium-239/40% Zinc-65/27%	Neptunium-239/32% Zinc-65/32%	Phosphorus-32/31% Zinc-65/28%
Dominant Pathway/%	D. Water/87%	D. Water/83%	D. Water/80%
Untreated Drinking Water	1.9	1.4	1.2
Bonneville (without salmon)	0.4	0.4	0.3
Dominant Radionuclide/%	Zinc-65/53%	Zinc-65/66%	Zinc-65/54%
Dominant Pathway/%	D. Water/70%	D. Water/70%	D. Water/70%
Untreated Drinking Water	0.7	0.7	0.5
Astoria (without salmon)	0.3	0.3	0.3
Dominant Radionuclide/%	Zinc-65/46% Phosphorus-32/19%	Zinc-65/48% Phosphorus-32/20%	Zinc-65/50%
Dominant Pathway/%	D. Water/70%	D. Water/70%	D. Water/71%
Untreated Drinking Water	0.5	0.4	0.4
Astoria Shellfish	2.0	2.0	2.0
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%
Ocean Salmon	0.8	0.8	0.8
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%
Willapa Bay	1.6	1.3	1.3
Dominant Radionuclide/%	Zinc-65/99%	Zinc-65/99%	Zinc-65/99%
Dominant Pathway/%	Oysters/100%	Oysters/100%	Oysters/100%

The screening doses presented in Tables 10.7 and *10.11* are generally compatible with the HEDR Phase I results for Richland and McNary (PNL 1991), as well as with results of the HEDR "dominant radionuclides" study for Richland (Napier 1991). All results for the typical individual are within a factor of two of the median doses reported in the Phase I Columbia River

40,47 *TABLE 10.12*. *Organ Doses from Columbia River Pathways for the Typical Individual*

Location/Organ[a]	Dose (mrem)		
	1964	1965	1966
Richland			
EDE	7.8 As, Np, Zn[b]	5.1 As, Na, Zn	4.2 As, Na, Np
RBM	6.0 P, Zn	3.3 P, Zn	3.0 P, Zn
GI-LLI	39 As, Np	28 As, Np	20 As, Np
Thyroid	13 I	6.7 I	11 I
McNary			
EDE	1.0 Np, Zn	0.8 Zn, Np	0.7 P, Zn
RBM	1.2 P	1.0 P	1.1 P
GI-LLI	5.0 Np	3.3 Np	2.6 Np, P
Thyroid	4.0 I	2.5 I	4.2 I
Bonneville (without salmon)			
EDE	0.4 Zn	0.4 Zn	0.3 Zn
RBM	0.5 P, Zn	0.5 Zn, P	0.4 P, Zn
GI-LLI	0.5 Zn, P	0.5 Zn, P	0.4 P, Zn
Thyroid	2.9 I	1.9 I	1.8 I
Astoria (without salmon)			
EDE	0.3 Zn, P	0.3 Zn, P	0.3 Zn, P
RBM	0.4 P, Zn	0.4 P, Zn	0.3 Zn, P
GI-LLI	1.0 Zn, Ru	1.0 Ru, Zn	0.9 Zn, Ru
Thyroid	0.1 Zn	0.1 Zn	0.1 Zn
Salmon (Bonneville and Astoria)			
EDE	0.8 Zn	0.8 Zn	0.8 Zn
RBM	1.0 Zn	1.0 Zn	1.0 Zn
GI-LLI	1.1 Zn	1.1 Zn	1.1 Zn
Thyroid	0.7 Zn	0.7 Zn	0.7 Zn
Clams/Mussels/Crabs (Astoria)			
EDE	2.0 Zn	2.0 Zn	2.0 Zn
RBM	2.5 Zn	2.5 Zn	2.5 Zn
GI-LLI	2.7 Zn	2.7 Zn	2.7 Zn
Thyroid	1.8 Zn	1.8 Zn	1.8 Zn
Willapa Bay (oysters)			
EDE	1.6 Zn	1.6 Zn	1.6 Zn
RBM	2.0 Zn	2.0 Zn	2.0 Zn
GI-LLI	2.2 Zn	2.2 Zn	2.2 Zn
Thyroid	1.4 Zn	1.4 Zn	1.4 Zn

(a) For organs, EDE = effective dose equivalent, RBM = red bone marrow, GI-LLI = gastrointestinal tract - lower large intestine.
(b) Radionuclides that together add up to over 50% of the dose to this organ; Zn = zinc-65, P = phosphorus-32, Ru = ruthenium-106, I = iodine-131, Np = neptunium-239, As = arsenic-76, and Na = sodium-24.

Summary Report (PNL 1991), although they tend to be somewhat lower. All results for the maximally exposed individual are within a factor of two of the 95th percentile values reported in the Phase I report, although the results tend to be somewhat higher. Another similarity with the earlier calculations is that the organ receiving the largest dose would have been the gastro-intestinal tract, indicating the importance of the short-lived radionuclides that are not readily absorbed by the body. These similarities are expected because the water concentrations and bioaccumulation factors used are very close to the Phase I estimates.

A small possibility exists that people could have obtained a large part of their regular water supply directly from the Columbia River without processing through a municipal water treatment system. Potential organ doses resulting from drinking 1.2 liters/day of untreated water directly from the river are shown in Table 10.13. The doses shown in Table 10.13 are slightly larger than those for typical individuals in Table 10.12. This is because no treatment is assumed, as opposed to the water treatment cleanup factors from Table 10.4 applied to the typical individual, and because there would be essentially no additional holdup time prior to consumption. These factors of reduced decay time and no removal by treatment result in an estimated doubling of the drinking water dose.

The calculated external pathway doses are always quite small. The largest doses were for the maximally exposed individual in Richland. The sum from boating, swimming, shoreline exposure, and exposure to irrigated fields would always have been less than 1 mrem to the typical individual; external doses would have been less than 10% of the total for the maximally exposed individual.

85 *External dose is quite low even for persons who may have been occupationally exposed to Columbia River water or sediments. As an upper bound, a person working on submerged structures may be considered to spend 2000 hours per year submerged in the Columbia River (a full working year). The highest dose calculated would be for the Richland location for the year 1964. For this combination, the external dose would still be less than 90 mrem per year, which is only about 60% of the dose an individual could have received from*

40,47 TABLE 10.13. *Effective Dose Equivalent, Organ Doses, and Contributing Radionuclides for a Typical Individual[a] Drinking Untreated Columbia River Water*

Location/Organ[b]	Dose (mrem) 1964	1965	1966
Richland			
EDE	*15 Np, As, Zn*[c]	*9.0 As, Na, Np*	*7.5 As, Na, Np*
RBM	*[illegible]1 P, Zn*	*6.6 Na, P*	*5.7 P, Zn, Na*
GI-LLI	*77 Np, As*	*48 As, Np*	*3.6 As, Np*
Thyroid	*18 I*	*10 I*	*15 I*
McNary			
EDE	*1.9 Np, Zn*	*1.4 Zn, Np*	*1.2 Zn*
RBM	*1.8 P*	*1.5 P, Zn*	*1.6 P*
GI-LLI	*10 Np, Cr*	*6.6 Np*	*5.0 Np*
Thyroid	*5.3 I*	*3.3 I*	*5.5 I*
Bonneville			
EDE	*0.7 Zn*	*0.7 Zn*	*0.5 Zn*
RBM	*0.9 Zn, P*	*0.9 Zn, P*	*0.7 Zn, P*
GI-LLI	*1.9 Cr*	*1.5 Zn, Cr*	*1.1 Cr, Zn*
Thyroid	*4.0 I*	*2.5 I*	*2.4 I*
Astoria			
EDE	*0.5 Zn*	*0.4 Zn*	*0.4 Zn*
RBM	*0.6 Zn, P*	*0.5 Zn, P*	*0.5 Zn, P*
GI-LLI	*2.0 Cr, Ru*	*1.8 Ru, Cr*	*1.9 Cr, Ru*
Thyroid	*0.2 Zn*	*0.2 Zn*	*0.2 Zn*

(a) A typical individual is assumed to drink 1.2 liters of water per day. Doses resulting from other consumption rates can be obtained by direct ratio.
(b) For organs, EDE = effective dose equivalent, RBM = red bone marrow, GI-LLI = gastrointestinal tract - lower large intestine.
(c) Radionuclides that together add up to over 50% of the dose to this organ; Zn = zinc-65, P = phosphorus-32, Cr = chromium-51, Ru = ruthenium-106, I = iodine-131, Np = neptunium-239, As = arsenic-76, Na = sodium-24.

consumption of resident fish. It is likely that few people would have been exposed via this prolonged exposure. This pathway is considered in the recommendations to the TSP for future work on the river pathway (Napier and Brothers 1992a, 1992b).

The dose from ingestion of irrigated crops would also have been small. The largest calculated dose to a maximally exposed individual, who consumed nearly 500 kilograms of vegetables and milk, was less than 10% that of eating 40 kilograms of resident fish. An individual who was typical in all respects except for irrigating a garden and eating predominantly from it would have received, at most, double the dose from the drinking-water pathway.

Dose from inhalation of resuspended soil contaminated by irrigation water was negligible: less than one one-millionth of the dose from eating fish.

Although calculations for drinking water give a dose that is only 5% to 10% as large as that calculated for the maximally exposed individual from eating fish, drinking water would have been the major pathway for the majority of the population, represented by the typical individual. The drinking-water doses estimated here for "typical" individuals are all within a factor of two of those reported in the 1964, 1965, and 1966 Hanford Site annual reports (Foster and Wilson 1964; Foster, Soldat, and Essig 1966; Honstead, Essig, and Soldat 1967).

The dose from eating salmon migrating up the river would be about the same as the dose from eating an equivalent amount of resident fish at Astoria. Because the salmon did not eat, and therefore presumably did not greatly increase in radionuclide concentration as they migrated upstream, they would probably have contributed a pound-for-pound dose that is less than that from resident fish at locations closer to Hanford. This assumption will have to be investigated further before any definitive statements can be made about the dose resulting from salmon consumption above Bonneville Dam.

The doses reported in Tables 10.8 and 10.9 for consumption of salmon are based on an assumed consumption rate of 100 kg/yr. For the possible case of a subsistence fisherman consuming up to 1 kg/d, the dose would be about 0.7 rem/yr from zinc-65. It is possible that other radionuclides could contribute incrementally to this upper-bound estimate for locations in the river nearer to Hanford.

As described in Section 9.4, the plume from the Columbia River out into the Pacific Ocean tended to travel in a northerly direction along the

Washington coast in the winter and in a southerly direction and slightly seaward along the Oregon coast in the summer (*Frederick 1967a, 1967b*). For this reason, the concentrations of radionuclides in shellfish on the Washington coast (e.g., Willapa Bay) tended to be higher than those along the Oregon coast. The major radionuclide in Willapa Bay oysters was zinc-65. The dose resulting from consumption of the oysters would have been directly proportional to the quantity of oysters consumed. For a nominal amount of 20 kg/yr, the dose would have been around 15 mrem. A dose of the same general magnitude was attributable to consumption of 20 kg/yr each of mussels, crabs, and clams from the estuary of the Columbia River. Additional information concerning the diets of groups who *consumed* significant quantities of these foods is needed before definitive statements can be made about the doses they received. The results indicate that consumption of estuary shellfish may have been more important than consumption of resident fish, depending on the relative rates of intake.

10.6 SCALING MID-1960s DOSES TO OTHER TIMES

33 Radionuclide monitoring data are most comprehensive for the decade of the 1960s. Before that time, there was no technology for easily discriminating among the various radionuclides represented by the gross beta measurements. It is therefore much more difficult to piece together a complete picture of contaminants in the river for periods earlier than about 1960. *Monitoring data alone do not allow estimation of doses like those in Tables 10.7 through 10.10 for periods other than the mid-1960s or for locations other than those used in these calculations. The HEDR Project staff have recommended to the TSP that additional modeling activities be undertaken (Napier and Brothers 1992a, 1992b) to allow additional calculations to be made. Until such activities are begun*, however, a rough estimate can be made on the basis of the gross beta measurements. Annual total beta measurements derived from the literature are presented in Table *10.14*. The initial construction of the reactors in the late 1940s and early 1950s, the increase in individual reactor power levels in the late 1950s, and the gradual shutdown of the reactors in the late 1960s are all reflected in the Columbia River total beta measurements shown in Table *10.14*. If the individual doses are assumed to scale in rough

TABLE *10.14*. Annual Average Total Beta Concentrations, Columbia River at Pasco, Washington

Year	Concentration (pCi/L)	Reference
1945	470	Clukey (1957)
1946	210	Clukey (1957)
1947	180	Clukey (1957)
1948	110	Clukey (1957)
1949	220	Clukey (1957)
1950	520	Clukey (1957)
1951	990	Clukey (1957)
1952	1,410	Clukey (1957)
1953	2,120	Clukey (1957)
1954	1,750	Clukey (1957)
1955	2,160	Clukey (1957)
1956	3,000	Clukey (1957)
1957	5,080	Clukey (1957)
1958	9,150	Junkins and McConiga (1959)
1959	9,400	Foster and Junkins (1960)
1960	11,000	Nelson (1961)
1961	11,000	Nelson (1962)
1962	7,500	Wilson (1964)
1963	11,000	Wilson (1964)
1964	11,000[a]	Essig (1970)
1965	8,250[a]	Essig (1970)
1966	5,700[a]	Essig (1970)
1967	6,200[a]	Essig (1970)
1968	4,100[a]	Essig (1970)
1969	3,400[b]	Ballinger and Hall (1991)
1970	1,600[b]	Ballinger and Hall (1991)
1971	100[b]	Ballinger and Hall (1991)

(a) Based on number of operating reactors and ratios to phosphorus-32 and zinc-65.
(b) Based on number of reactor operating months.

proportion to the beta measurements, this table provides evidence that the largest doses probably occurred in the late 1950s through the mid-1960s.

