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RADIOACTIVE CONTAMINATION OF FISH, SHELLFISH, AND WATERFOWL EXPOSED TO HANFORD EFFLUENTS: ANNUAL SUMMARIES, 1945-1972

Hanford Environmental Dose
Reconstruction Project

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July 1992

Letter Report
for the Technical Steering Panel
and the Centers for Disease Control
under Contract Number 18620

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Dear Mr. Donnelly and Dr. Till:

LETTER REPORT SUMMARIZING HISTORICAL CONTAMINATION OF FISH, SHELLFISH, AND WATERFOWL

Enclosed for your information is the report, "Radioactive Contamination of Fish, Shellfish, and Waterfowl Exposed to Hanford Effluents: Annual Summaries 1945 - 1972." This report, though not a milestone report, contributes to work done under Subtask 0504, Surface-Water Monitoring Data. The report is a companion to a HEDR report issued in April 1992, "Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas," PNL-8083 HEDR.

Very truly yours,

M. D. Freshley for DBS

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Enclosure

cc: RH Gray
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SUMMARY

The objective of the Hanford Environmental Dose Reconstruction Project (HEDR) is to estimate the potential radiation doses received by people living within the sphere of influence of the Hanford Site. A potential critical pathway for human radiation exposure is through the consumption of waterfowl that frequent onsite waste-water ponds or through eating of fish, shellfish, and waterfowl that reside in/on the Columbia River and its tributaries downstream of the reactors. This document summarizes information on fish, shellfish, and waterfowl radiation contamination for samples collected by Hanford monitoring personnel and offsite agencies for the period 1945 to 1972. Specific information includes the types of organisms sampled, the kinds of tissues and organs analyzed, the sampling locations, and the radionuclides reported. Some tissue concentrations are also included. We anticipate that these yearly summaries will be helpful to individuals and organizations interested in evaluating aquatic pathway information for locations impacted by Hanford operations and will be useful for planning the direction of future HEDR studies.

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1.0 INTRODUCTION

The primary objective of the multi-year Hanford Dose Reconstruction (HEDR) Project is to determine the doses that people living in the vicinity of the Hanford Site could have received as a result of exposure to radioactive emissions from Hanford's nuclear operations. Exposure pathways under consideration include inhalation and/or ingestion of airborne gaseous and particulate materials and exposure to liquid contaminants discharged to surface-water habitats, including the Columbia River. This report summarizes radionuclide information for fish, shellfish, and waterfowl collected from the Columbia River and Hanford Site surface-water locations. Information is also included for fish and shellfish organisms collected from the Pacific coasts of Oregon and Washington, near the mouth of the Columbia River, and for fish obtained from several Columbia River tributaries downstream of the Site. The primary intent of this report is to provide a single concise summary of available information to assist those individuals and organizations interested in locating aquatic pathway data for contaminants originating at Hanford and for planning future HEDR studies.

This document contains annual summaries of radionuclide contamination information for fish, shellfish, and waterfowl for the years 1945 through 1972. Samples were collected to determine the impacts of operations at Hanford on organisms living on and near the Hanford Site or at distant locations where the potential for exposure to Hanford effluents existed. The period 1945 to 1971 includes those years when some or all of the original Hanford single-pass reactors were operating and actively discharging contaminated effluents. Information for 1972 was included to allow comparison to data collected following the shutdown of all single-pass reactors. Each summary contains information on the specific organisms sampled, the kinds of tissues and organs analyzed, the sampling locations, and the constituents reported. Some concentration data are also included. These data are included to give an indication of the radionuclide levels observed. However, the primary intent of this paper is not to provide concentration data but to identify sources of information that may be useful.

A large number of documents were reviewed to obtain the information in this report, and these have been referenced at the end of each annual summary. There may be other documents containing additional information that were not located and included in this review. However, it is probable that the material summarized here is representative of the information reported during these years.

2.0 STUDY APPROACH

Over the years, environmental studies near Hanford were conducted by Oregon and Washington State institutions, by state and federal agencies, and by Hanford environmental-monitoring personnel. Studies during this period by offsite organizations were limited in scope because of security requirements at the Hanford Site and restricted access to the Hanford Reach prior to 1978. Therefore, much of the information summarized here was obtained from published Hanford periodic and special environmental reports. All the documents referenced in this report are publicly available and can be found in the DOE Richland Field Office (RL) public reading room or can be obtained from the National Technical Information Service.

A large number of laboratory studies were also conducted at Hanford during this time period. Much of this work focused on determining the effects of reactor effluents on fish and other aquatic organisms and the uptake of radionuclides by various animal species. Results of these laboratory studies have not been included in these summaries. However, a detailed history of aquatic studies conducted at Hanford from 1944 to 1984 has recently been published (Becker 1990).

REFERENCE

Becker 1990 Becker, C.D. "Aquatic Bioenvironmental Studies: The Hanford Experience 1944-84." 1990. Studies in Environmental Science. Vol. 39. Elsevier, New York.

3.0 SAMPLE COLLECTIONS

The first fish samples were collected from the Columbia River near the reactor outfalls (HW-3-2894 DEL). When it became apparent that fish were accumulating significant quantities of Hanford-derived radionuclides, collection soon was extended to Columbia River locations both upstream and downstream of the Hanford Site and to locations on the Yakima, Snake, and Walla Walla Rivers. By the late 1940s, fish were being collected from the Columbia as far downstream as Bonneville Dam. In later years, samples were collected near the mouth of the Columbia River and at Pacific coastal locations in Washington, Oregon, and Alaska.

River organisms were initially collected at randomly selected locations to define the extent of contamination spread. Samples were also collected at locations where impacts to aquatic life were likely or where fish were easily obtained. However, as the Hanford monitoring program matured, permanent sampling stations, used for routine sampling, were established. The data from these locations were reported in periodic Hanford environmental reports. Many samples were still collected at non-routine locations, and the data were sometimes reported in special studies reports. The first non-Hanford radiological studies on Columbia River organisms were published in the early 1950s (Robeck et al. 1954). Table 3.1 summarizes the general sampling locations for fish, shellfish, and waterfowl collected during the years 1945 through 1972 for both Hanford and offsite studies. Specific sampling locations within these areas varied from year to year and are identified in the individual annual summaries.

TABLE 3.1. Summary of Fish, Shellfish, and Waterfowl Sampling Locations 1945-1972

Sample Date	Fish				Shellfish		Waterfowl
	Pacific Coast	Columbia River	Yakima River	Snake and/or Walla Walla River	Columbia River	Pacific Coast	
1945		X					
1946		X	X				X
1947		X					X
1948		X					X
1949		X			X		X
1950		X			X		X
1951		X	X	X	X		X
1952		X	X	X	X		X
1953		X					
1954		X			X		X
1955		X			X		X
1956	X	X					X
1957		X					X
1958							
1959	X	X				X	X
1960	X	X				X	X
1961	X	X				X	X
1962	X	X				X	X
1963	X	X				X	X
1964		X				X	X
1965		X			X	X	X
1966		X				X	X
1967		X		X(a)		X	X
1968		X				X	X
1969		X				X	X
1970		X				X	X
1971		X				X	X
1972		X				X	X

(a) Willamette River.

3.1 FISH

Fish were the first aquatic organisms collected for radionuclide analysis following the startup of the reactors in 1945 (HW-3-2894 DEL). Results for analyses of various Columbia River fish and fish tissues have been documented in periodic Hanford Site reports almost yearly since 1945. Samples were collected to determine the extent of contamination spread, the physical impact on aquatic organisms, the identities of the radionuclides that the organisms were accumulating, and the actual doses to the organisms. Over the years, collections included many Columbia River fish species and some Pacific coast fish species. By 1948, samples were being collected at Bonneville and shipped to Hanford for radioanalysis (HW-23093). By 1950, it was apparent that accumulations in some fish species posed a larger threat to human health than accumulations in others, so the research became more focused. Analyses indicated that whitefish were the local food fish with the highest tissue concentrations, so efforts to collect whitefish increased. Other food fish were also collected, but radionuclide concentrations in food fish that were more popular with local fishermen, like large-, and smallmouth bass, were generally lower. By the mid-1950s, researchers realized that important adult anadromous fish species, primarily salmonids, accumulated very low levels of radionuclides because of short residence times in the Columbia River and because they do not eat during the spawning period. The Columbia River fish species that consistently had the highest tissue concentrations were those species that consumed algae and/or aquatic invertebrates. These included adult suckers, shiners, peamouth, and whitefish. Concentrations in juvenile and small (generally less than five grams) fish of all species (including salmon) collected downstream of the reactor outfalls near the Site were also usually elevated.

As mentioned, Pacific coast fish were also collected and analyzed. Collections for these fish occurred between 1956 and 1963 and were made both by Hanford personnel and by other offsite organizations. Specimens for analysis were also collected from Columbia River tributaries downstream of the Site, including the Yakima, Walla Walla, Snake, and Willamette Rivers. Most of these samples were obtained within a few miles of the river confluences and

were analyzed to determine if contaminated fish from the Columbia were moving into other waterways.

Intensive Columbia River fish sampling continued through the period covered by this report, but most sampling conducted near Hanford after the mid-1950s was done by Site personnel.

3.2 SHELLFISH

Both freshwater and marine shellfish were collected and analyzed for Hanford-derived radioactive contaminants. The first analyses for marine shellfish samples collected for the Hanford environmental-monitoring program were reported in 1959 (HW-SA-2857; HW-63654 REV; HW-66550; HW-64371). Results for marine samples collected by offsite organizations did not appear until the early 1960s and were reported through the mid-1960s. Organisms collected included primarily bivalve mollusks (clams, oysters, mussels), but many other taxa, including crabs, shrimp, and octopi, were also occasionally sampled. Several times in the 1960s, samples of canned marine shellfish from regional and worldwide locations were also purchased and analyzed for comparison purposes (HW-64371; HW-63824). Beginning in 1959-60, the Hanford monitoring program began sampling Pacific coast oysters from Willapa Bay, Washington, on a routine basis (HW-64371). The collection of these samples continued into 1972. Following the closure of the last production reactor at Hanford in 1971, levels of Hanford-derived radionuclides in coastal organisms dropped rapidly, and routine oyster sampling by Hanford personnel was curtailed.

Some freshwater shellfish samples were also collected from the Columbia River between 1949 and 1955 and again in 1965 (Table 3.1).

3.3 WATERFOWL

The first data reported for waterfowl collected both on and off the Site appeared in 1946 (HW-7-5428; HW-7-5301). From 1947 to the early 1950s, many of the ducks collected and analyzed were from stocks planted and maintained by Hanford personnel at specific locations on the Columbia River near the reactor discharges and on onsite waste ponds. Between 1951 and 1959, wild birds were usually obtained from onsite waste ponds or from the Columbia River within the

boundaries of the Hanford Site. Collections increased dramatically in 1960 when the monitoring program at Hanford began supplementing onsite collections by purchasing the heads of waterfowl harvested by local area hunters. In 1961 approximately 3400 bird heads were purchased for radionuclide analysis (HW-71999). Most of these birds were obtained near the Hanford Site, but some were collected at distant locations in Washington, Oregon, and California. Bird-head purchases continued through 1964, but the number of heads obtained after 1961 decreased dramatically. After 1964, sampling by Hanford personnel continued, and many animals were collected on and near the Site and near surrounding communities. During these years, specimens were usually collected during the established hunting season so that samples were representative of birds available for public consumption.

REFERENCES

HW-63654 REV — Foster, R.J. and R.L. Junkins. 1960. Off-Project Exposure from Hanford Reactor Effluent. General Electric Company, Hanford Works, Richland, Washington.

HW-71999 — Foster, R.F. (manager), and I.C. Nelson (editor). 1962. Evaluation of Radiological Conditions in the Vicinity of Hanford For 1961. General Electric Company, Hanford Works, Richland, Washington.

HW-3-2894 DEL — Healy, J.W. 1945. Special Studies Branch Weekly Reports for the Period May 20, 1945 to December 31, 1945. Hanford Engineer Works, Richland, Washington.

HW-64371 — Junkins, R.L., E.C. Watson, I.C. Nelson, and R.C. Henle. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1959. General Electric Company, Hanford Works, Richland, Washington.

HW-23093 — Olson, P.A., and R.F, Foster. 1952. Accumulation of Radioactivity in Columbia River Fish in the Vicinity of the Hanford Works. General Electric Company, Hanford Works, Richland, Washington.

HW-7-5301 — Parker, H.M. 1946. Health Instrument Section Report for October, 1946. General Electric Company, Hanford Works, Richland, Washington.

HW-7-5428 — Parker, H.M. 1946. Health Instrument Section Report for November, 1946. General Electric Company, Hanford Works, Richland, Washington.

HW-63824 Perkins, R.W. and J.M. Nielsen. 1960. Radioactivity in Foods Resulting from Columbia River Water Radioisotopes. In: Nielson, J.M., Radiological Chemistry Operation, Semi-Annual Report, July-December, 1959. General Electric Company, Hanford Works, Richland, Washington.

Robeck, G.G., C. Henderson, and R.C. Palange. 1954. Water Quality Studies on the Columbia River. GEH-21328, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Washington, D.C.

HW-65600 Watson, D.J., J.J. Davis, and W.C. Hanson. 1960. "Zinc-65 in Marine Mollusks Near the Mouth of the Columbia River." In: Warner, D.E., editor, Hanford Biology Research Annual Report for 1959, pp. 183-187. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-SA-2857 Watson, D.G., J.J. Davis, and W.C. Hanson. 1962. Inter-species Differences in Accumulation of Gamma Emitters by Marine Organisms Near the Columbia River Mouth. General Electric Company, Hanford Works, Richland, Washington.

4.0 SAMPLING LOCATIONS

Between 1945 and 1972, samples were collected at many locations on and near the Site and at numerous distant locations. The general or specific locations for most of these sampling sites can still be identified because the site names are similar, or the same, to those still used today. However, the exact locations of some of the historical sampling sites mentioned in this report are uncertain because site names have been changed, locations were not recorded, and/or historical knowledge has been lost. Figures 4.1 through 4.6 help the reader locate many of the sites mentioned in the following annual summaries. These figures do not include the specific location of every sample collection site, but the locations of some of those not illustrated are described in the annual summaries.

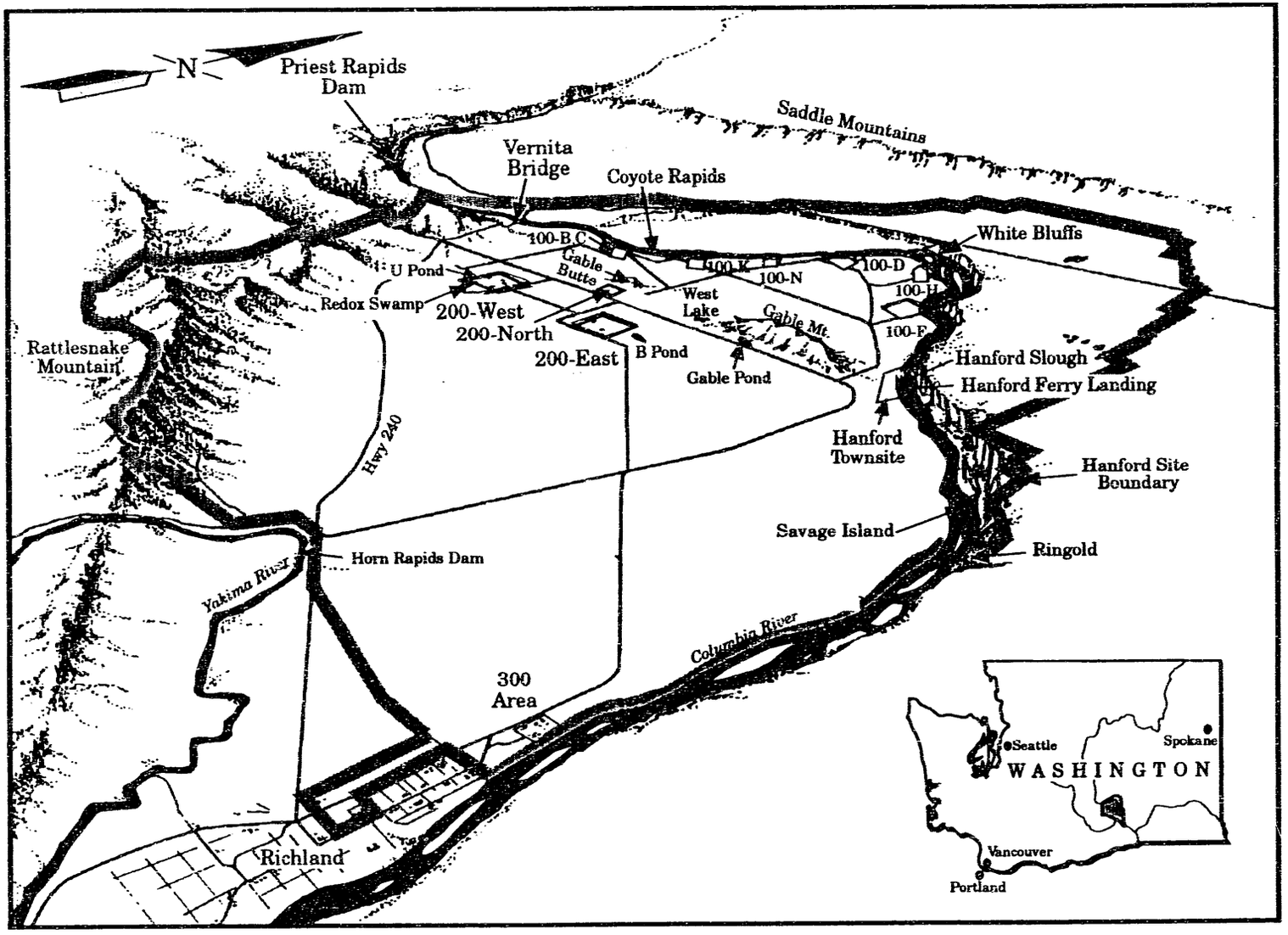

FIGURE 4.1. Fish, Shellfish, and Waterfowl Sampling Locations on the Hanford Site

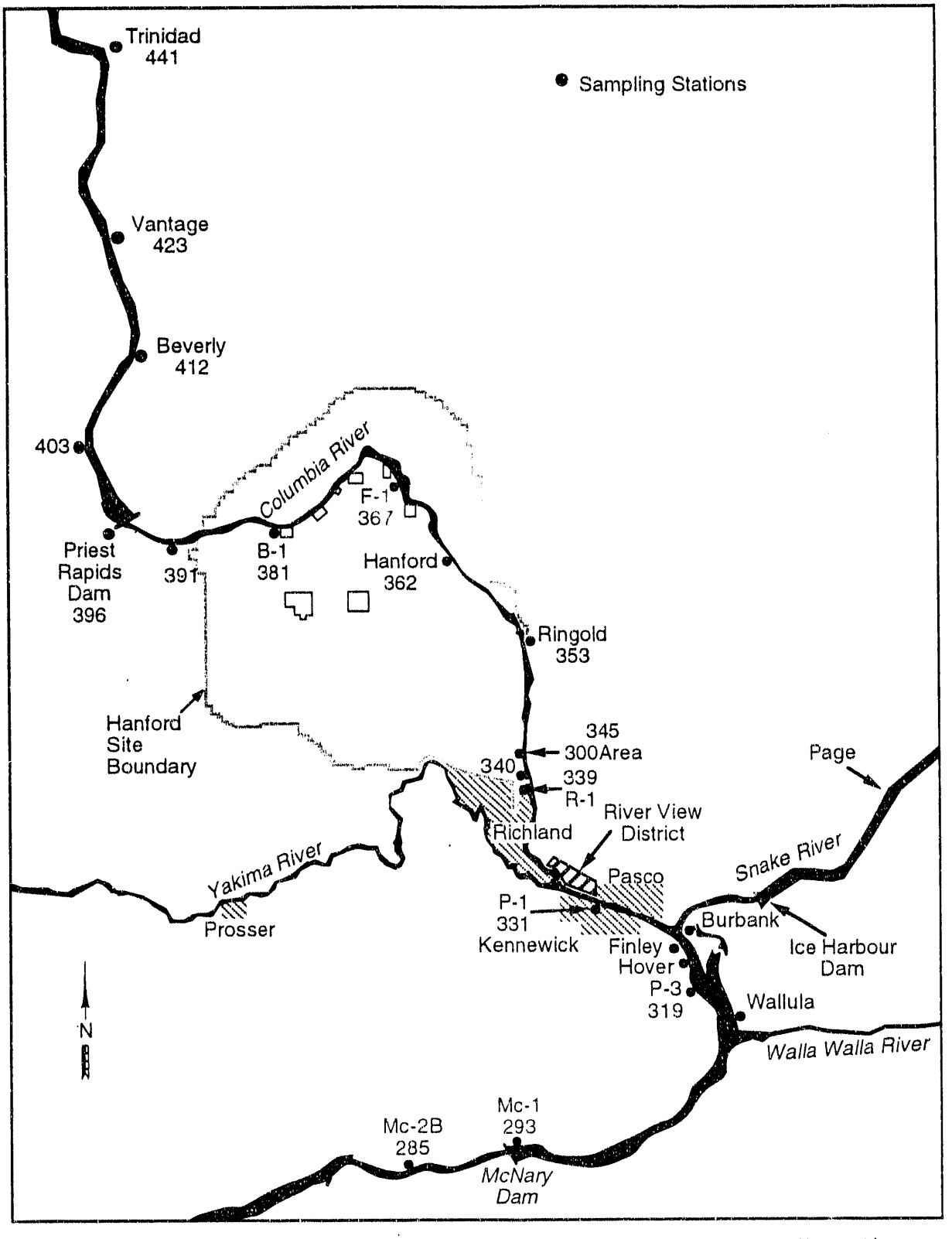

FIGURE 4.2. Fish, Shellfish, and Waterfowl Sampling Locations Near the Hanford Site - Numbers preceded by letters represent sampling sites; other numbers signify the distance (in river miles) upstream from the mouth of the Columbia River.