As an example of scaling of the doses based only on the gross beta measurements, an attempt is made to predict the dose to a maximally exposed individual in 1966 in Richland on the basis of the estimated 1964 dose reported in Table 10.7 and the measurements in Table *10.11*. The 1964 dose estimate is 0.16 rem. The 1964 and 1966 annual average gross beta measurements are 11,000 and 5700 pCi/L, respectively. The estimate for 1966 can be calculated as

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$$(0.16\ \text{rem})\ \frac{5700\ \text{pCi/L}}{11{,}000\ \text{pCi/L}} = 0.083\ \text{rem}$$

The calculated estimate from Table 10.7 is 0.082 rem, indicating reasonable accuracy by this technique. Because reactor operating parameters and water treatment changed over time, it is probable that estimates for earlier years will not be as good as this example. Also, because the mix of radionuclides changes with radiological decay downstream of Richland, this technique will not work as well for the downstream locations. However, this example provides some evidence for the conclusion that scaling on gross beta concentrations provides an indication of the relative magnitude of the possible doses.

1,5,7,9,10,11

11.0 DISCUSSION AND RECOMMENDATIONS

The operational period for the eight original Hanford reactors was 1945 to 1971. The period from 1945 through 1956 was one of gradually increasing radionuclide concentrations in Columbia River water. This corresponded to the increase in the number of reactors from three in 1945 to eight by April 1955. Between 1957 and 1965, the activity in the river increased significantly, reaching an annual maximum sometime between 1959 and 1965. This increase in concentrations resulted from increased power levels and is reflected in Figure 7.1, which shows the annual average total beta concentration in river water at Pasco, Washington. Between 1965 and 1971 the reactors were shut down one by one, significantly decreasing activity levels in the river.

Within any one year, there was also a wide range of activity at the river monitoring stations. This variation was partly due to activation of natural elements in the river water (Section 5.2) and chemical additives (Section 5.3). Other lesser causes, related to reactor operations, were the occurrence of fuel element ruptures (Section 5.5.2) and the purging of reactor piping (Section 5.4). An indication of this variability is illustrated in Figure 5.3, which shows monthly averaged daily release rates of beta activity from the reactors at the point of release to the river.

An instream river process affecting water concentrations was the uptake and release of radionuclides by river sediment as discussed in Section 9.5. After the effluent was discharged into the river, radionuclides such as zinc-65 were sorbed by suspended and bed sediments (primarily sand, silt, and clay). During low flow periods, much of the suspended sediment was deposited in areas of reduced velocity. This is particularly true of the estuary where large volumes of sediment can accumulate. As a result, when river flows were high, resuspension of deposited sediments yielded higher than expected radionuclide concentrations in the water.

The combined effect of the many variables involved in effluent activity was evidently the reason why early efforts by Hanford contractors failed to provide a reliable relationship between reactor power levels, river flow, and *downstream concentrations within the Hanford reach. Also, there was the effect of the effluent plume (as discussed in Section 8.1) that resulted in variation in measured concentrations across the channel upstream of Pasco.*

Another set of variables, apart from reactor operations and sediment, are downstream travel time and radionuclide decay. The data shown in Table 8.1 indicate a considerable variation in peak concentration travel time (e.g., 3.6 to 14.6 days to Vancouver) depending on whether the river discharge was low, medium, or high. The travel times are representative of 1964 when McNary, The Dalles, and Bonneville dams were operating. Before McNary and The Dalles dams were constructed, less travel time was required to reach downstream locations, but travel time data for that period are not available. Considering the short half-life of some radionuclides (e.g., phosphorus-32 = 14.28 days), travel time and the rate of radionuclide decay certainly had some effect on downstream concentrations.

11.1 <u>ADEQUACY OF MONITORING DATA</u>

The monitoring data for the Hanford reach, from the reactors downstream to Pasco, have more continuity over the 1945-1990 time period than any other location. Some gaps exist in the data, but they are minimal. The one shortfall in the Hanford reach data (and the lower river) is the lack of concentrations of individual radionuclides for water, sediment, and biota before 1958. For the years previous to 1958, the concentrations are reported as total beta and are not readily usable in dose calculations.

The most significant gap in the monitoring data is for the early years downstream of Pasco, because sampling was not extended below that location until after 1950. Many of the Native American fishing grounds were apparently located along the river below Pasco and upstream of The Dalles, Oregon, with the major fishing ground at Celilo Falls (Section 3.2). There were other fishing grounds outside of this reach, and these will need to be identified by the Native Americans and TSP as locations for dose calculations. Although there were no sampling stations at the known Native American fishing grounds, some data (water and sediment concentrations) exist at locations in the general vicinity after 1950.

During the 1950s and later, the nearest water sampling station to the Celilo Falls fishing ground was at The Dalles, Oregon, about 10 to 15 river miles downstream of the falls. Water samples were collected for the years 1953, 1955, 1957, and 1963-1964 by Hanford contractors. Water and sediment were sampled by the state of Oregon at The Dalles Dam from 1961 and on into the 1970s, which provides some data for that vicinity during the last years of operation of the original eight Hanford production reactors. However, the monitoring by the state of Oregon was after Celilo Falls was inundated by The Dalles Dam and reservoir system and fishing activity had moved elsewhere.

The effluent plume data, consisting of measured water temperature and radionuclide concentrations, provide a reasonably accurate description of the plume boundaries and dispersion. Although gaps in the data exist, there may be sufficient data to develop a downstream dispersion relationship for the plume from the reactors to Pasco. Downstream of Pasco, mixing is essentially complete.

The shoreline exposure data, including that received in boating activities, appear to be sufficient enough in the Hanford reach to provide a reasonably accurate estimate of exposure over the time period of interest. Interpolation between survey time periods should provide reasonable values of exposure rates for use in the HEDR Project. A final decision on the use of these data should come from the dose calculation task.

Background radioactivity measurements for the Columbia River are very limited. The sampling stations at Wills' Ranch and above 100-B are available (one or the other) from 1945 through 1957 and 1959. Samples were collected at Priest Rapids Dam from 1966 through 1969. These three stations are located above the reactors and would be representative of the river just above Hanford. Background radioactivity would be expected to vary along the 390-mile length from the reactors to the mouth because of international weapons testing and local geology. No estimates of these concentrations were found. The Yakima River samples are not considered representative of the Columbia River since the Yakima originates in a completely different drainage area.

Routine sampling of fish began about 1950 in the Hanford reach, especially near the reactor sites. The early sampling could also be considered as exploratory since little was known about the uptake and effects of radioactivity on biota. The sampling and studies of biota gained momentum during the 1950s and were extended to the mouth of the Columbia River. Offsite agencies commenced sampling during the 1960s, primarily in the lower river and coastal areas. The databases from the collection of sampling programs and studies are numerous and need to be combined into a common database to evaluate the data for dose calculations. Data on concentrations of radioactivity in biota have the same problem as water and sediment data in that all results before 1958 are reported in total beta activity.

11.2 COMPARISON OF SAMPLING METHODS

The very first methods of sampling and analyzing water, sediment, and biota were not discussed in the reports (only a few exceptions); only the data were listed and discussed. The Hanford reports do not provide any details on sampling procedures and laboratory analysis techniques used in producing the database of concentrations. There are unpublished laboratory notebooks and other documents that could be reviewed and evaluated, but this would be a large effort beyond the scope of this report.

A qualitative assessment of the monitoring program from the early days up to the 1960s is that it involved a certain amount of trial and error sampling. The Hanford Site had no clear guidelines to follow, and detection equipment was still being developed. Hanford contractors were not sure of exactly how radioactivity was distributed in the river and where sinks (such as sediment uptake) in the system occurred. As the work progressed, experience was gained, sampling methods were refined, and equipment was developed to identify specific radionuclides.

The USPHS database for 1951 through 1953 provides an opportunity to compare Hanford results with an independent source. The best year for comparison is 1953 because of the extent of sampling results from both sources. Comparisons for other years in the 1960s may be possible depending on compatibility of sampling locations and times.

11.3 RELIABILITY OF REPORTED DATA

The known databases, and those found during the course of the literature review, were developed by different individuals and groups. The sampling and laboratory analysis procedures were not described in the Hanford documents. The methods were described in varying degrees of detail in the offsite documents. However, the methods and procedures were not necessarily the same for all agencies.

To determine the reliability and to estimate the uncertainty of the reported data requires a considerable effort beyond the scope of this report. Such an effort requires the development of a computerized database for the 1945 to 1990 time period that includes onsite and offsite databases. A computerized onsite database is available for the years beginning in 1971, but all prior data are still in hard copy form (annual reports and other documents).

11.4 RECOMMENDATIONS

The following recommendations are offered based on a preliminary evaluation of data and information found in the Hanford and offsite literature:

- *Use simple routing techniques using flow time data, tributary inflows, and decay rates for 2 or 3 isotopes of interest. Select a year where at least some data exist for the lower river. The results would be used to develop a conceptual river system model as a forerunner to reconstruction modeling.*
- *Use a one-dimensional hydraulic model to route effluent from the reactors and to reconstruct water concentrations at downstream locations where dose is to be estimated.*
- *Use source term data to reconstruct specific radionuclide concentrations in water for locations of interest downstream of Pasco. Evaluate the results with Hanford and offsite agency monitoring data where possible.*
- *Use source term data to reconstruct specific radionuclide concentrations in water for locations upstream of Pasco for the years of interest before 1958.*
- *Investigate the uptake and release of radionuclides using hydraulic routing and measured data to determine if an empirical relationship can*

be developed. The relationship will be used to estimate concentrations of specific radionuclides at locations where sediment contributes to the concentration during high discharges and where bottom sediment concentrations are needed for bioaccumulation work.

- *Use the measured effluent plume data, together with routine monitoring data, to develop an empirical relationship for estimating plume concentration in the Hanford reach above Pasco.*

- *Develop a comprehensive historical database for all river and coastal water and sediment sampling stations from both Hanford and offsite sources.*

- *Develop a comprehensive database for biota from both Hanford and offsite sources to include bioaccumulation factors. The database would be used to determine the adequacy of the data for dose calculations and follow-on work.*

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APPENDIX A

COLUMBIA RIVER HYDROLOGIC DATA SOURCES

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COLUMBIA RIVER HYDROLOGIC DATA SOURCES

This appendix summarizes the major sources of hydrologic, hydraulic, and other related data that describe the Columbia River flow regime and provide data for transport calculations. Some sources contain river data specific to the Hanford Site, while others include water-quality data (e.g., sediment, water temperature) or fish and wildlife information. Because several categories of data and information are often included in the separate references, each reference is listed individually with a brief summary of the kinds of pertinent data and information it contains.

1. *Williams, J. R., and H. E. Pearson. 1986.* Streamflow Statistics and Drainage-Basin Characteristics for the Southwestern and Eastern Regions, Washington, Volume II: Eastern Washington. USGS Open-File Report 84-145-B, U.S. Geological Survey, Denver.

Monthly discharge for all years of record for the U.S. Geological Survey gauging stations on the Columbia River and its tributaries.

2. Woods, V. W. 1954. A Summary of Columbia River Hydrographic Information Pertinent to Hanford Works, 1894-1954. HW-30347, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Daily discharge (in cubic feet per second) at the Trinidad, Washington, gauge (river mile [RM] 441), about 50 miles upstream of Hanford, from January 2, 1943, to December 31, 1953. Various staff gauges at the Hanford Site were calibrated relative to the Trinidad discharge readings, assuming negligible drainage basin inflow between Trinidad and the Hanford gauges. The Hanford gauges used mean sea level as datum. Evidently, temporary gauges were set at four locations until others could be permanently established at the 100-B, 100-D, and 100-F areas. The gauge locations (daily readings) and periods of record are as follows:

Location	Period of Record
Coyote Rapids	July 7 *through* December 31, 1943
Wahluke	July 9 *through* December 26, 1943
White Bluffs	July 5 *through* December 30, 1943
Hanford	July 8 *through* December 30, 1943
181-B Pumphouse	July 15, 1944, *through* December 31, 1953
181-D Pumphouse	March 1, 1944, *through* December 8, 1944[(a)]
	March 2, 1944, *through* December 31, 1953
181-F Pumphouse	July 1, 1944, *through* November 4, 1944[(a)]
	April 24, 1945, *through* December 31, 1954

(a) Intermittent readings taken during construction.

3. General Electric Company. 1962. A Compilation of Basic Data Relating to the Columbia River. HW-69368, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Compilation of all river data, both published and unpublished, including such categories as river flows, radioactivity, sediment, effluent studies, water quality, and possible effects of Hanford effluent on river biota. Examples of *water-quality* variables are temperature, pH, and turbidity. Most of the data were collected near the reactor areas. Other locations were Trinidad, Priest Rapids, Richland, and the McNary reservoir.

4. Honstead, J. F., J. W. Healy, and H. J. Paas. 1951. Columbia River Survey Preliminary Report. HW-22851, General Electric Company, Hanford Works, Richland, Washington.

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Water samples, depth soundings, and velocity measurements were taken concurrently at about 19 locations between 100-B and Pasco, Washington, at three different flow conditions (rising hydrograph, peak flow, and stable low flow). A fourth survey was conducted below a single reactor during a time when it was the only effluent source. The data are presented as river cross sections with velocity contours (isovels). Analysis of the water samples provided data for plotting the profile of the effluent plume.

6. U.S. Army Corps of Engineers. 1949. Report on Flood of May-June 1948. Columbia River and Tributaries (Upstream from Snake River). Seattle District, Seattle.

Flood hydrographs of the upper Columbia River and tributaries, increments of the lower Columbia River flood peak at The Dalles, and a water-surface profile for July 21, 1949.

7. Robeck, G. G., C. Henderson, and R. C. Palange. 1954. Water Quality Studies on the Columbia River. U.S. Department of Health, Education, and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati.

a. Discharge and river stage curves for Columbia River near Hanford and near Umatilla for July 1951 - June 1953.

b. Flow time curves for the Columbia River from RM 368.5 (reactor area) to RM 292 (McNary Dam site) for discharges ranging from 46,000 to 500,000 cubic feet per second. Curves were developed for conditions before and after impoundment by McNary Dam.

c. Routine physical and chemical measurements of water quality, including turbidity, temperature, and pH. Readings were taken approximately once weekly from January 1951 to February 1953 for about 12 cross sections between Priest Rapids and the McNary Dam. Measurements were also taken on the Yakima River at Kiona, Enterprise, and the *West* Richland Highway bridge; on the Snake River at Page and near the mouth; and on the Walla Walla River at the US Highway 410 bridge and the US Highway 395 bridge. The turbidity and temperature data are plotted.

8. Columbia River Estuary Data Development Program

The Columbia River Estuary Data Development Program was a 6-year program of study authorized by the U.S. Congress in October 1978 and completed in 1984. The objectives were to increase understanding of the ecology of the Columbia River estuary and to provide information useful in making decisions about land and water use. The research was divided into 13 work units. Three of the units described and mapped the productivity and biomass patterns of the estuary's primary producers and their levels.

Seven units dealt with the higher trophic levels in the estuarine food web. These included zooplankton and larval fish, benthic infauna, epibenthic organisms, fish, avifauna, wildlife, and marine mammals. The goals of these units were to describe and map the abundance patterns of the invertebrate and vertebrate species and their relationships to physical factors.

The other three work units are, perhaps, the most relevant to the *Hanford Environmental Dose Reconstruction* Project. These units dealt with sedimentation and shoaling, currents, and circulation. The goals were to characterize and map the bottom sediment distribution, to characterize sediment transport, to determine the causes of bathymetric change, and to determine and model circulation patterns, vertical mixing, and salinity patterns. Included with these reports is a detailed set of planform and bathymetric maps and portfolios.

9. River Maps and Cross Sections

Various sets of river channel maps and cross sections are available from the U.S. Army Corps of Engineers North Pacific Division Office in Portland, Oregon, and from district offices in Walla Walla, Washington; Seattle, Washington; and Portland, Oregon.

a. 1894 - river surveys and depth soundings.

b. 1955 - detailed sounding measurements in maps PD-7-24/0 to PD-7-24/22.

c. 1963 - Columbia River longitudinal channel profile.

d. 1986 - 145 cross sections from Priest Rapids to the Yakima River.

Navigation charts of the Columbia River from Priest Rapids Dam to the mouth are available from the U.S. Coast and Geodetic Survey.

10. Sedimentologic Data

The primary sources for these data are the U.S. Geological Survey and the U.S. Army Corps of Engineers division and district offices.

a. Daily record of water discharge, sediment concentration, and total sediment discharge for the following locations and dates:

Location	Date
Columbia River at Pasco	August 1962 *through* September 1966
Snake River at Pasco	August 1962 *through* September 1964
Columbia River at Umatilla	August 1965 *through* September 1966

b. Mean weekly suspended sediment concentrations and mean weekly sand and total sediment discharges at Pasco, Umatilla, and Vancouver for 1964 through 1966.

c. Mean particle-size distribution of surficial-sediment samples from the riverbed (mid-channel and shoreward) at Pasco, Hood River, and Vancouver taken intermittently during 1962 through 1965. Each sample is dated as to the day of its collection.

APPENDIX B

TABLE OF RADIONUCLIDES *AND UNITS OF MEASURE*

Table of Radionuclides

Radionuclide		Half-Life	Radiation[(a)]
Antimony-124	(^{124}Sb)	60 days	β^-, γ
Arsenic-76	(^{76}As)	26.5 hours	β^-, γ
Barium-140	(^{140}Ba)	12.8 days	β^-, e^-, γ
Cerium-144	(^{144}Ce)	284 days	β^-, e^-, γ
Cesium-137	(^{137}Cs)	30.0 years	β^-, e^-, γ
Chromium-51	(^{51}Cr)	27.8 days	e^-, γ
Cobalt-58	(^{58}Co)	71.3 days	β^+, γ
Cobalt-60	(^{60}Co)	5.26 years	β, γ
Copper-64	(^{64}Cu)	12.8 hours	β^-, e^-, β^+, γ
Europium-152	(^{152}Eu)	12 years	β^-, β^+, e^-, γ
Europium-154	(^{154}Eu)	16 years	β^-, e^-, γ
Gallium-72	(^{72}Ga)	14.12 hours	β^-, γ
Iodine-129	(^{129}I)	1.7×10^7 years	β^-, e^-, γ
Iodine-131	(^{131}I)	8.05 days	β^-, e^-, γ
Iron-55	(^{55}Fe)	2.6 years	γ
Iron-59	(^{59}Fe)	45.6 days	β^-, γ
Lanthanum-140	(^{140}La)	40.22 hours	β^-, γ
Manganese-54	(^{54}Mn)	303 days	e^-, γ
Manganese-56	(^{56}Mn)	2.58 hours	β^-, γ
Neptunium-239	(^{239}Np)	2.35 days	β^-, γ, e^- (D.R.)
Niobium-95	(^{95}Nb)	35 days	β^-, γ
Phosphorus-32	(^{32}P)	14.28 days	β^-
Plutonium-239	(^{239}Pu)	24,390 years	α, e^-, γ (D.R.)
Plutonium-240	(^{240}Pu)	6,580 years	α, e^-, γ (D.R.)
Potassium-40	(^{40}K)	1.42×10^9 years	β^-, β^+, γ
Ruthenium-103	(^{103}Ru)	39.6 days	β^-, γ
Ruthenium-106	(^{106}Ru)	368 days	β^-, γ
Samarium-153	(^{153}Sm)	46.8 hours	β^-, e^-, γ
Scandium-46	(^{46}Sc)	83.9 days	β^-, γ

Table of Radionuclides			
Radionuclide		**Half-Life**	**Radiation[a]**
Sodium-24	(^{24}Na)	15.0 hours	β^-, γ
Strontium-89	(^{89}Sr)	57.7 days	β^-, γ
Strontium-90	(^{90}Sr)	28.1 years	β^- (D.R.)
Technetium-99	(^{99}Tc)	2.12×10^5 years	γ, e^-, β^-
Tritium	(^{3}H)	12.26 years	β^-
Zinc-65	(^{65}Zn)	245 days	β^+, e^-, γ
Zirconium-95	(^{95}Zr)	65 days	β^-, γ (D.R.)

(a) Conversion electrons (e^-) are listed if they are prominent in the electron spectrum. Decay products may give rise to daughter radiation. This is indicated, where prominent, by the notation (D.R.).

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UNITS OF MEASURE

cfs	cubic feet per second
Ci	curies
dpm/g	disintegrations per minute per gram
dpm/L	disintegrations per minute per liter
m^3	cubic meter
µCi/g	microcuries per gram
µCi/L	microcuries per liter
µg/m^3	micrograms per cubic meter
µR/h	microroentgens per hour
mL	milliliter
mrem	millirem
mrep/h	millireps per hour
mR/h	milliroentgens per hour
nCi/m^3	nanocuries per cubic meter
nCi/g	nanocuries per gram
ppm	parts per million
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi/kg	picocuries per kilogram
RM	river mile
rem	roentgen equivalent man

APPENDIX C

BIBLIOGRAPHY

APPENDIX C

BIBLIOGRAPHY

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APPENDIX D

SUMMARY OF TECHNICAL STEERING PANEL COMMENTS AND BATTELLE, PACIFIC NORTHWEST LABORATORIES RESPONSES

APPENDIX D

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

Document Number PNWD-2034 HEDR

Document Title Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
1.	P. C. Klingeman (PCK)	New Section 11.0	Add new section titled "Discussions and Conclusions" to tie together several items, as identified in the ET Subcommittee meeting discussion of the draft report. The items mentioned in the Subcommittee meeting as important to consider for such a new chapter include: Comparability of the methods used for the various reported studies: a) sampling methodologies, and b) measurement methodologies. In particular, a special point should be made about whether or not (and what) volatile materials might have been driven off during sampling or sample processing. The adequacy of the monitoring data for dosimetry. Where and why? The size of the data base encountered in developing this report and the relative merits (pros and cons) of assimilating the data base into a computer file for use in HEDR or by others in the future. Reliability/uncertainty of the reported data. Additional comments/discussion about fish, benthic organisms, waterfowl, etc., that could be part of food chains leading to human exposures and doses, including specific discussion of iodine doses from the water and fish.	Section 11.0 added.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			Recommendations for follow-on work that you consider to be needed so that this segment of HEDR can be completed without leaving uncertainties about the role of the river pathway in contributing to dose. For example, is there a need to use source-term information as an independent check on environmental monitoring data and, if so, for what years and locations?	
2.	PCK	Section 10.0	Section 10.0 may involve gross oversimplifications that lead to dose calculations that are not necessarily conservative. For example, 1) many radionuclides have been "culled out" before making the calculations, and 2) monitoring locations have not been shown in the report to be those locations where radionuclides are most likely to accumulate in the aquatic environment (therefore exposures from water, sediment and aquatic organisms have not been shown to be representative or even typical).	NA - The calculations were not intended to be conservative, but to address the doses to various groups in as realistic a manner as possible. The preliminary work by Napier (1991) describing dominant radionuclides indicates that those radionuclides monitored provided a large fraction of the dose for most conceivable pathways. In general, the monitoring locations were selected to determine radioactivity concentrations at specific locations of interest based on potential public exposure. Other locations were selected based on data and information needs of specific studies. Also, it was difficult to determine at the outset just where

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
				radionuclides would tend to concentrate both physically and biologically. The numerous studies discussed in Sections 8.0 and 9.0 show that a considerable effort was undertaken to do just that.
3.	PCK	General Comment	Are there discrepancies between the data sets, such as USPHS vs. Hanford monitoring?	NA - There are some apparent discrepancies between the USPHS and Hanford data shown graphically in Robeck, Henderson, and Palange (1954). This is mentioned in the last paragraph of Section 9.6.
4.	PCK	General Comment	Have you encountered in the literature review any comments that might suggest that efforts might have been made to conduct environmental monitoring at locations that would not be "unfavorable" to the Hanford operations? Did you encounter any reports that contained statements suggesting "cover-up" of unfavorable data? Are you able to judge from the literature reviewed that best scientific principles (rather than efforts at "bias") always governed where, when and how environmental monitoring occurred?	NA - We have not encountered any comments in the literature regarding the purposeful selection of monitoring locations favorable to Hanford operations or any reports that suggested a coverup of unfavorable data. An opinion as to whether the "best scientific principles" always governed where, when, and how monitoring was carried out would require further review. As in all water quality sampling of this magnitude, there is a certain amount of trial and error sampling involved.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
5.	PCK	General Comment	The monitoring locations along the Columbia River do not specifically represent locations of intensive water-related activities (fishing, etc.) by Native Americans, based on what is known about such locations. Are there recommendations for follow-up work on the river pathway to better define the likely doses at such locations?	The monitoring locations were extremely sparse below the Snake River confluence where the primary Native American activities occurred (e.g., Celilo Falls). Recommendations for follow-on work are discussed in the added Section 11.0.
6.	PCK	General Comment	What are the impacts of retention basin time (2+ hours versus 4 hours) and of receiving river discharge on doses? Have the variabilities been adequately addressed in the report? Is further work needed as source-term information becomes available?	NA - Shorter retention times increased the level of radioactivity released to the river, and this problem is being addressed by the Task 03 source term work. This report only called attention to the basin time variability.
7.	PCK	General Comment	What are background radioactivity levels for the Columbia River between Hanford and the ocean?	Samples collected at locations above the 100-B reactor (e.g., Wills' Ranch, Priest Rapids Dam) provide data on the background levels. Background levels will be addressed in Task 07 Environmental Pathways and Dose Estimates. A brief discussion of background levels is included in the added Section 11.0.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
8.	PCK	General Comment	Wherever "total beta" is mentioned in the report the text should say "total non-volatile beta" because volatiles may have been driven off during sampling and/or sample processing.	A statement that the gross beta measurements may reflect only non-volatile beta has been added in Section 6.1.
9.	J. E. Till (JET)	Pages v and 1.1	The objectives of the report were not simply to perform a literature review but to help us decide if there are sufficient data available on part or all of the river for dose calculations. This must be added up front.	NA - An in-depth evaluation of the available data was to be conducted in follow-on work as described in the last section of the Executive Summary. However, a general overview of the available data is possible and this is discussed in the Executive Summary. Another section (Section 11.0) has been added to the report in an effort to provide more discussion on the reviewed data and information.
10.	JET	General Comment	Several vital pieces are missing from the report. First, a section defining background radionuclide concentrations and exposures from natural radionuclides must be added. Background data will help us in determining how far to go with detailed dose calculations and help keep radionuclides added to the river by Hanford in perspective. I believe this information is essential. I also am certain this information is available in the literature.	See response to comment 7.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
11.	JET	General Comment	The second important piece missing is a conclusion at the end. I understand we will receive a second report that draws conclusions and makes recommendations about the next steps; however, the authors must draw some conclusions about the quality and completeness of the data.	See added Section 11.0.
12.	JET	General Comment	I expected that we would assemble some kind of data base using the historical records. As a minimum, the references should have been annotated, i.e., a brief abstract written as part of the survey. At least this should be made clear that we did not develop a data base or annotated bibliography.	NA - An annotated bibliography is beyond the scope of the report, especially considering the large number of references. The task plans for FY 1992 state that work under this task will include participation in developing a reference database that will be developed by Task 05 (see comments 7 and 25) Environmental Monitoring.
13.	JET	General Comment	It should also be clarified that the review did not include an evaluation of bioaccumulation factors for aquatic biota. I am assuming this information will be included elsewhere. The report where it will appear should be stated.	Clarifying statements have been added to the discussion of Table 10.4 in the text.
14.	G. G. Caldwell (GGC)	Page 2.2, Para. 2, Lines 4-6	The authors state that a complete presentation of the data is not feasible in this report, but they could indicate where and how other scientists and the public could access it.	NA - The intent of the statement is to qualify that only ranges of values, maximum, and averages will be quoted in the report because a complete listing of all data is