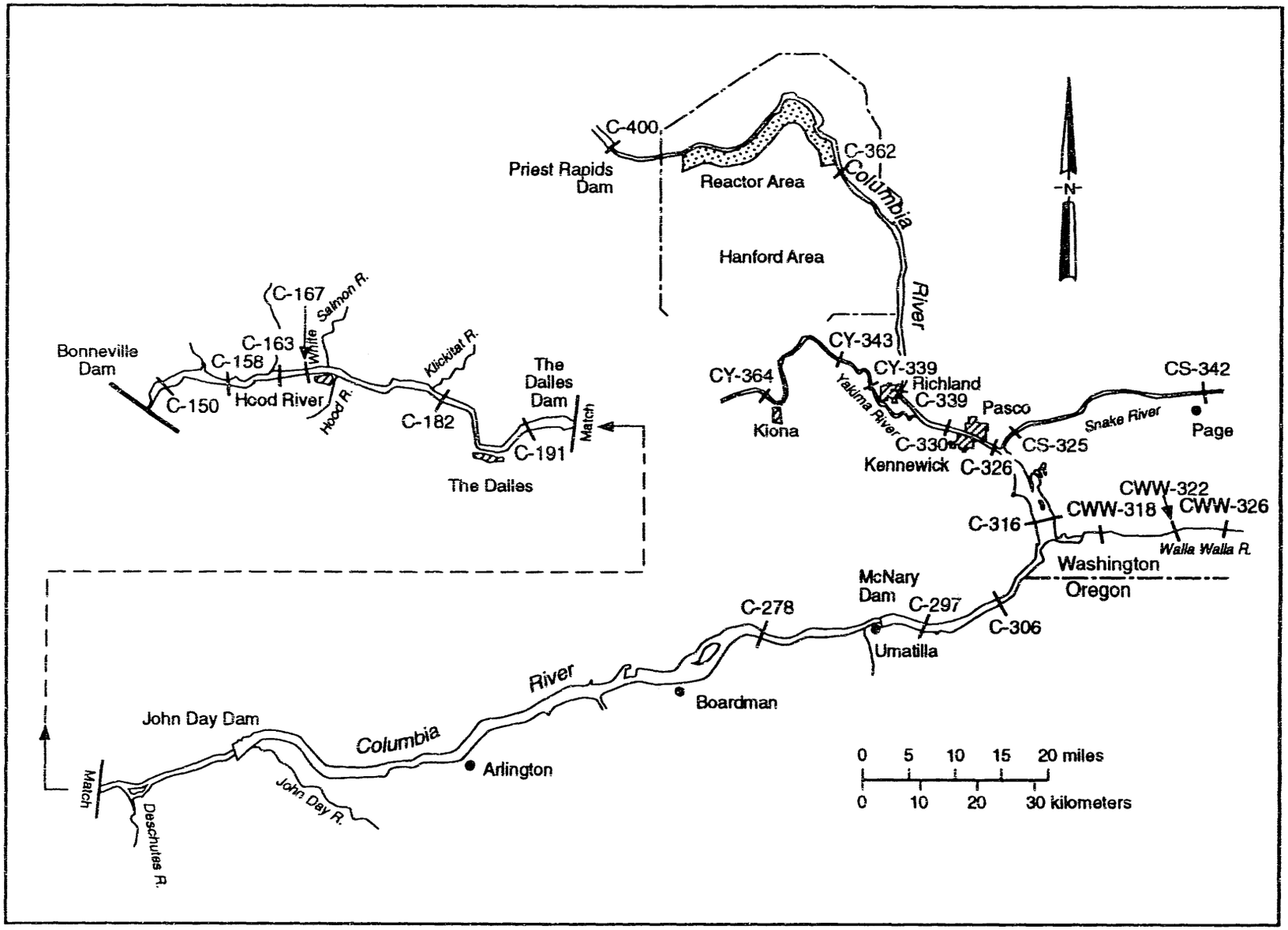

FIGURE 4.3. Fish and/or Shellfish Sampling Locations and River Mile Notations for the Columbia River from Priest Rapids Dam to Bonneville Dam

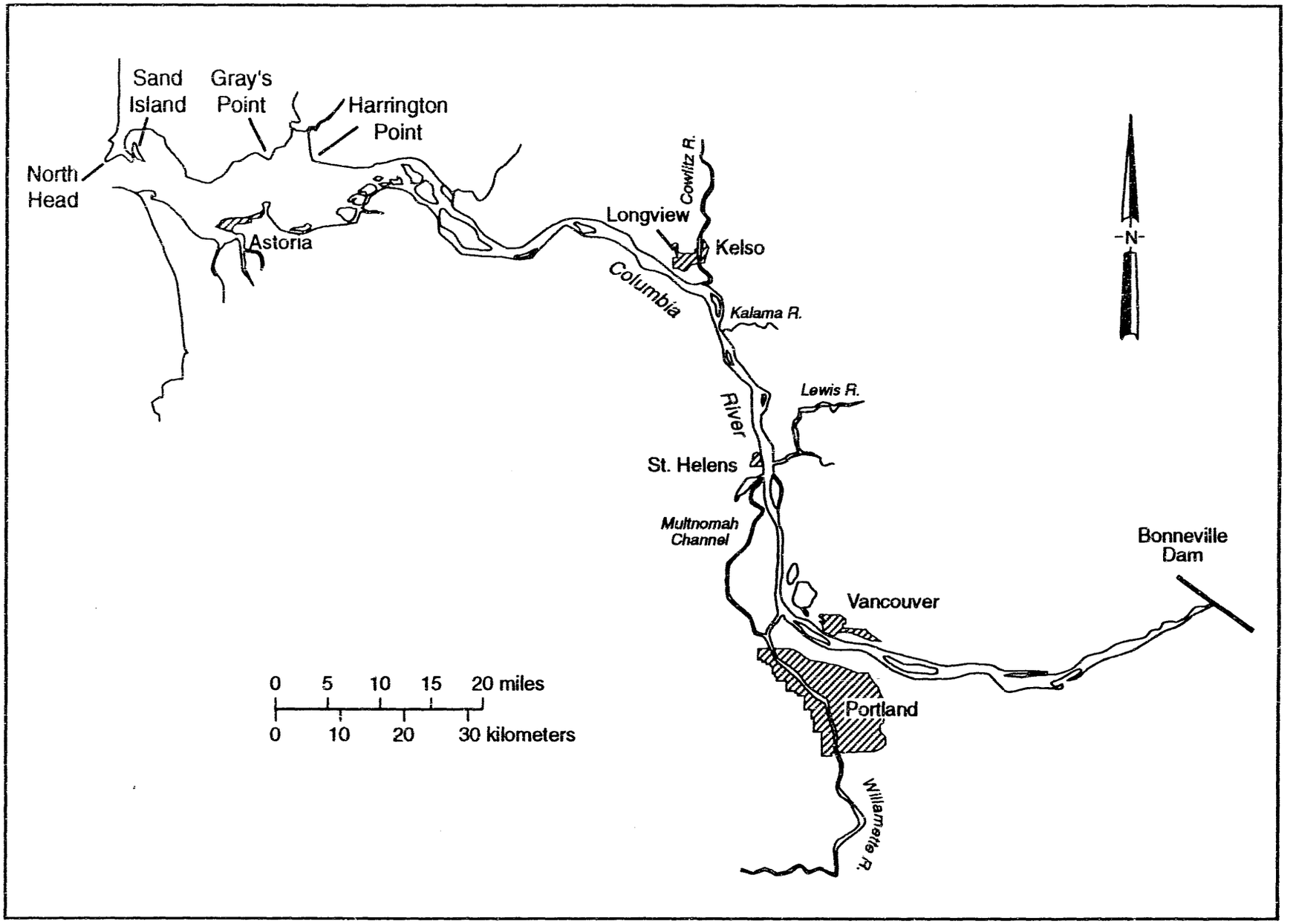

FIGURE 4.4. Fish and/or Shellfish Sampling Locations on the Columbia River Below Bonneville Dam

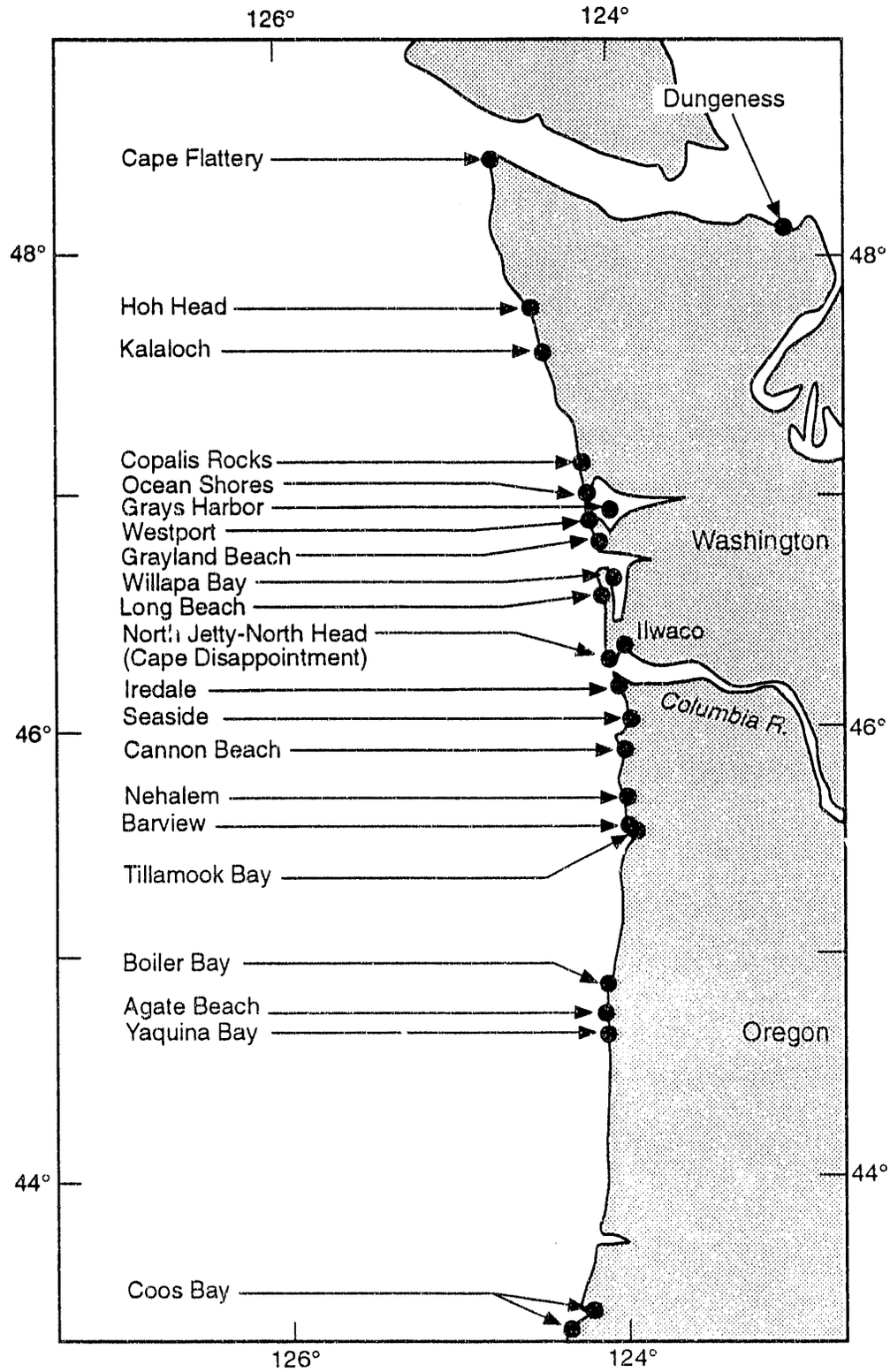

FIGURE 4.5. Fish and/or Shellfish Sampling Locations Along the Pacific Coasts of Washington and Oregon