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
				impractical. The reader can find the complete database or pertinent information by reviewing the references cited in the text.
15.	GGC	Page 3.1, Para. 2, Lines 3-5	Indicates that the first radioactive effluent reached the mouth of the Columbia in "several days." I think they should be more specific, use the actual number.	NA - The actual number is not known; however, the effluent certainly traveled rapidly enough to arrive at the mouth in "several days" as compared to weeks or months. See the travel time values in Table 8.1, which include holdup time in McNary and The Dalles reservoirs.
16.	GGC	Page 4.7, Para. 1, Lines 4-5	Indicates that periphyton "could" affect external dose, but did it in fact occur?	NA - Periphyton could have increased external dose over that received from immersion in water because of the high level of radionuclide accumulation. External contact could have easily happened, but this requires an assumption to be made in the dose calculations performed under Task 07.
17.	GGC	Page 4.7, Para. 2, Lines 9-12	"May" and "could" but did these things actually happen?	NA - These processes do occur along the Columbia River.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
18.	GGC	Page 4.9, Para. 2, Line 4	What is "fall" chinook?	NA - "Fall" chinook refers to the fall season spawning run.
19.	GGC	Page 4.9, Para. 3, Line 1	What are "upper river bright stocks?"	Clarification of the upper river bright stocks (URB) has been added to Section 4.6.1.
20.	GGC	Page 4.13, Para. 2, Lines 6-7	Why was no attempt made to determine the age and radionuclide concentration? Is it important? Can age be estimated from weight and length? If so, the age/radionuclide concentration may be calculated.	NA - This was not an objective of the referenced study. Only the radionuclide concentration was to be determined.
21.	GGC	Page 5.10, Table 5.1, Last line	Should "thoria" be "thorium"?	NA - Thoria (thorium oxide) is the correct term.
22.	GGC	Page 5.11, Para. 1, Lines 4-6	Does the 2-3 pounds of uranium discharged from the pond include the natural uranium present in the cooling water as well?	NA - Natural uranium was not mentioned in the report by Singlevich and Paas (1949).
23.	GGC	Page 5.11, Para. 2, Lines 4-6	If 12-60 pounds of uranium was in the discharge and only trace quantities measured, where did the uranium go? Dilution? Sediment? Was there any contribution to dose, even temporarily?	NA - Dilution by Columbia River water was probably the most dominant process affecting the discharge of uranium.
24.	GGC	Page 5.13, Para. 3, Lines 8-9	If there was continuous venting and discharge on the island, were any measurements made? Was the island off limits to fishermen and hunters?	NA - The river along the reactor area was off limits to the public.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
25.	GGC	Page 5.14, Para. 2, Lines 7-10	Can an "old timer" be found to clarify the calculation procedure? Are any of Parker's notebooks available for this time period?	NA - An analysis of activity levels and variability of releases of radioactivity will be conducted under Task 03 Source Terms and published in their reports.
26.	GGC	Page 6.12, Lines 1-2	Can core samples of sediments behind the various dams be used to validate current estimates?	NA - The usefulness of the sample results will be evaluated in follow-on work; however, it is doubtful that the results could be used for validation.
27.	GGC	Page 8.3, Para. 3 Lines 1-2	Do these data include the pipe hole leaks mentioned on page 5.13?	NA - The vent holes were in an outfall pipe which discharged effluent to the river. Effluent released through the vent holes was merely part of the total effluent discharged to the river.
28.	GGC	Page 8.7, Para. 5, Lines 8-13	I think this is the answer to the pages 5.13 and 8.3 questions.	The authors agree.
29.	GGC	Page 8.10, Lines 1-5	Were any of the ruthenium flakes present?	NA - Ruthenium flakes were not mentioned in the reviewed report.
30.	GGC	Page 8.10, Para. 3, Lines 9-10	Would insertion of the equation used be helpful?	NA - The equation would serve no useful purpose for this report but may prove useful in later work.

NA - No action.

APPENDIX D

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Document Title Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
31.	P. D. McGavran (PDM)	Section 10.0	Perhaps because Section 10.0 was an "add on" some of the text reads as though no preliminary dose estimates are offered - as though Section 10.0 was not there. For example, p. xiii might say "...use to support final dose estimates..."	Clarification has been added to the text on p. xiii, last paragraph.
32.	PDM	Page 10.4, Last para.	How does Table 10.3 show that Salmon are higher near the mouth of the river? Chinook and coho, each from one location are shown in the table?	Clarification has been added to the text.
33.	PDM	End of Section 10.0	At the end of Section 10.0, there is a description of estimating doses from gross beta measurement proportions. It is not clear to me how often, to what extent this will be used, how good the quality of data is so that doses like those in Table 10.7 can be calculated for how many years? I understand that you all discussed this in subcommittee and some of these quality/data gap questions will be addressed in a letter report due in June. Perhaps this report, because it's titled "Data Review," should say this: "Quality/gaps are being assessed and will be summarized in a later report..."	Clarification has been added to the text.
34.	G. S. Roessler (GSR)	Cover	Title: I would recommend changing the title to include preliminary dosimetry. For example, "Literature, Data Review, and Preliminary Dosimetry..."	NA - The preference is to leave the title as is. The preliminary dose estimates are not the focus of the report although they tend to invite interest from the reader.

NA - No action.

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

Document Number PNWD-2034 HEDR   Document Title Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
35.	GSR	Page vii, General Comment	This is an excellent executive summary. The whole document is well done and will be a good source document. I continue to be impressed by the concise, clear manner in which these documents are written recently.	NA
36.	GSR	Page viii, Lines 2-3	Yakima River - Do you report on what the background radionuclides and levels were in the Yakima?	The Yakima River was periodically sampled. See Tables 6.1 and 6.2.
37.	GSR	Page xiii, Para. 1	Although it is explained in Section 10.0, it would be helpful to include a few lines as to why the 1964-1966 dates were chosen.	Clarification has been added to the text on page xii.
38.	GSR	Page xiii, Para. 2, Line 6	In case someone reads only this report and only the executive summary, the half lives of the radionuclides should be listed.	The half-lives are included in the original Appendix B.
39.	GSR	Page xiii, Para. 3, Lines 1-2	...eat very little fish. Like minnows? Yuk.	Clarification has been added to the text. Also see comment 48.
40.	GSR	Page xiv, Table ES.1	Suggest you use mrem. I assume these are not EDE rem.	The units in Table ES.1 and Section 10.0 tables have been revised to mrem.
41.	GSR	(Previous) Page xvii	This page is an excellent addition.	NA - See comment 63. The unit list was added to the end of Appendix B.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
42.	GSR	(Previous) Page xviii	Is this page necessary since all radionuclides are written out in the text? Do you mean ^{99}Tc or ^{99m}Tc? See B-2. Here you have ^{99}Tc but with ^{99m}Tc half-life.	Abbreviated form of radionuclides from previous page xviii has been added to Appendix B. Half-life and radiation corrected to technetium-99.
43.	GSR	Page 6.1, Para. 3	This is an important statement that needs to be supported by a reference. Also, this sentence makes one wonder when the first reactor was built. I recommend you take the first sentence under 6.1 and move it up to 6.0.	Text has been revised.
44.	GSR	Page 6.2, Para. 3, Line 1	1944? Should it be 1945?	Corrected.
45.	GSR	Page 6.11 Para. 2, Lines 3-4	Reference the Ground Water report here.	Reference added to text.
46.	GSR	Page 10.7	I agree with the comments of others on the panel that some re-evaluation needs to be made of the bioaccumulation factors.	See response to comment 13.
47.	GSR	Page 10.14, Table 10.7	Use mrem. Also on the following tables.	See response to comment 40.

NA - No action.

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

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Document Title Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
48.	GSR	Page 10.16, Line 2	...little fish. Maybe you mean sardines and not minnows.	Clarification has been added to the text. Also see comment 39.
49.	GSR	Page 10.25, Equation	Get rid of italics in units. If you are using WordPerfect and the Equation Editor, you can get rid of italics by using the following: function {equation goes here}.	Corrected. Equation moved to page 10.25.
50.	M. A. Robkin (MAR)	Page 3.1	N Reactor is described as a closed-loop cooling system and as such would not be expected to release water-borne radioactivity to the environment. The third sentence describes N Reactor radionuclides being released to the soil. It would be useful to describe where these radionuclides are coming from and why N Reactor is releasing them.	Clarification added to text.
51.	MAR	Page 3.7, Lines 10-12	The phrase "The plume extends over a latitude range of about 1000 kilometers" is unclear. Latitude is usually given in degrees, minutes and seconds. If the meaning is that the plume spreads north and south over 1000 kilometers, it should simply say so.	Clarification added to text.
52.	MAR	Page 3.7, Para. 1	What is an "ocean surface process." Why is the plume so described? If the point is that the fresh water floats on top of the salt ocean water, then just say so. What does it mean to speak about the plume "having the 'capacity'" to	Clarification added to text.

NA - No action.

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Document Title Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			transport finer sediments? If the plume is carrying fine sediments to the ocean and so transporting additional sorbed nuclides, then say so. If no such nuclide transport went on, then say so.	
53.	MAR	Page 3.8, Line 1	Change "extends" to "extend" (plural agreement).	Corrected.
54.	MAR	Page 4.4, Figure 4.2	Define "Net Plankton." "Net" can be taken two ways, i.e., as plankton trappable in a plankton net or as the net difference between two measures of plankton activity.	"Net plankton" is that caught in a plankton net. Clarification added to the figure caption.
55.	MAR	Page 4.12, Section 4.6.2	The list of resident fish conspicuously omits resident trout. Is this omission deliberate?	The omission is deliberate. There are no resident rainbow trout in the Columbia River; however, there may be some residual steelhead trout of hatchery origin. Steelhead trout are included under anadromous species in Section 4.6.1.
56.	MAR	Page 5.14, Para. 3, Lines 11-14	It would be helpful to give the date that the Priest Rapids construction began. Since the dam was not finished until 1959, most of the activity described by Figure 5.3 was produced before that.	More details on Priest Rapids Dam have been added to the text.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
57.	MAR	Page 6.9, Para. 1	Sediment is described as not being in the food chain. Bottom feeding organisms ingest sediment and sediment-borne nuclides should be considered in the pathway analysis. An estimate of the importance of this should be made to see if sediment can, indeed, be neglected.	The reference to the food chain has been removed. The original personal communication from R. F. Foster and J. K. Soldat referred to direct human consumption.
58.	S. N. Davis (SND)	Page vii, Para. 4, Line 1	Only beta activity was measured, not "radionuclide concentrations."	Text has been revised.
59.	SND	Page vii, Para. 4, Line 3	Change "to" to "of."	Corrected.
60.	SND	Page viii, Para. 1, Lines 11-12	Change sentence to read: "Also, only gross nonvolatile beta activity was measured because samples antedated gamma spectroscopy." (Antedate is preferred over predate.)	Text has been revised.
61.	SND	Page x, Last sentence	"...as the need warranted" conveys zero information. Basin retention time was shortened owing to higher power levels and the failure to modify structures to accommodate a larger discharge.	Text has been revised.
62.	SND	Page xiii, Para. 4	The data are not "...to support dose estimates." We hope that the data will provide the information needed to make rational dose estimates.	See response to comment 31.

NA - No action.