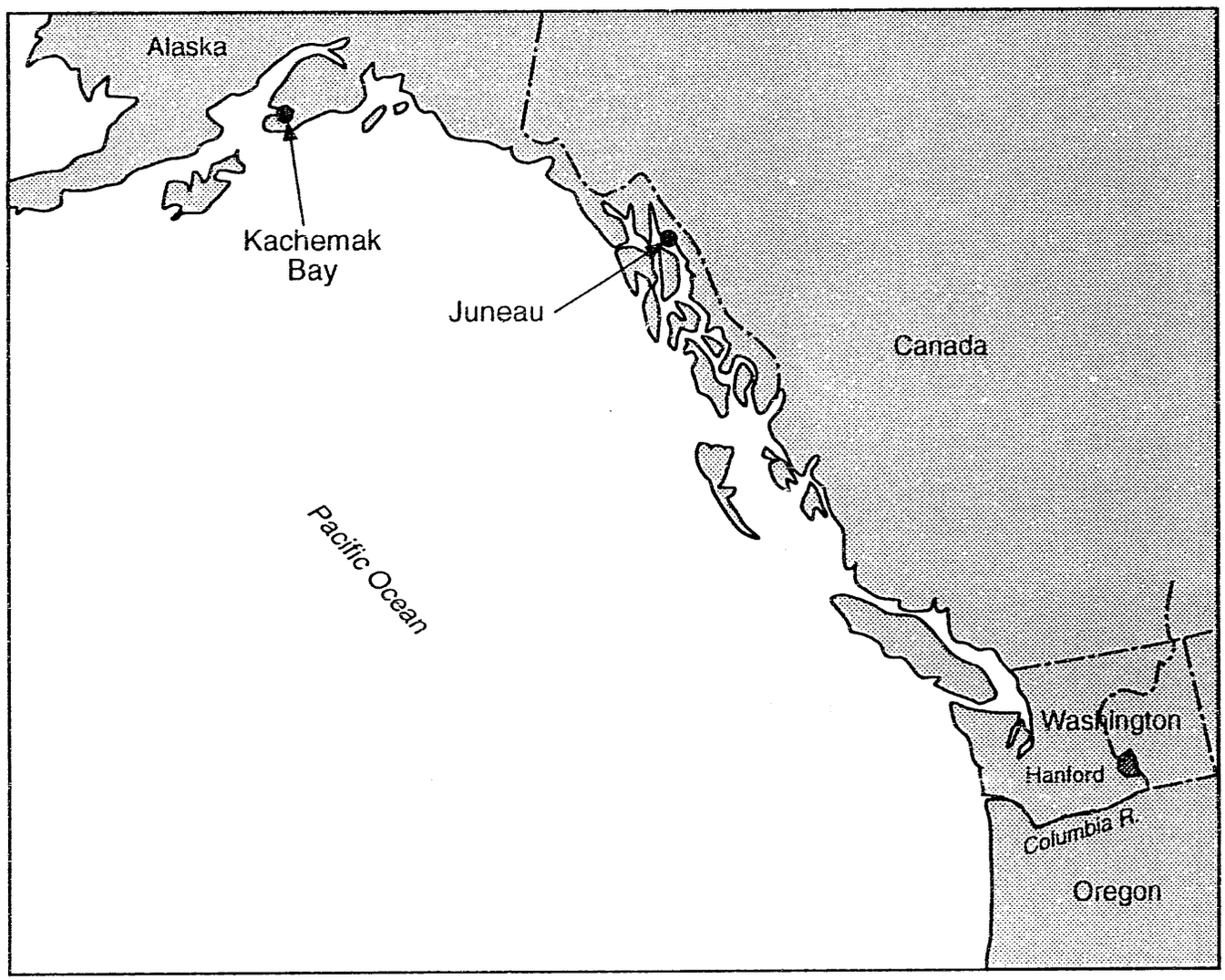

FIGURE 4.6. Fish and/or Shellfish Sampling Locations in Alaska

5.0 SAMPLE ANALYSES

Between 1945 and 1955, analysis results were generally reported as gross beta, "beta activity," or just "activity" per unit mass of tissue. Concentrations of specific radionuclides were sometimes provided, but identifications were usually accomplished through the use of decay curves to determine the activity half-life. Some alpha concentration data were also reported, usually in units of disintegrations/minute/ gram (d/m/g). In 1956 and 1957, researchers began using gamma-ray spectroscopy to identify specific gamma-emitting radionuclides. Most samples analyzed for gamma emitters in subsequent years were analyzed using this new procedure.

The radiation concentration and dose units used in this report are generally the same units reported in the original historical documents. By current standards some of these units are outdated. Table 5.1 lists the historical concentration and dose units as originally reported and the corresponding units in use today.

Animals were either analyzed whole or dissected so that individual tissues and organs could be examined. Small fish were usually analyzed whole. Sometimes several small fish were combined to generate a sample with enough mass for analysis. Most large fish were cut up. Concentration data for a large variety of fish tissues and organs were reported in most years.

Both marine and freshwater shellfish were usually separated from their shells prior to analysis. Data for most shellfish are for the soft tissues only; however, radionuclide levels in shells were occasionally measured.

Concentration data for a wide variety of waterfowl organs and tissues were reported during the 1940s and 1950s. After 1960, most analyses were done only on heads and muscle tissue. Generally, heads and/or muscle tissue were analyzed from birds collected on the Site, but only heads were obtained from local hunters for analysis (BNWL-90).

TABLE 5.1. Current and Historical Units for Reporting Radionuclide Concentrations and Radiation Dose

Unit	Symbol	Radiation	
		Historical Units	Current Units
milli (10^{-3})	m	mCi	mCi
micro (10^{-6})	μ	μCi	μCi
nano (10^{-9})	n	mμCi	nCi or 10^{-3} μCi
pico (10^{-12})	p	$\mu\mu$Ci	pCi
		10^{-6} μCi	pCi
		dis/min/kg	0.451 pCi/kg or 4.51×10^{-4} pCi/g
		μCi/kg	nCi/g
		Radiation Dose	
		mrep	mrem
		millirad	mrad
		rad	rad

REFERENCE

BNWL-90 Foster, R.F. (manager), and R.H. Wilson (editor). 1965. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964. Pacific Northwest Laboratory, Richland, Washington.

6.0 IMPORTANT RADIONUCLIDES

Early decay studies determined that different organisms and tissues accumulated different quantities of specific radionuclides. This was later confirmed with gamma-ray spectroscopy. For fish, the primary radionuclide of concern was phosphorous-32 (HW-36074; Robeck et al. 1954). Although the concentration of phosphorous-32 in reactor effluents was relatively small, fish tended to accumulate elevated quantities relative to normal Columbia River levels because the concentration of natural phosphorous in Columbia River water was low (HW-25021) and the element is active in biological systems. Other radionuclides of importance in fish included sodium-24, zinc-65, and manganese-25.

Shellfish tended to accumulate zinc-65 and phosphorous-32 in their tissues. These were the only two radionuclides of Hanford origin beyond the mouth of the Columbia River that were of radiological interest (HW-76526). Pacific coast oysters were found to contain more zinc-65 than other common seafoods (HW-80991).

Phosphorous-32 was also the major contaminant in waterfowl samples. However, other radionuclides, including potassium-40, zinc-65, strontium-90, and cesium-137, were also identified.

The concentrations of radionuclides in the Hanford environment were directly related to activities on the Site. Table 6.1 outlines the operating periods for the 8 once-through-cooling reactors that were on-line during the period covered by these annual summaries. This information may assist the reader in evaluating the concentration data that are provided in these annual summaries. A small amount of additional information on reactor operations is also included in some of the individual annual summaries.

TABLE 6.1. Operating Periods for Hanford's Once-Through-Cooling Reactors

Reactor	Startup Date	Retirement Date
100-B	September 1944	1968
100-D	December 1944	June 1967
100-F	February 1945	June 1965
100-H	November 1945	April 1965
100-DR	October 1950	December 1964
100-C	November 1952	April 1969
100-KW	January 1955	February 1970
100-KE	April 1955	January 1971

REFERENCE

HW-36074 Davis, J.J., D.G. Watson, and C.C. Palmiter. 1956. Radiological Studies in the Columbia River Through December, 1955. General Electric Company, Hanford Works, Richland, Washington.

HW-80991 Foster, R.F. (manager), and R.H. Wilson (editor). Evaluation of Radiological Conditions in the Vicinity of Hanford for 1963. General Electric Company, Hanford Works, Richland, Washington.

HW-25021 Kornberg, H.A. 1952. Biological Research Annual Report. 1951. General Electric Company, Hanford Works, Richland, Washington.

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7.0 OVERVIEW OF ANNUAL FISH, SHELLFISH, AND WATERFOWL SUMMARIES, 1945 - 1972

The remainder of this document summarizes annual radionuclide contamination data for fish, shellfish, and waterfowl for the years 1945 to 1972. Samples were collected by Hanford monitoring personnel and by offsite organizations, both government and private, from a large region surrounding the Site. Each summary includes information on the media, sampling locations, radionuclides measured/reported, and references. For ease of reading and reference, the data for each year are presented in separate sections.

8.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1945

8.1 MEDIA SAMPLED

8.1.1 Fish

The analysis of fish tissues for radiological contamination was just beginning at the Hanford Site in 1945. Samples were, therefore, few in number and randomly obtained.

Several suckers were collected from the Columbia River and analyzed for radionuclide contamination. Tissues examined included muscle, kidneys, liver, vertebrae, and skin and scales (HW-3-3442; HW-3-2894 DEL; HW-7-1228 DEL). The collection of a number of large (12-inch) Columbia River suckers was discussed (HW-3-2894 DEL). The first analyses on laboratory-raised fish were done on September 14, 1945.

8.1.2 Shellfish

There was no information obtained from reviewed documents concerning shellfish. It is probable that there were no shellfish collected from the Hanford Site or vicinity for radiological analyses in 1945.

8.1.3 Waterfowl

Information on waterfowl sampling was not located in the reviewed documents. It is likely that waterfowl were not collected from the Hanford Site and vicinity for radiological analyses during 1945.

8.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

8.2.1 Fish

Columbia River fish were collected from near the 1904 spillway in the 100-F Area (HW-3-2894 DEL).

8.3 RADIONUCLIDES MEASURED/REPORTED

8.3.1 Fish

During 1945, very little was known about the effects of radiological contamination on aquatic organisms. Samples were collected to determine dose to the organism; to find out how much radioactive material, if any, was depositing in the tissues; and to identify which radionuclides the organisms were accumulating. Identifications of specific radionuclides were generally accomplished through the use of decay curves to determine the half-life of the activity.

Activities were reported in Ci/g, μCi/g, or μCi/kg for the various tissues (HW-3-3442; HW-3-2894 DEL; HW-7-1228).

Decay curves developed on the Columbia River fish indicated that the activity had a half-life of about 15 days, signifying that the radionuclide was probably phosphorous-32 (HW-3-2894 DEL).

Most fish samples were ashed, then counted (HW-3-3442 DEL).

For the Columbia River suckers analyzed, the maximum activity was seen in the kidney (0.29 μCi/kg), and the lowest was found in the vertebrae (0.05 μCi/kg). The skin and scales had an activity of 0.21 μCi/kg, and the liver had 0.19 μCi/kg. Activity in the muscle was 0.08 μCi/kg (HW-3-3442; HW-3-2894 DEL; HW-7-1228 DEL). Initial decay curves indicated that the half-life of the activity was 10 to 30 days. Later reports narrowed this down to 15 days. An absorption curve on a skin sample yielded a 1.4 to 1.5 MeV beta (HW-3-2894 DEL).

Initial studies indicated that a good dissection technique was important to avoid contamination of other tissues (HW-3-2894 DEL).

Additional studies exposing salmon, trout, and salmon eggs to reactor effluent were discussed; highest activities were seen in the liver (HW-3-2894 DEL; HW-3-3442).

REFERENCES

HW-3-2894 DEL Healy, J.W. 1945. Special Studies Branch Weekly Reports for the Period May 20, 1945 to December 31, 1945. Hanford Engineer Works, Richland, Washington.

HW-3-3442 Healy, J.W. 1946. Accumulation of Radioactive Elements in Fish Immersed in Pile Effluent Water. Hanford Engineer Works, Richland, Washington.

HW-7-1228 DEL Parker, H.M. 1945. Monthly Reports - Health Instruments Section - for 1945. Hanford Engineer Works, Richland, Washington.

9.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1946

9.1 MEDIA SAMPLED

9.1.1 Fish

Fish from the Hanford Reach of the Columbia River and the lower Yakima River were collected and analyzed for radionuclide contamination. Species collected included squawfish (also called Oregon pike), bream (redside shiner), whitefish, course-scaled (largescale) suckers, fine-scaled (bridge-lip) suckers, mountain suckers, chiselmouth, sockeye salmon, smallmouth bass, pumpkinseed sunfish, chub (peamouth), and carp (HW-3-5501; HW-3-3383). Additional information on unidentified fish was also available (HW-7-4699; HW-11509; HW-7-4312). Small fish were analyzed whole, while large fish were dissected before being analyzed (HW-3-5501). Tissues analyzed included liver, kidneys, skin and scales, muscle, bone, and gills (HW-3-5501; HW-3-3383).

Laboratory studies were done throughout the year, exposing hatchery-reared salmon fingerlings and salmon eggs to various concentrations of reactor effluents. These studies are not discussed in this summary.

9.1.2 Shellfish

There were no shellfish data in the reviewed documents.

9.1.3 Waterfowl

Several ducks, teals, and coots were analyzed for radionuclide contamination. Tissues analyzed included gizzard, liver, cecum, muscle, bone, kidney, and blood (HW-7-5428; HW-7-5301; HW-7-4699; HW-3-3383; HW-7-4474).

9.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

9.2.1 Fish

Columbia River fish-collection areas included sites 1.5 and 10 miles above 100-B, near 100-F, 6 miles downstream from Hanford, and near the 300 Area (20 miles below 100-F) (HW-3-5501; HW-3-3383). Yakima River fish

were collected at locations 5 and 10 miles upstream from the mouth of the river (below and above the dam [probably Horn Rapids Dam], respectively) (HW-3-3383; HW-3-5501; HW-7-4699).

9.2.2 Waterfowl

Waterfowl were collected primarily from the 300 Area retention pond (HW-7-5301; HW-7-5145; HW-7-4699; HW-3-3383). One bird was sampled from the lower Yakima River (HW-7-5428).

9.3 RADIONUCLIDES MEASURED/REPORTED

9.3.1 Fish

Data for fish collected from the Columbia and Yakima Rivers in 1946 were reported in the routinely issued weekly and monthly Hanford Site reports. However, the information in these reports was often sketchy and incomplete. A more complete summary of the analytical information obtained from these fish was compiled in HW-3-3383. Additional detailed analytical information for many of the fish and wildlife samples collected can be found in notebook HEW-594-T.

Fish samples were monitored for beta activity. Tabulated results were generally reported in units of μCi/kg (HW-7-4699; HW-3-3383) or mμCi/kg (HW-3-5501).

Fish tissues were ashed and dissolved with several applications of nitric acid on platinum (HW-3-3442) or stainless steel (HW-3-5501) plates, then counted for five minutes to one hour. Results for platinum plates were corrected for 20% geometry (HW-3-3442). Geometry corrections for 1-inch and 1.5-inch stainless steel plates were 20% and 15%, respectively. Analyses were usually done within six hours of collection, but count delays ranged from 2 to 30 hours. Counts were not corrected for decay (HW-3-5501). Decay studies were done on samples with the highest initial counts. These studies indicated that the radionuclide in greatest concentration was phosphorous-32 (HW-3-3383; HW-3-5501; HW-11509). Longer-lived material appeared to be potassium-40 (HW-11509; HW-3-5501).

Radioactivity levels in fish tissues were highest in kidneys and livers. The maximum activity, 0.5μCi/kg, was found in the liver of a sucker from near Hanford (HW-3-5501; HW-11509).

River fish collected in 1946 showed similar activity levels at 100-F and Hanford, while fish collected at the 300 Area averaged about 75% the levels detected at Hanford (HW-11509).

Fish tissues showed a significant increase in activity from May to August. This increase varied with radionuclide concentrations in the water and inversely with river flow. Elevated water temperature may also have contributed to the increased activity. Muscle tissue showed the smallest seasonal fluctuations due to its low rate of uptake and the presence of a longer-lived material (probably potassium-40) (HW-3-5501).

Concentration factors (fish activity/water activity) for phosphorous-32 in fish approached 100,000 X (HW-11509; HW-3-5501). Concentration factors for various fish and fish body parts were reported (HW-3-5501).

In HW-3-5501, concentration data were tabulated by collection location. Concentrations increased as summer progressed and highest levels were seen in August. Maximum activities for each location are listed below:

1.5 miles above 100-B:	Maximum was <40 mμCi/kg in the gills of a red-side shiner.
10 miles above 100-B:	Maximum was <40 mμCi/kg in the gills of a red-side shiner. Two salmon were collected at this location. Maximum activities were found in the kidney (~20 mμCi/kg) and in the muscle (~2mμCi/kg).
100-F Area in July:	The maximum was 100 mμCi/kg in the skin of a whitefish. The average for muscle for several species was ~10 mμCi/kg.
100-F Area in August:	The maximum was <1000 mμCi/kg in the kidney of a sunfish. The average for muscle for several species was 14 mμCi/kg.
Near Hanford:	A maximum activity of 500 mμCi/g was seen in the liver of a largescale sucker in August. The average activity in muscle for several species of fish in the month of August was 20 mμCi/kg.

Near the 300 Area:	Maximum activity (150 mμCi/kg), was seen in the bone and liver of a largescale sucker and in the gills of a chiselmouth. The average activity in muscle for several species of fish in the month of August was 17 mμCi/kg.
Yakima River:	A sucker collected below the dam on the lower Yakima River had some activity in the muscle (10 ± 2 counts per minute). A carp caught above the dam had no activity in its body tissues.

"Fish may accumulate radioactive materials principally through ingestion of smaller animals and plants which had previously accumulated these elements" (HW-3-5501).

A shiner and a squawfish were caught in early May about 1.5 miles above 100-B. Maximum activity in the squawfish (0.0018 μCi/kg) was found in the kidney. Little or no activity was found in the shiner (HW-3-3383).

In mid-May, a squawfish caught from the river at 100-F exhibited activity in all tissues. The maximum activity was 0.05 μCi/kg in the muscle (HW-3-3383).

In late May and early June four suckers and a chiselmouth were caught 0.75 miles northeast of the 300 Area. The maximum activity was 0.04 μCi/kg in the liver of one sucker. Other activities ranged from 0.003 to 0.03 μCi/kg (HW-3-3383).

A sucker caught 5 miles up the Yakima River in the late May and early June time period had low activities, with the muscle being the only tissue above background (0.002 μCi/kg) (HW-3-3383).

In mid-June, 2 suckers, 2 shiners and a whitefish were caught 10 miles upstream from 100-B. Maximum activity (0.04 μCi/kg) was found in the gills of a shiner. Other activities ranged from 0.01 to 0.001 μCi/kg (HW-3-3383).

In late June/early July, four fish were caught near 100-F. The maximum activity (0.5 μCi/kg) was found in the kidney of a shiner. Other activities ranged from less than 0.002 to 0.1 μCi/kg. The maximum activity observed in five fish collected near Hanford during the same time period was 0.15 μCi/kg

in the bone of a sucker. Other activities in the fish from Hanford ranged from 0.0027 to 0.12 μCi/kg (HW-3-3383).

In mid-July, eight fish were caught near the 300 Area. A maximum activity of 0.048 μCi/kg was found in the liver of a whitefish. Eleven fish were also collected nine miles upstream from 100-B during this time period. Activities ranged from 0.001 μCi/kg in the bone of a shiner to a maximum of 0.9 μCi/kg in the kidneys of a sunfish (HW-3-3383).

In late July and early August, six fish sampled nine miles above 100-B had activities ranging from 0.002 to 0.02 μCi/kg. Five fish from 100-F had activities ranging from 0.01 to 0.47 μCi/kg (HW-3-3383).

In August, seven fish from Hanford showed activities from 0.004 to 0.5 μCi/kg in all organs. Six fish caught near the 300 Area had concentrations ranging from 0.005 to 0.15 μCi/kg (HW-3-3383).

9.3.2 Waterfowl

A single duck was collected from the lower Yakima River in November. Traces of alpha activity were found in the gizzard and liver. A maximum beta level of 10^{-2} μCi/kg was found in the cecum (HW-7-5428).