APPENDIX D

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
63.	SND	(Previous) Page xvii	Too many acronyms. Eliminate CRAG, CREDDP, HEDOP, PNRBC, and SESP.	Acronyms and abbreviations list was removed as it is not that useful.
64.	SND	Page 3.3, Para. 2, Line 1	Sentence is wordy. Suggest: "Information on the Columbia River can be obtained from numerous references of which..."	NA
65.	SND	Page 3.3, Para. 2, Line 7	"...called out..." is jargon, replace with "used."	Corrected.
66.	SND	Page 4.3, Para. 3, Last line	Use past tense. Work has been finished and report has been written. Make this correction throughout the manuscript.	Corrected.
67.	SND	Page 5.5, Para. 3, Line 5	Sodium dichromate at a concentration of 2 mg/l contributes 0.35 mg/l of sodium in solution which is only 17% of the average natural sodium in solution. The phrase "...contributed much..." is misleading.	Text has been revised.
68.	SND	Page 5.9, Para. 4, Line 1	Three fission products not two are listed.	Text has been revised.

NA - No action.

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
69.	SND	Page 5.10	Give concentration also in pCi/L to be consistent with units.	NA - Units are used as they are stated in the original reference as discussed in Section 2.0. Follow-on work will use common units.
70.	SND	Page 5.14, Para. 3, Lines 15-16 Page 5.15, Lines 1-2	Chemical conditions in the river would not allow significant variations of Mn <u>in solution</u>. Variations were, perhaps, in the suspended solids that passed through filters, although I doubt this explanation. Why not delete speculation by deleting last two sentences?	NA - The personal communication from R. B. Hall states otherwise.
71.	SND	Page 6.4 Para. 2, Last sentence	Why not use the same units throughout? Convert both alpha and beta values to pCi/L.	NA - See response to comment 69.
72.	SND	Page 7.4, Table 7.1	Check 6th value for tritium on table. Remove decimal point.	The value has been corrected to 110 pCi/L.
73.	SND	Page 10.10, Para. 3, Line 5	Without all the data, the argument for a value of 64 is not convincing. The use of the default value would almost increase the dose by a factor of 10. Because zinc is so important, this is not a trivial issue.	NA - See response to comment 13.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
74.	SND	Pages 10.10-10.13	Some Native Americans claim that large amounts of crayfish and fresh-water clams were consumed. If so, these individuals would probably be the maximally exposed group.	NA - The tribal representatives have not provided HEDR staff with any consumption rate estimates for use in this type of calculation. The available bioaccumulation data for both clams and crayfish indicate that both have uptakes of zinc and phosphorus much larger than for fish. The examples quoted in this report clearly show that these pathways can contribute significantly, even for moderate consumption rates. The "recommendations" report should clearly indicate that both fish and shellfish need to be considered.
75.	SND	Appendix B, Page B.1	Add "D.R." after Neptunium-239, Plutonium-239, and Plutonium-240.	The table has been revised.
76.	SND	General Comment	All references to beta activities should specify whether or not volatile constituents were included in the counting. From the descriptions of sample preparation which are given, I would assume that the bulk of the measurements were of nonvolatile beta radiation. The volatility of a given radionuclide prior to counting is a complex function of preparation temperature, composition of the residue, and time. Certainly, significant	See response to comment 8.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			amounts of tritium were not measured. Also all dissolved gases which might include carbon dioxide with C-14 and the radioactive noble gases would have been lost. Some or all of I-129 and I-131 might have been lost. Other radionuclides of varying volatilities which might have been partly lost are S-35, Zn-65, As-76, Br-82, Ru-106, Cd-115, and Hg-197. The potential difference between actual beta activity including volatiles and the lower measured activity should be explained.	
77.	J. Thomas (JT)	General Comment	There is no mention of contaminated waterfowl. With their exposure to the river and other surface waters and consumption of contaminated aquatic vegetation, this is a significant pathway that Battelle has ignored. Several documents report severely contaminated ducks with the primary contaminant being P-32. Historically, these samples have been assumed to come from ducks which only inhabit the effluent basins, but I am not aware of any documents which substantiate this assumption. HEDR needs to consider this as a pathway. One duck sampled in 1969 could have given a bone dose six times the exposure standard at that time.	NA - Waterfowl were potentially contaminated from both the Columbia River and the confined surface waters at the Hanford Site (retention basins, ponds, etc.), but it is impossible to determine the contribution from each potential source. Data on the concentration of radioactivity in waterfowl are currently being assembled and will be included in later reports.

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
78.	JT	Section 5.5	Section 5.5 on accidental releases has at least two important deficiencies. First, there is no mention of the PRTR accident in September of 1965 which released some contamination directly to the Columbia. The PRTR facility was located in the 300 Area. Second, the section on leaks from the retention basins does not mention a 1945 memo from Healy to Parker. In HW-3-3259, Healy discusses the possibility that the D and F basins are leaking. Neither Section 12.0 nor Appendix C of PNL-8083 list this report. If I can find this deficiency in five minutes, how many other failings are there?	A discussion of the PRTR accident has been added to Section 5.5 (ref. new Section 5.5.4). The information contained in the memo of 11/26/45 (HW-3-3259; Healy to Parker) has been added to Section 5.5.
79.	JT	Page 6.1	In Section 6.0, page 6.1, the report states: "operational changes that resulted in significant reductions in the contaminant loading to the river..." Battelle offers this as one of the reasons for dividing the operational history into three segments. However, this obscures the fact that operational changes also resulted in significant increases in the contaminant loading to the river. A publicly-funded project such as HEDR should not be used for Battelle's attempts of rewriting history to benefit its fellow Hanford contractors. The TSP should force Battelle to strike this and similar statements.	The operational changes referred to were the sequential reactor shutdowns that occurred between 1964 and 1970. The text on page 6.1 has been changed accordingly.
80.	JT	Pages 6.1-6.2	On pages 6.1 to 6.2, the report states: "Releases to the river were controlled by self-	Parker's 1952 memo (HW-24356) summarizes the early history of

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			imposed dose limits because there were no standards or concentration guides for radionuclide discharges to the river." It then cites a 1952 report by Parker to support this statement (HW-24356). However, when I checked the reference document, I discovered that it doesn't say what Battelle says it does. The reason Parker gives for there not being a standard was that his department objected to a 1951 attempt to set standards (HW-24356, p.4). Parker does not state the basis for his department's objections. Furthermore, Parker stated that the purpose of the reference document was not to impose any dose limits: "It is not the intent of this document to issue to the Manufacturing Department a set of mandatory regulations for control of effluent activity" (HW-24356, p.6). Battelle should learn to read historical documents more carefully.	the attempts to identify permissible limits to effluent releases while temporarily adhering to an existing limit. The limit was based on an immersion dose rate for external exposure at the point of release to the river and was, essentially, self-imposed. It was recognized that eventual release limits would be based on radiobiological data and this would require lengthy studies. Parker's memo offers current (1952) recommendations for the immersion dose rate and reactor operating guidelines for review and stated that setting mandatory regulations was not the memo objective. The text in Section 6.1 has been revised to include information on the immersion dose rate.
81.	JT	Page 6.3, Table 6.1	Concerning the references in Table 6.1, I could not find Wills' or Foster's ranch on the maps included with the report. Perhaps these could be added to the final version.	The Wills' Ranch and Foster Ranch locations have been added to Plate 1.
82.	JT	Page 9.22, Para. 4	On page 9.22, the Battelle report only mentions one of the purposes of the USPHS study of the Columbia. The other purpose was to assess "the	The other purpose (effect on stream purification) was included in the same paragraph in the

NA - No action.

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			effect of radioactive wastes on the normal stream purification factors" (HW-22181, p. 13).	original draft report. See page 9.23.
83.	JT	Page 9.24	On page 9.24 and elsewhere in PNL-8083, Battelle states that the data from USPHS report can be used as an independent database for comparison with the Hanford data for 1951-1953. I have found evidence that refutes the independent status of the USPHS work. First, in numerous reports from meetings of the Columbia River Advisory Group (CRAG), there was frequent mention that the 1951-1953 study was a cooperative one between USPHS and the AEC. One USPHS official, C. C. Ruchoft, even went so far to say that USPHS groups performed "services at the request of the (Atomic Energy) Commission" (GEH-19226). Second, at least some of the data collected by USPHS personnel was analyzed by the General Electric Health Instruments Division laboratory. For at least the first part of the study, USPHS scientists did not have any equipment to "perform the counting operations" (HW-22181, p. 23).	The authors feel the statements in the reports GEH-19226 and HW-22181 do not refute the independent status of the USPHS database. A detailed analysis of the database is planned for the follow-on work for FY 1992. The results will be included in a letter report to the TSP during the first quarter of FY 1993.
84.	JT	General Comment (Section 10.0)	The treatment of bioaccumulation factors in Section 10.0 is insufficient. In June 1950, R. F. Foster presented a paper to CRAG and noted an accumulation factor of 200,000 for P-32 in certain organisms (HO-1, Columbia River Symposium, R. L. Plum, p. 22). The current Battelle report states that the maximum is	See response to comment 13.

NA - No action.

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

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Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
			100,000 (p. 10.9). Furthermore, there is no discussion of how the thermal pollution from the Hanford reactors affected the factors for bioaccumulation. Additionally, Napier does not sufficiently justify his selection rationale for the accumulation factors.	
85.	JT	Page 10.11, Table 10.5	Napier's exposure pathway parameters on page 10.11 are unacceptable. Regarding swimming, there is no mention of how close to the reactors the people swam. I have had people tell me that they use to sneak into the exclusion zone to swim where the river was really warm. It also appears that the 100 hours might not be sufficient to encompass the time a worker would spend per year in the river constructing docks and pilings. I have met a man who is dying of several kinds of cancer who worked as a diver in the Columbia River doing various construction work in the 1950s and 1960s. The parameter for drinking water must be changed to consider those people who drank untreated river water. In addition to people's recollections, I know of at least one reference by H. V. Clukey to river boat crews drinking untreated water (HW-47152, p. 2).	Additional calculations have been added to address untreated drinking water. External doses from water immersion all were extremely low, so that increasing the time to 2000 hours/year (a full working year in the water) would increase the immersion dose rate at Richland in 1964 (the highest) to only 90 mrem, about a 50% increase to the maximally exposed individual dose. A paragraph has been added to address this effect on page 10.20.

NA - No action.

APPENDIX D

SUMMARY OF TSP COMMENTS AND BNW RESPONSES

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Document Title Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
86.	JT	General Comment	There is at least one other report that Battelle apparently neglected to include in its literature and data review: "An Evaluation of the Pollutional Effects from Hanford Works." It was the final report of CRAG and was prepared by E. C. Tsivoglou and M. W. Lammering. The March 1961 report encompasses a detailed critique of the Hanford monitoring programs of the Columbia River. It points out errors in the assumptions and/or techniques employed in obtaining samples and the analysis of them.	NA - Information from CRAG report of March 1961 will be reviewed and evaluated during the follow-on work conducted in FY 1992-1993.

NA - No action.

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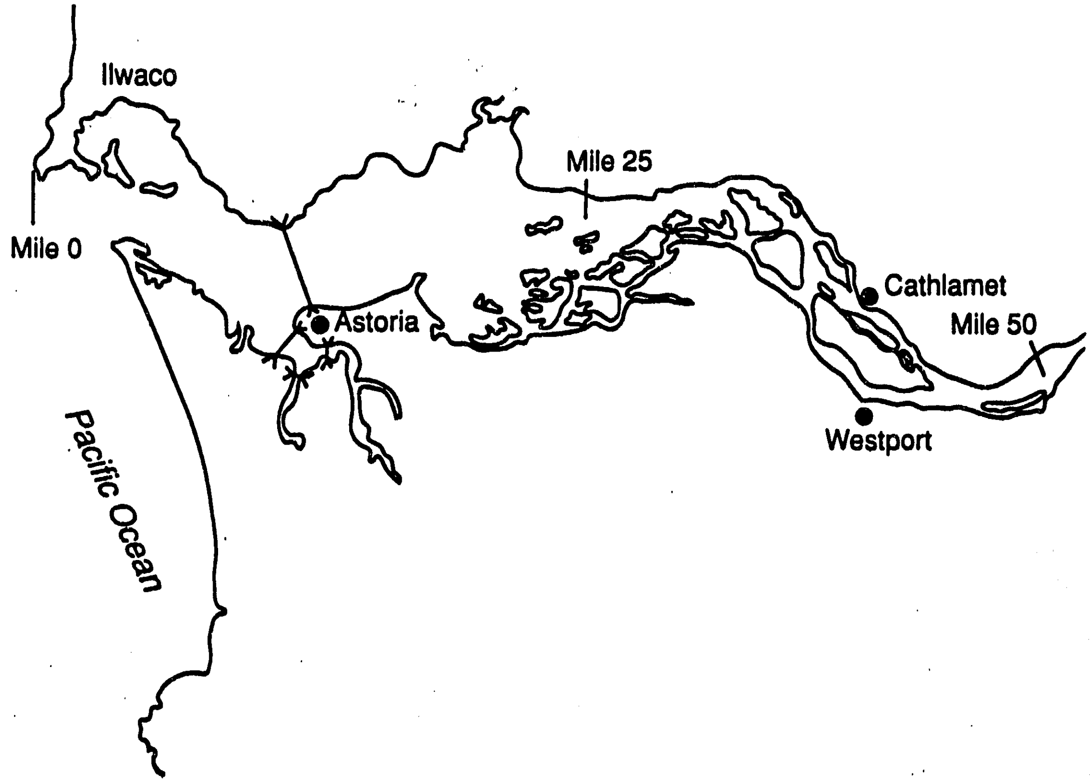
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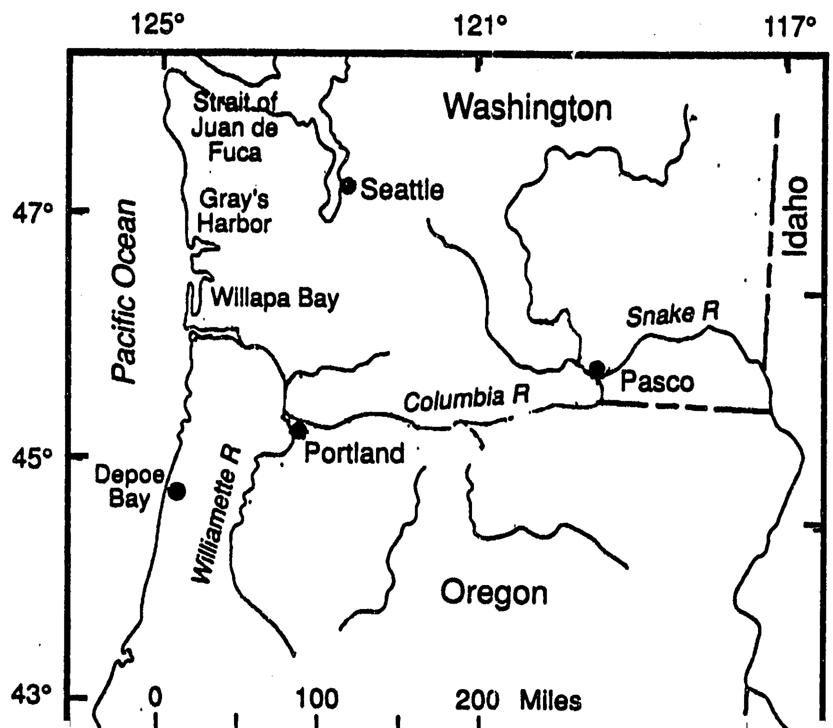
Cathlamet
Mile 50
Westport
Pacific Ocean


125°
121°
117°
47°
45°
43°
Washington
Strait of Juan de Fuca
Seattle
Gray's Harbor
Willapa Bay
Pacific Ocean
Idaho
Snake R
Pasco
Columbia R
Portland
Depoe Bay
Willamette R
Oregon
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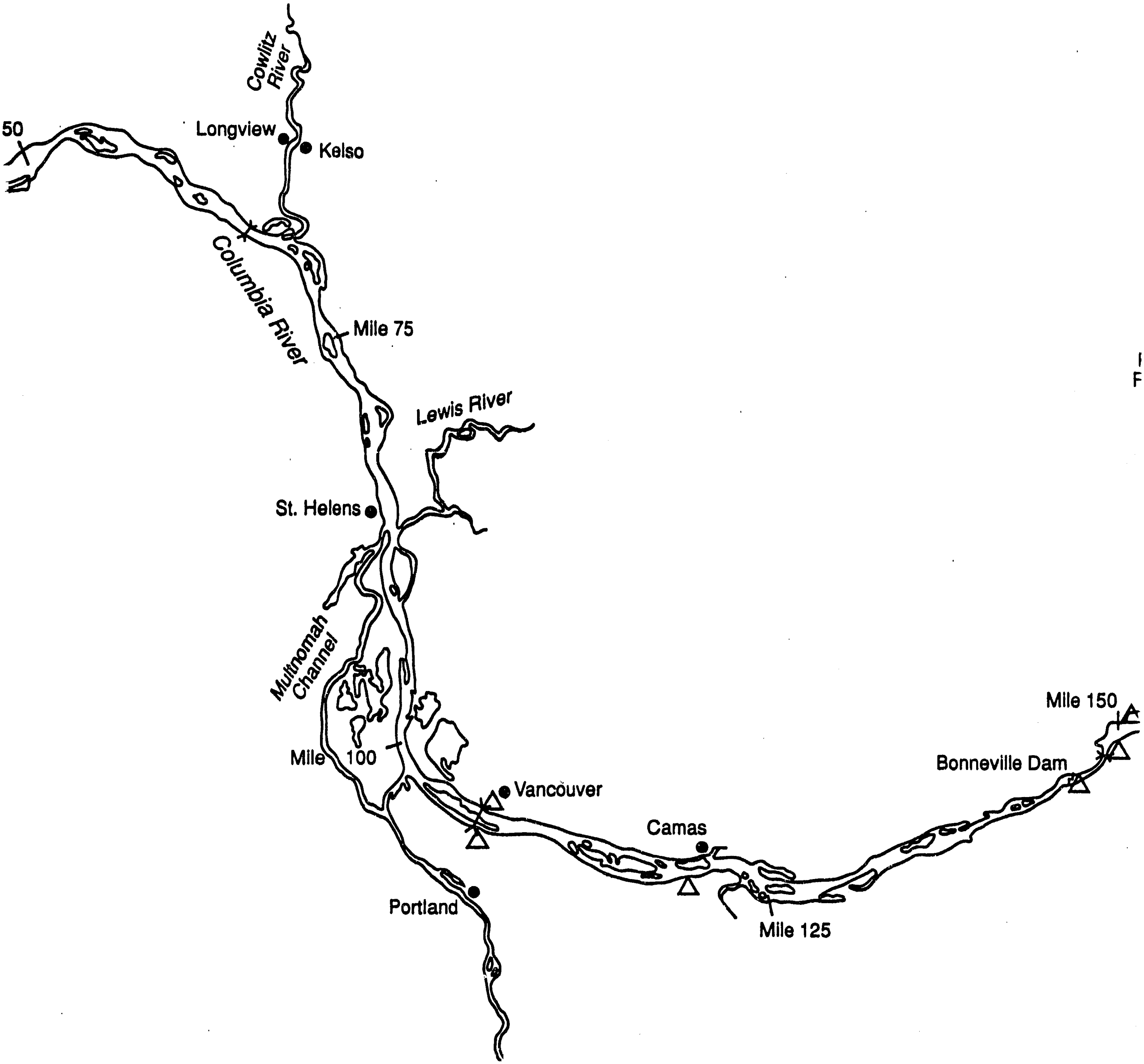
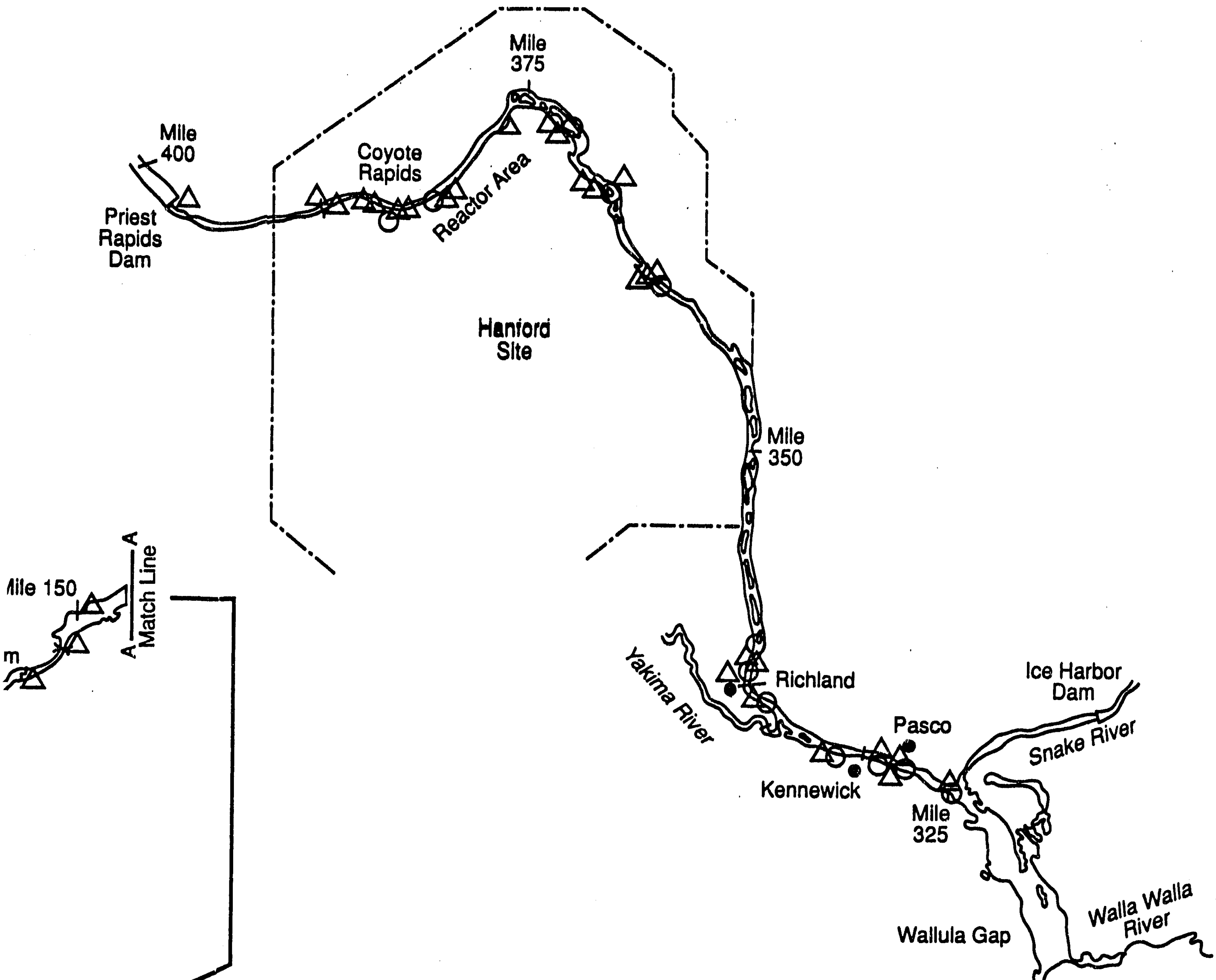
200 Miles



Cowlitz River
50
Longview
Kelso
Columbia River
Mile 75
Lewis River
St. Helens
Multnomah Channel
Mile 100
Vancouver
Camas
Portland
Mile 125
Mile 150
Bonneville Dam



Mile 400
Priest Rapids Dam
Coyote Rapids
Reactor Area
Mile 375
Hanford Site
Mile 350
Richland
Yakima River
Pasco
Kennewick
Mile 325
Ice Harbor Dam
Snake River
Walla Walla River
Wallula Gap
Mile 150
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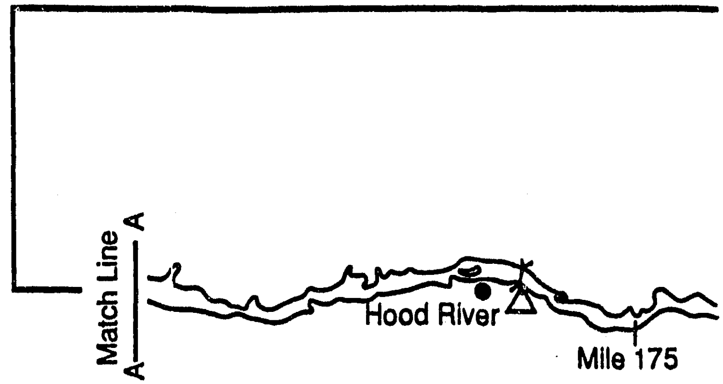
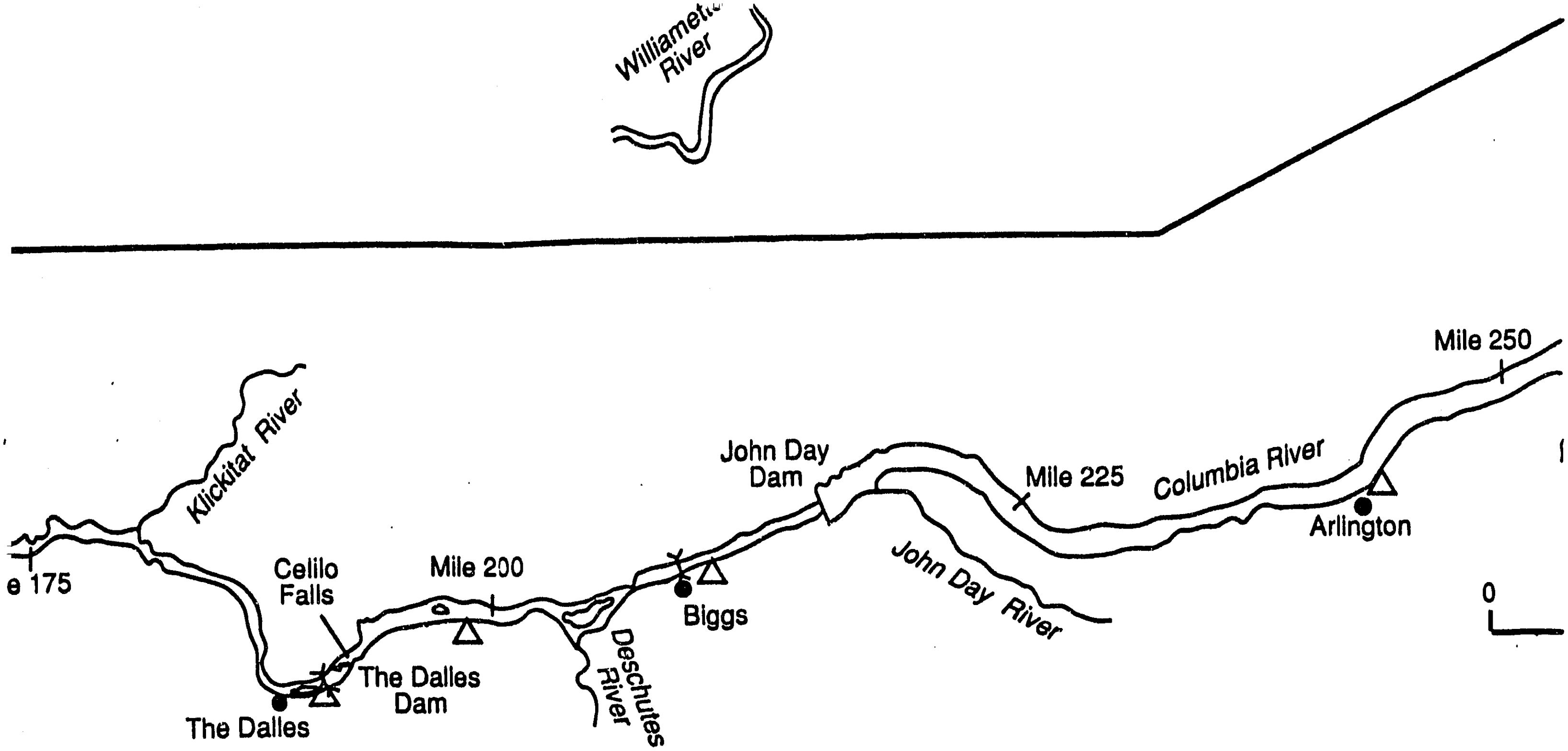
Index Map of Part of the Columbia River Basin