Analyses of tissues from waterfowl collected from the 300 Area retention pond indicated that about 90% of the measured alpha activity was uranium (HW-7-5428).

Maximum concentrations of alpha and beta seen in the cecum of waterfowl collected from the 300 Area retention pond in October were 70,000 dis/min/kg and 0.08 μCi/kg, respectively. Alpha and beta activity in muscle and edible tissues were 5200 dis/min/kg and 0.028 μCi/kg, respectively (HW-7-5301).

One coot sampled from the 300 Area pond in September had an alpha count of 0.00013 dis/min/kg in the cecum (HW-7-5145).

The gizzard from a teal collected from the 300 Area pond in August had an alpha level of 3500 dis/min/kg. The leg bone of the teal had a maximum beta activity of 0.066 μCi/kg (HW-7-4699; HW-3-3383).

Liver, kidney, and bone samples from several birds collected from the 300 Area pond in July had alpha levels of about 500 dis/min/kg (HW-7-4474).

Two coots and a duck were sampled from the 300 Area pond in July. Maximum alpha counts (220,000 dis/min/kg) were found in the contents of the duck cecum. High alpha counts were seen in other body tissues also. Alpha results were obtained using experimental methods. Beta levels ranged from 0.001 μCi/l in the blood to 0.1 μCi/kg in the cecum of the duck. Beta activity in coot breasts was on the order of 0.001 μCi/kg (HW-3-3383).

REFERENCES

HW-7-4312 Gamertsfelder, C.C. 1946. Health Instrument Section Report for June, 1946. Hanford Engineer Works, Richland, Washington.

HW-7-4474 Gamertsfelder, C.C. 1946. Health Instrument Section Report for July, 1946. General Electric Company, Hanford Works, Richland, Washington.

HW-7-4699 Gamertsfelder, C.C. 1946. Health Instrument Section Report for August, 1946. General Electric Company, Hanford Works, Richland, Washington.

HW-3-3383 Healy, J.W., and P.L. Eisenacher. 1946. Health Instrument Section Special Studies Reports - January thru August, 1946. Hanford Engineer Works, Richland, Washington.

HEW-0594-T Herde, K.E. 1946. Technical Notebook for the Period Covering 12/6/45 Through 8/29/46, Copy 1-B. Hanford Engineer Works, Richland, Washington.

HW-3-5501 Herde, K.E. 1947. Radioactivity in Various Species of Fish from the Columbia and Yakima Rivers. Hanford Engineer Works, Richland, Washington.

HW-11509 Herde, K.E. 1948. Radioactivity of Pile Effluent and Its Biological Significance. General Electric Company, Hanford Works, Richland, Washington.

HW-7-5145 Parker, H.M. 1946. Health Instrument Section Report for September, 1946. General Electric Company, Hanford Works, Richland, Washington.

HW-7-5301 Parker, H.M. 1946. Health Instrument Section Report for October, 1946. General Electric Company, Hanford Works, Richland, Washington.

HW-7-5428 Parker, H.M. 1946. Health Instrument Section Report for November, 1946. General Electric Company, Hanford Works, Richland, Washington.

10.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1947

10.1 MEDIA SAMPLED

10.1.1 Fish

Columbia River fish were collected and analyzed for radionuclide contamination. Species sampled included fine-scaled (bridgelip) suckers, course-scaled (largescale) suckers, chiselmouth, mountain suckers, squawfish, shiners, whitefish, smallmouth bass, chub (peamouth), sockeye salmon, bullheads, and carp. Tissues analyzed included liver, sperm, eggs, kidney, gill, skin, bone, gonads, and muscle; gut contents and feces were also tested. Analyses results were not reported for all fish collected.

Fish were apparently collected weekly from April 2, 1947, to April 6, 1948 (HW-3-5160). Data were reported for fish collected from July 1947 through October 1947. "Six or less fish were taken for assay each week. Game fish were not caught in abundance but were always sampled when available" (HW-11344).

Laboratory studies exposing Chinook Salmon and Chinook Salmon eggs to reactor effluent water were conducted throughout the year. Summary information was reported in biweekly fish lab reports (HW-7267; HW-7668; HW-7547; HW-7432; HW-8166; HW-8308; HW-8080; HW-7325; HW-7822; HW-7951; HW-7132; HW-8421). Data for experiments conducted through October 20, 1947, were described in greater detail in HW-8944. The data from these laboratory exposures are not discussed in this summary.

10.1.2 Shellfish

If any shellfish were collected and analyzed during 1947, the data were not discussed in the reviewed documents.

10.1.3 Waterfowl

Twenty-four pekin ducks (a white, domestic breed) were placed on the Columbia River for monitoring purposes. Tissues analyzed included thyroid, pancreas, bone, liver, spleen, gonads, kidney, muscle, lung, blood, and brain; feces, and, when available, eggs were also analyzed (HW-12079).

10.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

10.2.1 Fish

Fish were collected from the west bank of the Columbia River in the "Hanford vicinity" (HW-11344).

10.2.2 Waterfowl

Waterfowl were collected from a colony established on the Columbia River at 100-F (HW-12079).

10.3 RADIONUCLIDES MEASURED/REPORTED

10.3.1 Fish

"Tissues were assayed for beta emitting materials" (HW-11344).

Results for various tissues sampled from fish caught during 1947 were reported in a table in units of mμCi/kg. These fish were specifically selected because of their high radioactivity levels. Peak activities were seen about October 1, when river flows were average. The maximum activity (1.1 μCi/kg) was seen in the gut contents of a course-scaled (largescale) sucker caught in early October. The maximum activity found in fish tissues (0.85 μCi/kg) was found in the bone of a fine-scaled (bridgelip) sucker collected on September 9, 1947 (HW-11344).

Samples analyzed were from 1 to 5 grams. Ashed tissues were counted between two and seven hours after being collected. A 15% geometry was used to interpret results. Experimentation indicated that as much as 60% of the radioactivity was lost during the ashing process. Consequently, reported levels may have been low by a factor of 1.5 to 2.0.

Decay studies and beta absorption studies were done on some samples. Results indicated that phosphorous-32 was the primary constituent, and sodium-24 represented 10% of the total activity in about half of the tissues. Concentrations of potassium-40 in several fish tissues also were discussed (HW-11344).

The average activity level for fine-scaled (bridgelip) suckers and chiselmouth caught from the Columbia River between July and October was 40 mμCi/kg. The average for smallmouth bass and course-scaled (largescale) suckers was 30 mμCi/kg. Mountain suckers, whitefish, and squawfish had an average activity level of 20 mμCi/kg, and sockeye salmon had an average activity of 5 mμCi/kg (HW-11344).

"Muscle was consistently lowest in activity, never being over 0.1 μCi/kg" (HW-11344). The maximum activity found in the muscle of a sucker was 0.1 μCi/kg. Activities ranged from 0.02 to 0.1 μCi/kg in six fish sampled (HW-11344). The maximum activity found in the muscle of a bass was 0.03 μCi/kg, with activities ranging from 0.01 to 0.03 μCi/kg in three fish (HW-11344). The maximum activity found in the muscle of whitefish was 0.04 μCi/kg. Activities ranged from 0.02 to 0.04 μCi/kg in two fish sampled (HW-11344). The maximum activity found in the muscle of sockeye salmon was 0.007 μCi/kg, with activities ranging from 0.004 to 0.007 μCi/kg in three fish sampled (HW-11344).

In April up to 70% of the activity in fish was from sodium-24. In May 1947, fish were found to have lower sodium-24 activities. A decrease in sodium-24 activities was seen in May 1946, also. The uptake of sodium-24 appeared to be seasonal, but the cause was unexplained (HW-7-6392).

The maximum activity for twenty-four fish caught in May from the Columbia was 0.16 μCi/kg, in liver tissue (HW-7-6392).

10.3.2 Waterfowl

Thyroids containing iodine-131 originating from 200 Area stack effluents had the highest activities of all tissues (HW-12079).

Decay studies indicated that phosphorous-32 was the principal radioisotope present in waterfowl tissues, although a longer half-lived element presumed to be iron-59 was occasionally present (HW-12079).

Results for various tissues were presented in table form in units of μCi/kg (HW-12079).

A maximum concentration of 1.3 μCi/kg was found in the thyroid of a duck analyzed in October 1947 (HW-12079).

The maximum activity found in the muscle tissues of ducks was 0.01 μCi/kg, sampled in September and October (HW-12079).

REFERENCES

HW-7668 Foster, R.F. 1947. Fish Laboratory Report for the Last Half of September, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7822 Foster, R.F. 1947. Fish Laboratory Report for the First Half of October, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7951 Foster, R.F. 1947. Fish Laboratory Report for the Last Half of October, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-8080 Foster, R.F. 1947. Fish Laboratory Report for the First Half of November, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-8166 Foster, R.F. 1947. Fish Laboratory Report for the Last Half of November, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-8308 Foster, R.F. 1947. Fish Laboratory Report for the First Half of December, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-8421 Foster, R.F. 1947. Fish Laboratory Report for the Last Half of December, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-11344 Herde, K.E. 1948. A One Year Study of Radioactivity in Columbia River Fish. General Electric Company, Hanford Works, Richland, Washington.

HW-12079 Herde, K.E., and J.F. Cline. 1949. Radioactivity in Pekin Ducks on the Columbia River. General Electric Company, Hanford Works, Richland, Washington.

HW-3-5160 Olson, P.A., and R.F. Foster. 1946. Fish Laboratory Report - December 1946 Through June 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7132 Olson, P.A. 1947. Fish Laboratory Report for the First Half of July, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7267 Olson, P.A. 1947. Fish Laboratory Report for the Last Half of July, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7325 Olson, P.A. 1947. Fish Laboratory Report for the First Half of August, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7432 Olson, P.A. 1947. Fish Laboratory Report for the Last Half of August, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-7547 Olson, P.A. 1947. Fish Laboratory Report for the First Half of September, 1947. General Electric Company, Hanford Works, Richland, Washington.

HW-8944 Olson, P.A. 1948. Some Effects of Pile Effluent Water on Young Silver Salmon. General Electric Company, Hanford Works, Richland, Washington.

HW-7-6392 Parker, H.M. 1947. Health Instrument Section Report, June 6, 1947. General Electric Company, Hanford Works, Richland, Washington.

11.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1948

11.1 MEDIA SAMPLED

11.1.1 Fish

Columbia River fish were analyzed for radionuclide contamination. Species sampled included mountain suckers, fine-scaled (bridgelip) suckers, course-scaled (largescale) suckers, chiselmouth, squawfish, shiners, chubs (peamouth), Rocky Mountain whitefish, smallmouth bass, bullheads, silver trout (kokanee), carp, white sturgeon, and sockeye salmon (HW-11344; HW-23093). Blueback (sockeye) salmon were also collected (HW-10714 E). Small fish (<5 grams) were analyzed whole, sometimes using more than one specimen of the same species to achieve the desired mass of tissue. Large fish were dissected so that individual tissues and organs could be analyzed. In addition to feces, tissues routinely examined included liver, kidney, ovary or testes, bone, gills, skin, scales, and muscle. Other tissues included blood, spleen, intestine, gall bladder, stomach, heart, eye, brain, and fin (HW-11344; HW-23093). Some information on fish and fish tissues was discussed in documents covering data collected between 1947 and 1952, but it was difficult to determine which results were obtained from fish collected in 1948 (HW-23093; HW-11344). Additional 1948 collections included salmon fry (HW-12573) and dead whitefish (HW-11861).