Williamette River
Klickitat River
e 175
Celilo Falls
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Biggs
John Day Dam
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Columbia River
Arlington
Mile 250
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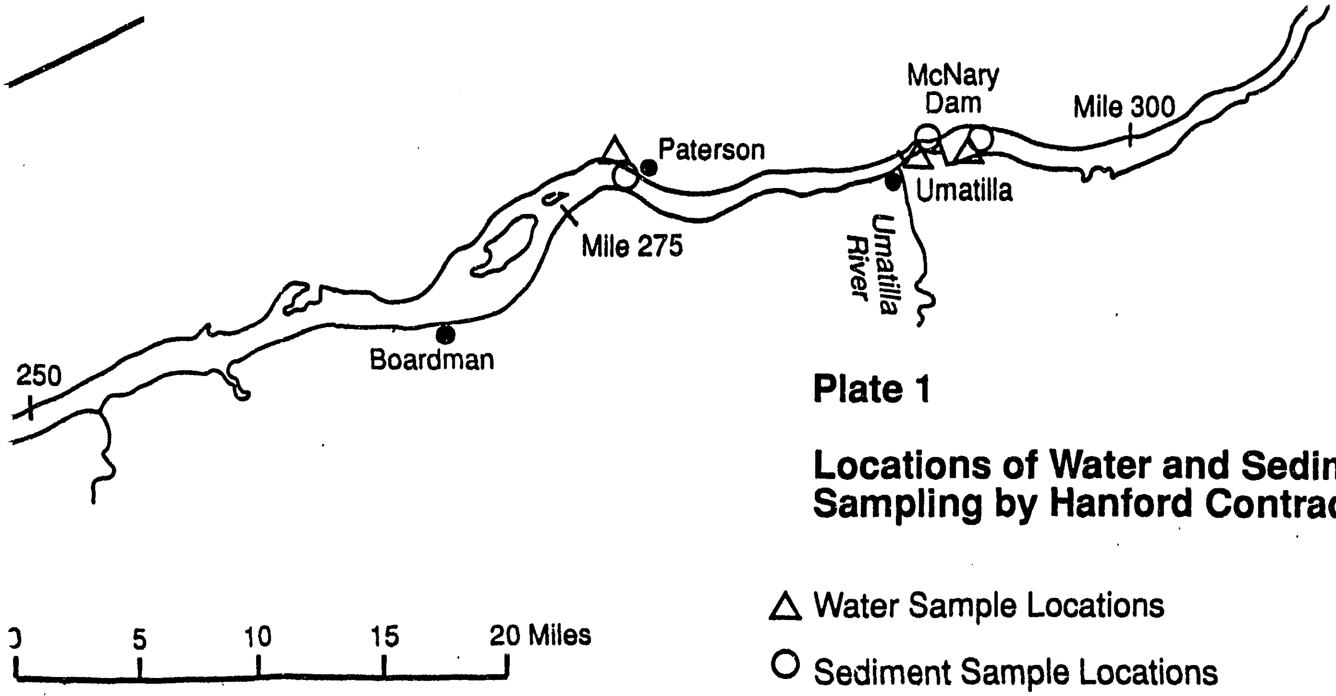
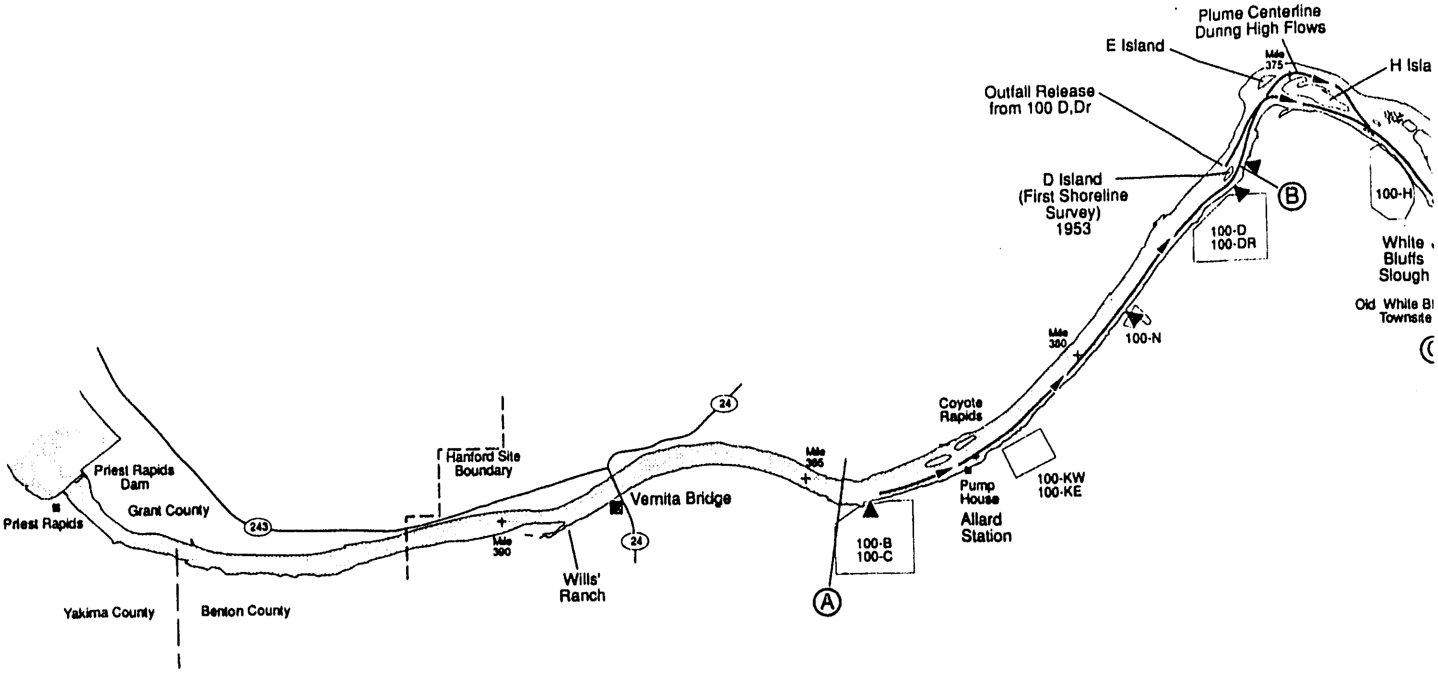
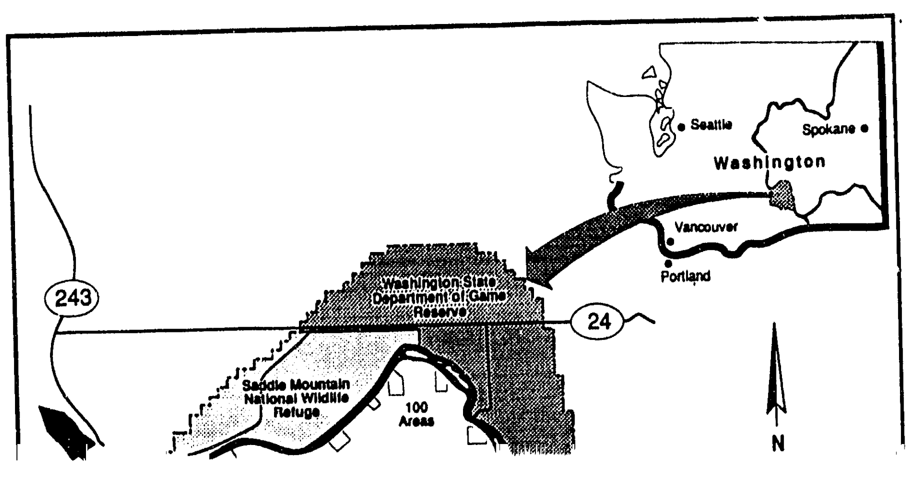
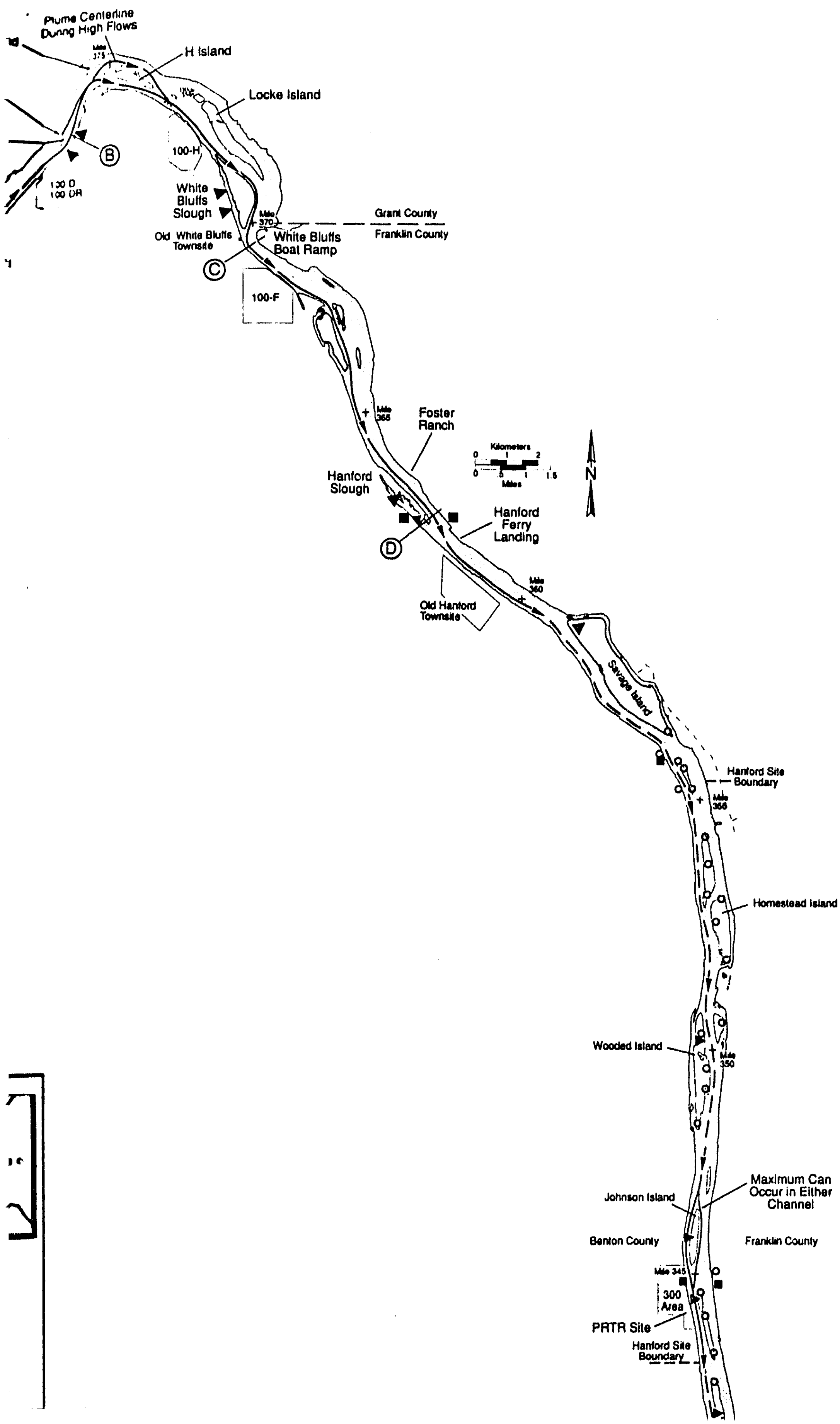