Laboratory studies exposing fish to various concentrations of reactor effluent were conducted throughout the year and discussed in bi-monthly fish laboratory reports and Health Instrument Divisions monthly reports. Laboratory studies are not discussed in this summary.

11.1.2 Shellfish

Shellfish sampling and analyses were not addressed in the reviewed douments.

11.1.3 Waterfowl

Waterfowl collected and analyzed in 1948 included pekin ducks (a white domestic breed), which were maintained in colonies at several locations on the

Site (HW-11499 E; HW-11226 E; HW-12079; HW-8859; HW-9191 K; HW-9595 K; HW-10714 E), as well as teals (HW-10993 E). Samples examined included thyroid, liver, pancreas, bone, muscle, brain, lung, spleen, kidney, ovaries or testes, and blood (HW-11499 E; HW-12079; HW-10993 E; HW-11226 E). Soft tissues, whole bone, bone shaft, spongy bone, and bone marrow were also analyzed (HW-10714 E).

11.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

11.2.1 Fish

Routine Columbia River fish collections were made from the west bank in the "Hanford vicinity" (HW-11861; HW-12086 E; HW-11344). Dead whitefish were collected from the west bank of the river between Priest Rapids and Richland, Washington. (HW-11861). Some small fish and parts of large fish (frequently sturgeon) were sent to Hanford bi-weekly from Bonneville for analysis (HW-23093).

11.2.2 Waterfowl

Ducks were periodically collected from colonies established on the Site for monitoring purposes. Locations included 100-F (HW-12079; HW-11499 E; HW-8859; HW-9595 K; HW-10714 E), the 200-N Area, and the 300 Area pond (HW-11226 E; HW-10993 E).

11.3 RADIONUCLIDES MEASURED/REPORTED

11.3.1 Fish

Fish were "assayed for beta-emitting materials." Decay studies and beta-absorption studies were done on some samples (HW-11344). During 1948, few results were reported for specific fish or fish tissues. However, when results were given, they were reported in units of μCi/kg (HW-11499 E; HW-12086 E; HW-10714 E; HW-10993 E; HW-11226 E; HW-11861).

In July 1948, four blueback (sockeye) salmon were captured in a net at Hanford as part of the routine biweekly collections. A very small amount of radioactivity (0.005 μCi/kg) was found in the tissues analyzed (HW-10714 E).

Phosphorus-32 was the predominant radionuclide present in fish, with small amounts of sodium-24 present in some cases (HW-23093; HW-11344).

Fish tissue samples were ashed with acid and heat, then counted (HW-23093). A 15% geometry was used to interpret results. Experimentation indicated that as much as 60% of the radioactivity was lost during the ashing process (HW-11344).

During the first part of December 1948, a large number of dead or dying whitefish were found along the Columbia River shoreline between Priest Rapids and Richland. Activity levels in these fish included 0.03 μCi/kg in gills, liver, and testes; 0.01 μCi/kg in muscle; and 0.02 μCi/kg in bone. These results were comparable to results for whitefish sampled from this location in previous months. The whitefish apparently died from an unknown kidney ailment (HW-11861). It is possible that this ailment was tuberculosis. Tuberculosis affects many Columbia River whitefish and often causes discolorations, or lesions, in the kidney (Lund and Abernathy, 1978).

A chiselmouth collected in August as part of routine sampling had 0.5 μCi/kg in the liver, kidney and bone (HW-10993 E; HW-20277-RD).

Activities in fish caught at Richland were about two-thirds of those seen in fish caught at Hanford (HW-23093).

Fish feces samples collected in September had concentrations of 0.4 μCi/kg. A sucker showed similar activity in the eggs, bone, and liver (HW-11226 E).

The juvenile stages were more radioactive than the adult stages (HW-23093).

The 100-B Area reactor was restarted in September, resulting in higher activities in the water (HW-11226 E).

The food chain is the most important process by which radioactivity is accumulated. The kinds of food, amount eaten, size, rate of growth, and metabolism all contribute to the amount of radioactivity present (HW-23093).

A sucker collected in October showed activities of 0.4 μCi/kg in the liver and bone, and 0.3 μCi/kg in the gill. A squawfish had 0.4 μCi/kg in the gill (HW-11499 E).

Seasonal variations are related to metabolic rate rather than the activity density of the water (HW-23093).

In the vicinity of Hanford, a sucker collected during winter had a concentration of about 0.15 μCi/kg in the gills, liver, and bone, which is comparably low and due to the colder weather (HW-12086 E; HW-20277-RD).

The calcareous tissue of the scales had the highest radionuclide concentrations in virtually every species. The liver had the highest of any visceral organs and, with the exception of the eyes and fat, the activity of the muscle was below that of the other tissues (HW-23093).

Increases of radioactivity in fish from year to year were attributed to changes in nuclear reactor operations, rather than to accumulation of long-lived isotopes (HW-23093).

11.3.2 Waterfowl

Waterfowl monitoring stations (duck colonies) were set up at various locations on the Site. However, because the birds were not free to change locations, tissue concentrations may have been artificially high and not representative of tissue activities in wild birds.

Phosphorus-32 was the predominant radionuclide present in waterfowl, although iron-59 was occasionally present (HW-12079).

Waterfowl thyroids containing iodine-131 from 200 Area Stack gas contamination had the highest activity of all waterfowl tissues. In 1948, the average activity found in waterfowl thyroids was 0.33 μCi/kg, with a maximum of 0.7 μCi/kg. Average activities in the liver and bone were 0.027 μCi/kg, with maximum activities of 0.06 and 0.15 μCi/kg, respectively. The average activity found in the muscle was 0.013 μCi/kg, and the maximum activity was 0.03 μCi/kg (HW-12079).

In January 1948, a pekin duck from the 100-F area colony was analyzed after it was killed by a predator. The highest activity was 0.2 μCi/kg in the thyroid. The kidney and bone marrow contained 0.01 μCi/kg and 0.04 μCi/kg, respectively (HW-8859).

A female pekin duck from the monitoring program was analyzed in February. The highest activity was 0.6 μCi/kg in the thyroid. Activities

for other tissues included 0.12 μCi/kg in bone, 0.06 μCi/kg in the pancreas, 0.046 μCi/kg in the liver, 0.036 μCi/kg in the kidney, 0.035 μCi/kg in the spleen, 0.02 μCi/kg in muscle, 0.013 μCi/kg in blood, and 0.002 μCi/kg in the lung (HW-9191 K).

In March, a female duck from the colony on the river at 100-F was sacrificed. Activities were 30 to 60 percent less than those seen the previous month (HW-9595 K).

Thyroid readings in July were twenty to thirty times less than readings obtained 18 to 24 months previously, due to the increased cooling time of slugs (irradiated fuel elements) (HW-10714 E).

In July, activity densities for a domestic duck collected from the Columbia River at 100-F were 0.2 μCi/kg for the thyroid and less than 0.02 μCi/kg for all other tissues. A duck from R Ditch, in the 200-N Area, had about 0.03 μCi/kg in soft tissue, 0.2 μCi/kg in whole bone, 0.3 μCi/kg in the bone shaft, and less than 0.04 μCi/kg in the spongy bone and marrow. Decay studies suggested that the radionuclide in the whole bone sample was strontium-89 (HW-10714 E).

In August 1948, a pekin duck from the 200-N area had activities of 0.38 μCi/kg in the thyroid, 0.047 μCi/kg in the liver, 0.034 μCi/kg in the pancreas, 0.14 μCi/kg in the bone, and 0.014 μCi/kg in the muscle. A mature pekin duck from the 100-F Area had activities of 0.08 μCi/kg in the thyroid, 0.016 μCi/kg in the liver and bone, 0.026 μCi/kg in the pancreas, and 0.011 μCi/kg in the muscle (HW-10993 E).

Two teals and a pekin duck from the 300 Area were analyzed in August. The pekin duck had the highest thyroid activity (0.072 μCi/kg) while levels in the teal thyroids were 0.02 μCi/kg and <0.04 μCi/kg. The teals had higher counts in the liver (0.01 μCi/kg and 0.007 μCi/kg) and bone (0.007 μCi/kg and 0.005 μCi/kg) than the pekin duck (0.004 μCi/kg in the liver and <0.002 μCi/kg in the bone) (HW-10993 E).

Ducks maintained at the 200-N monitoring area were killed by coyotes in September, terminating the study at that location (HW-11226 E).

In September, maximum beta activity in thyroid and bone was 1.1 μCi/kg in ducks collected from 200-N area ponds. The maximum activity in muscle was 0.03 μCi/kg from a duck at 100-F Area (HW-11226 E).

In October, a duck that had been on the river at 100-F for fourteen months was sacrificed. The highest activity (0.12 μCi/kg) was found in the thyroid. The feces had an activity of 0.1 μCi/kg, and the bone, blood and brain had an activity of 0.01 μCi/kg. The activity in the muscle, liver, and kidney was 0.03 μCi/kg, and that of the spleen and gonads was 0.04 μCi/kg. The lung had an activity density of 0.02 μCi/kg and the pancreas had 0.05 μCi/kg. Results in the thyroid were less than those from a year ago. Activity levels in other tissues were two to five times higher than those seen the previous year (HW-11499 E).

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12.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1949

12.1 MEDIA SAMPLED

12.1.1 Fish

Columbia River fish were analyzed for radionuclide contamination. Species collected included squawfish, course-scaled (largescale) suckers, shiners, shad, ammocoete (lamprey larva), stickleback, chiselmouth, whitefish, dace, chinook salmon, sculpins, sunfish, smallmouth bass, fine-scaled (bridgelip) suckers, mountain suckers, bullhead, silver trout (kokanee), carp, sturgeon, and chub (peamouth) (HW-23093). Small fish (<5 g) were analyzed whole, sometimes using more than one specimen of the same species to obtain the desired mass of tissue. Large fish (>5 g) were dissected before being analyzed. Tissues routinely examined included scales, muscle, liver, bone, gills; feces were also typically analyzed. Additional tissues analyzed included ovaries or testes, kidney, heart, stomach, intestine, spleen, blood, fins, eyes, and brain; stomach contents were also tested (HW-23093). Not all fish were analyzed for every constituent. Both juvenile and adult fish were examined.

12.1.2 Shellfish

Freshwater clams were collected and analyzed for radionuclide contamination (HW-12573).