Plate 1

Locations of Water and Sediment Sampling by Hanford Contractors


Plume Centerline
During High Flows
E Island
H Isla
Mile 375
Outfall Release
from 100 D,Dr
D Island
(First Shoreline
Survey)
1953
B
100-H
100-D
100-DR
White
Bluffs
Slough
Old White Bl
Townsite
Mile 380
100-N
Coyote
Rapids
Mile 385
Pump
House
Allard
Station
100-KW
100-KE
100-B
100-C
A
Hanford Site
Boundary
Vernita Bridge
24
Mile 390
Wills'
Ranch
Priest Rapids
Dam
Grant County
243
Priest Rapids
Yakima County
Benton County


Seattle
Spokane
Washington
Vancouver
Portland
243
24
Washington State
Department of Game
Reserve
Saddle Mountain
National Wildlife
Refuge
100
Areas
N


Plume Centerline During High Flows
H Island
Locke Island
100-H
100 D
100 DR
White Bluffs Slough
Grant County
Franklin County
Old White Bluffs Townsite
White Bluffs Boat Ramp
100-F
Foster Ranch
Kilometers
Miles
N
Hanford Slough
Hanford Ferry Landing
Old Hanford Townsite
Savage Island
Hanford Site Boundary
Homestead Island
Wooded Island
Johnson Island
Maximum Can Occur in Either Channel
Benton County
Franklin County
300 Area
PRTR Site
Hanford Site Boundary

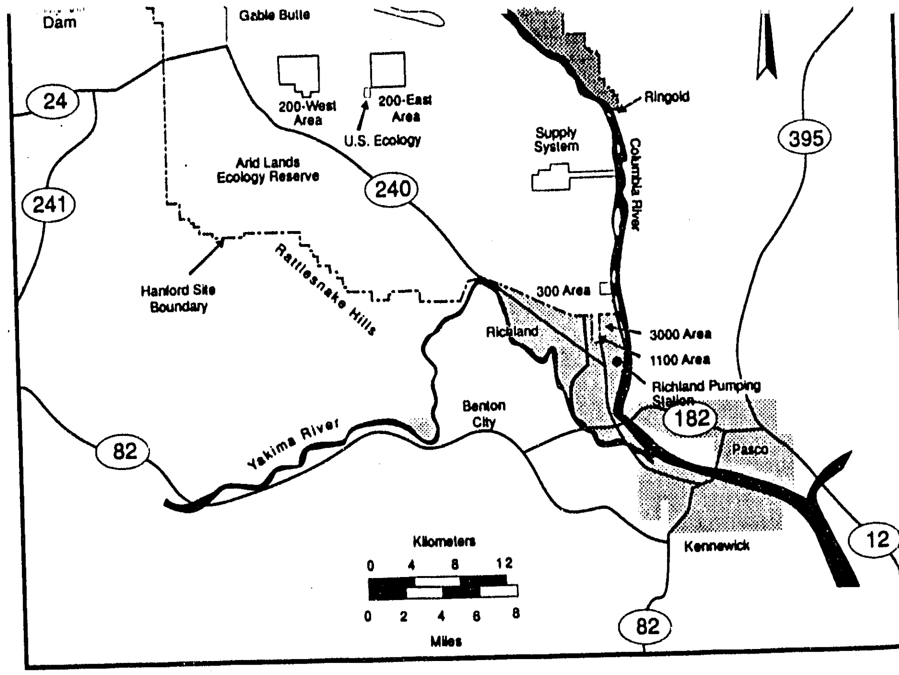


Plate 2

The Hanford Reach - Showing Surveys of Shoreline Radioactivity Exposure Rates and the Effluent Plume Centerline

Surveys of Shoreline Radioactivity Exposure Rates

1953 Shoreline Survey (Paas 1953). D Island only.

Ⓐ - Ⓓ 1959 Shoreline Survey (McConiga and Rising 1959) - Both shorelines surveyed each mile from point Ⓐ to point Ⓓ. Alternate
Ⓓ - Ⓔ shorelines surveyed each mile from point Ⓓ to point Ⓔ

○ 1962 Shoreline Survey (McConnon 1962).

■ 1966 Shoreline Survey (Grande 1966).

Ⓐ - Ⓑ 1966 Shoreline Survey (Lodge 1966). Reactor shoreline surveyed every quarter mile and opposite shoreline surveyed every half mile from
Ⓑ - Ⓒ point Ⓐ to point Ⓑ. Both shorelines surveyed evey half mile from point Ⓑ to point Ⓒ. Islands D, E, and H, and Locke Island surveyed.

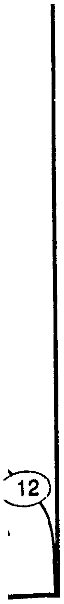
▲ 1974 Shoreline Survey (Fix 1975).

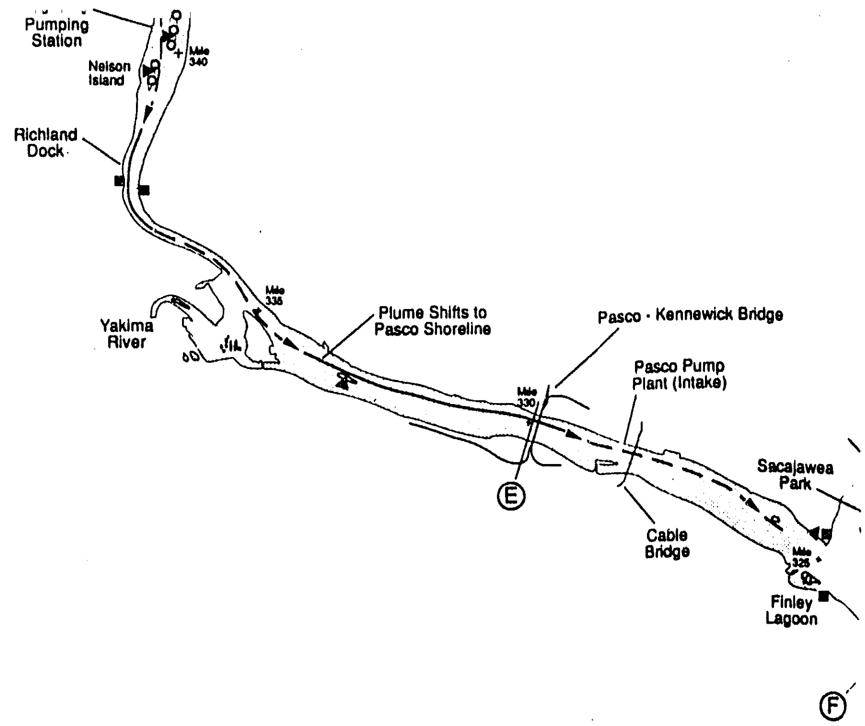
Ⓐ - Ⓕ 1978-79 Shoreline Survey (Sula 1980). Islands and selected recreational shoreline areas surveyed from point Ⓐ to point Ⓕ.

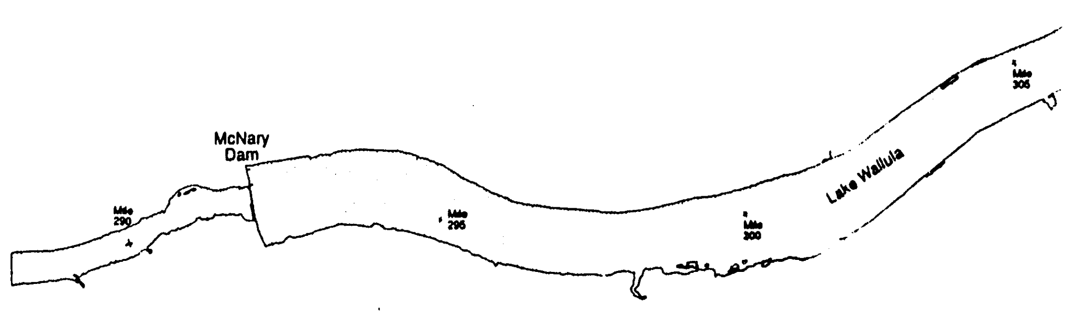
Effluent Plume Centerline

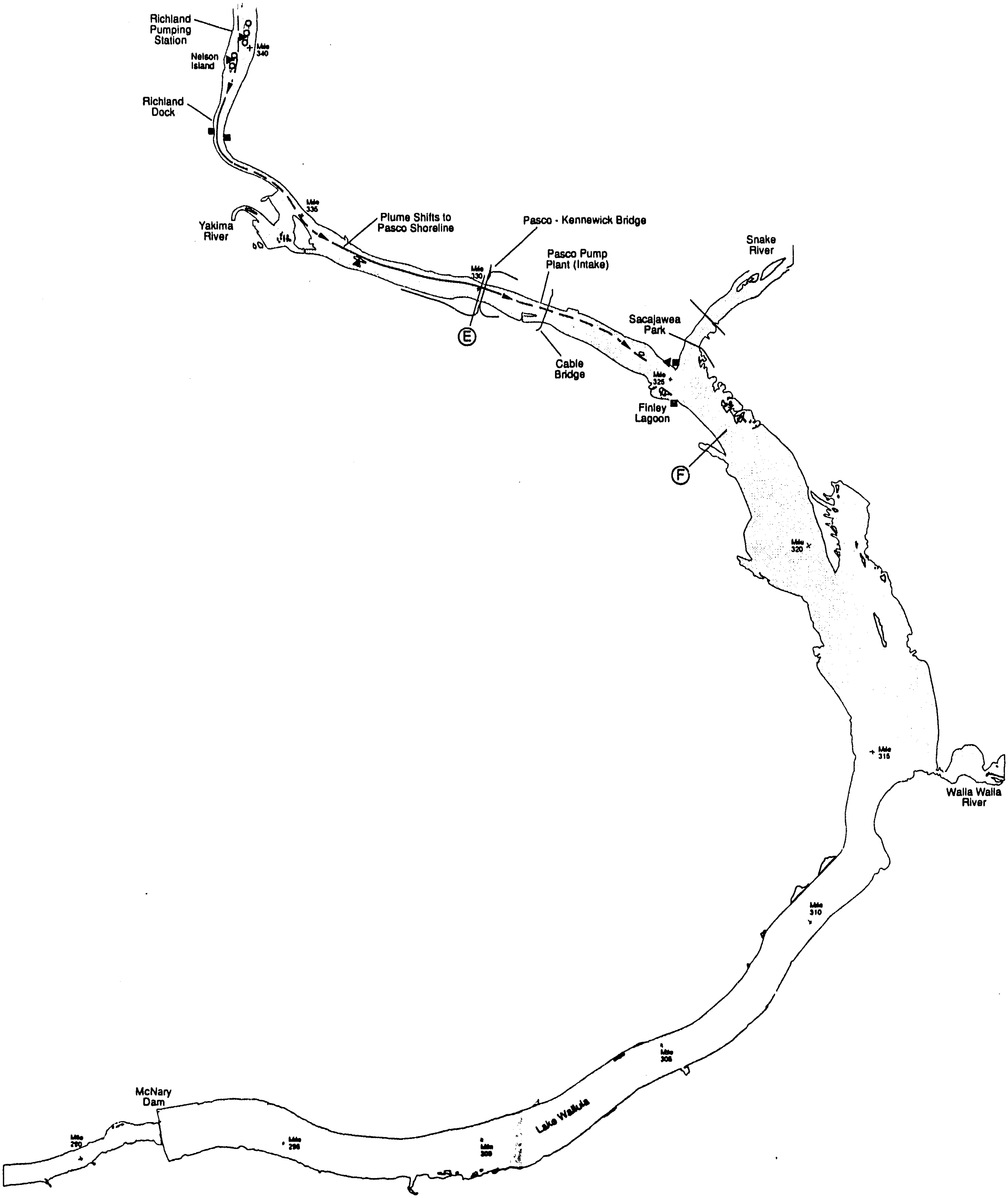
——→ Effluent plume centerline based on transect data

— —→ Assumed effluent plume centerline (no transect data available).


12


Pumping
Station
Nelson
Island
Mile
340
Richland
Dock
Mile
335
Yakima
River
Plume Shifts to
Pasco Shoreline
Pasco · Kennewick Bridge
Mile
330
Pasco Pump
Plant (Intake)
E
Sacajawea
Park
Cable
Bridge
Mile
325
Finley
Lagoon
F


McNary
Dam
Mile
290
Mile
295
Mile
300
Lake Wallula
Mile
305



Richland Pumping Station
Nelson Island
Mile 340
Richland Dock
Mile 335
Yakima River
Plume Shifts to Pasco Shoreline
Pasco - Kennewick Bridge
Mile 330
Pasco Pump Plant (Intake)
E
Cable Bridge
Snake River
Sacajawea Park
Mile 325
Finley Lagoon
F
Mile 320
Mile 315
Walla Walla River
Mile 310
Lake Wallula
McNary Dam

END

DATE FILMED

2 / 18 / 93