12.1.3 Waterfowl

Waterfowl examined for radionuclide contamination included Canada geese, mallards, American widgeons (baldpate), gadwalls, green-winged teals, American goldeneyes, coots, and pekin ducks (a white, domestic breed) (HW-18645). In addition to feces, tissues were also examined, including bone, thyroid, pancreas, liver, spleen, gonads, kidneys, muscle, lung, blood, and brain (HW-18645).

12.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

12.2.1 Fish

Sampling locations for Columbia River fish included a station above 100-B, between 100-B and 100-D, between 100-D and 100-H, between 100-H and 100-F; below 100-F; Hanford; the 300 Area (see Figures 4.1 and 4.2); Richland and Pasco, Washington; McNary Dam; Bonneville Dam, and Biggs Junction, Oregon. Large fish were collected from a small eddy area immediately upstream of the Hanford Ferry Landing and from the Bonneville Dam area (HW-23093).

12.2.2 Shellfish

Clams were collected from the Columbia River near Bonneville Dam (HW-12573).

12.2.3 Waterfowl

Waterfowl were collected from LaCrosse, Washington; Kennewick, Washington (HW-15550 E DEL; HW-18645); the 300 Area pond (HW-12937 E); 200-N Area; 300 Area; Hanford (HW-13793 E); 100-F Area (HW-14043 E), near the reactors; 5 miles downstream from the reactors; 15 miles downstream from the reactors; 20 miles downstream from the reactors (see Figures 4.1 and 4.2); the 200-E pond; Benton City, Prosser, and Richland, Washington (HW-18645).

12.3 RADIONUCLIDES MEASURED/REPORTED

12.3.1 Fish

Fish were monitored for beta activity. Results were expressed in units of μCi/g wet or live weight (HW-23093). Results in monthly reports were reported in units of μCi/kg (HW-12937 E; HW-14338 E).

In September 1949, activities in juvenile fish collected near McNary Dam were found to be about one third of the activities in fish collected at Hanford (HW-14596 E).

During the month of March 1949, the scales from a sucker collected in the vicinity of Hanford showed an activity density of 0.1 μCi/kg (HW-12937 E).

Fish sampled during the month of July were found to be five to ten times more radioactive than fish caught earlier. This increase was believed to be due to the reduced flow of the river, warmer water, and the increased power level of the 100-D reactor (HW-20277-RD; HW-14043 E).

Smallmouth and largemouth bass are the most common game fish taken from the Columbia River in the vicinity of Richland during the summer months and are the least radioactive of all species. The maximum concentration found in bone was 6×10^{-4} μCi/g (HW-23093).

During the month of July 1949, a concentration of 1.3 μCi/kg was found in the scales of a chiselmouth and was the highest yet recorded for a Columbia River fish (HW-20277-RD).

Economically, salmon were of the greatest value. Trout, bass, whitefish, and sturgeon were also of considerable value to sportsmen (HW-23793).

The food chain is the most important process by which radioactivity is accumulated. The kinds and amounts of food eaten, fish size, rate of growth, and associated metabolism all contribute to the amount of radioactivity present (HW-23093).

Samples of fish collected during July at Biggs Junction, Oregon, 150 miles downstream of Hanford, showed about one tenth as much activity as the Hanford samples (HW-20277-RD).

Juvenile fish are more radioactive than adults (HW-23093).

Activity in the water during the month of August 1949 was fifty percent greater than August 1948, and the activity of the aquatic organisms was two to five times greater. An activity of 5.4 μCi/kg found in the scales of a sucker was about 3500 times that of the water. The flesh of a smallmouth bass from Hanford was 0.06 μCi/kg (HW-14338 E; HW-20277-RD).

In most cases, the liver had the greatest radionuclide concentration of any of the visceral organs. Scales were the most radioactive tissue, muscle the least (HW-23093).

The level of radioactivity was dependent upon geographic location within the river and ecological relationships, including food habits, metabolic rate, and life span (HW-23793).

Activities in fish during the months of November and December 1949 decreased due to the decline in water temperatures and the subsequent slowing of metabolic rates (HW-15267 E; HW-15550 E DEL).

There was a gradual decrease in the amount of radioactivity present in organisms with decreasing distance below the reactor areas. This decrease can be attributed to natural decay, dilution and dissipation of the radioactive materials, and the removal by organisms (HW-12573).

Phosphorus-32 accounted for less than one percent of the activity in the water, but over 90% of the activity in the fish. Some sodium-24 was found to be present in fish as well (HW-23793; HW-23093).

Suckers had the highest radionuclide concentration of all Columbia River fish examined (HW-23093).

Increases in the radioactivity in fish from one year to the next are attributed to changes in nuclear reactor operations, rather than accumulation of long-lived isotopes (HW-23093).

12.3.2 Waterfowl

Clams collected from Bonneville Dam were analyzed for radionuclide contamination. Results reported in the reviewed document were illegible (HW-12573).

12.3.3 Waterfowl

Phosphorus-32 was the principal isotope present in contaminated ducks (HW-18645).

A pekin duck that had been on the 300 Area pond for eight months had 11 μg of uranium per gram of bone (HW-12937 E).

Three new monitoring stations were established in June, 1949, by planting pekin ducks at the 200-N Area and the 300 Area, and by planting pheasants, Canada geese, and mallard ducks at Hanford (HW-13793 E).

A special study was conducted at the 100-F Station in June to compare the uptake rates for different aged pekin ducks. Younger birds had considerably higher accumulation rates, due to more rapid phosphorus turnover. Bone from four- and six-week-old ducklings had a concentration of 0.4 μCi/kg, beta; an eight-week-old bird had 0.2 μCi/kg, beta; and a two-year-old drake had less than 0.01 μCi/kg, beta (HW-13793 E).

The three principal sources of radioactive contamination available to waterfowl at Hanford were nuclear reactor cooling water, waste-water ditches and ponds, and volatile fission wastes from stack gases (HW-18645).

A new high level of radioactivity in waterfowl (8 μCi/kg) was found in August 1949, in the bone of a pekin duckling from the 100-F Area. Other tissues were also much higher than previously seen (HW-14338 E; HW-18645).

Coots and ducks were sampled in October 1949. In general, the thyroids of animals taken within 30 miles of the 200 Area stacks were radioactive. Specimens taken at distances greater than 30 miles were not distinguishable from background (HW-14916 E).

The bones and thyroids of waterfowl usually had the highest radionuclide activities due to the accumulation of phosphorous-32 and iodine-131, respectively, in those organs (HW-18645).

Mallard ducks from LaCrosse, Washington, and Kennewick, Washington, sampled in December 1949, had less than 0.5 μCi/kg in the thyroid (HW-15550 E DEL).

The age of the bird analyzed had no significant effect on the activity densities accumulated, except in the bone (HW-18645).

In December 1949, a new test was developed for testing for iodine-131 in thyroids. Maximum activity in a pekin duck thyroid was 0.009 μCi/g. The maximum activity in duck thyroids collected near the Hanford reservation was 0.026 μCi/g. This concentration was in excess of the chronic maximum permissible concentration (MPC) of iodine-131 for human beings and was seen in a mallard obtained in Benton City, Washington (HW-18645).

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13.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1950

13.1 MEDIA SAMPLED

13.1.1 Fish

Columbia River fish were analyzed for radioactive contamination. Species collected included fine-scaled (bridgelip) suckers, course-scaled (largescale) suckers, mountain suckers, shiners, squawfish, chubs (peamouth), dace, sticklebacks, sculpins, chiselmouth, bluegills, smallmouth bass, rainbow trout, largemouth bass, carp, chinook salmon, whitefish, sturgeon, silver trout (kokanee), shad, and sunfish (HW-23093; HW-36074). Small fish (<5 g) were analyzed whole, sometimes using more than one specimen of the same species to obtain the desired mass of tissue (HW-23093). Large fish (>5 g) were dissected, then analyzed. Tissues routinely analyzed included scales, muscle, liver, and bone. Additional tissues tested included gills, ovaries or testes, kidney, heart, stomach, intestine, spleen, blood, fins, eyes, and brain; feces and stomach contents were also examined. Not all samples were analyzed for every constituent. For many species both adult and juvenile fish were analyzed (HW-36074; HW-48523 DEL; HW-23093).

13.1.2 Shellfish

The viscera, gill, mantle, and soft parts of the *Anodonta* clam were analyzed for radionuclide contamination (HW-36074). Freshwater mussels were also analyzed (HW-17971 E).

13.1.3 Waterfowl

Waterfowl analyzed included Canada geese, coots, common loons, pekin (a white domestic breed) and mallard ducks, and American mergansers (HW-18221 E; HW-18473 E; HW-18740 E; HW-18645; HW-19325 E). In addition to feces, tissues analyzed included bone, thyroid, liver, pancreas, spleen, gonads, kidney, muscle, lung, blood, and brain (HW-18645; HW-19021 E; HW-18740 E; HW-19325 E).

13.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

13.2.1 Fish

Columbia River fish-sampling locations included Priest Rapids (RM 387-396), Station B-1 (RM 381), Station D-2 (RM 375), Station H-1 (RM 372), Station H-2 (RM 369), Station F-1 (RM 367), Hanford (RM 362), Station 300 (RM 345), Richland (RM 339), Station P-1 (RM 331), Station P-2 (RM 329), Station P-3 (RM 319), Station McNary-1 (RM 298), McNary-2B (RM 285), Bonneville (RM 145.5), and Biggs Junction, Oregon (HW-23093; HW-36074). (See Figures 4.1 to 4.4.) Special whitefish samples were collected from Hanford (RM 362) (HW-48523 DEL). A few samples of small fish were collected from a small side channel on the shoreline below the 100-H reactor (HW-18438).

13.2.2 Shellfish

Clams (*Anodonta*) and mussels were collected from the Columbia River at Bonneville Dam (RM 145.5) (HW-36074; HW-17971 E).

13.2.3 Waterfowl

Waterfowl were collected near the reactors and five miles downstream of the reactors (HW-18645). A waterfowl colony was established on the river at 100-F (HW-18221 E). Other birds were collected in the 200 West area and above 100-F (HW-19325 E; HW-18221 E). (See Figures 4.1 and 4.2.)

13.3 RADIONUCLIDES MEASURED/REPORTED

13.3.1 Fish

Analytical results were reported as gross beta activity per gram of tissue. Tables of data included monthly maximum and average values for fish caught at each sampling station (HW-36074), as well as concentrations in individual tissues from individual fish (HW-48523 DEL; HW-36074). Various isotope concentrations were also discussed, but reported results were based on decay studies only.

Phosphorous-32 was the predominant radionuclide in fish from the Hanford vicinity (HW-23093; HW-36074).

The 100-DR reactor was started up during October 1950 (HW-21699).

The food chain is the most important process by which radioactivity is accumulated. The kinds and amounts of food eaten, fish size, rate of growth, and associated metabolism all contribute to the amount of radioactivity present (HW-23093).

The scales, bone, and liver were the most radioactive fish tissues, muscle the least (HW-36074; HW-23093).

Whitefish presented the greatest potential radiation hazard as a food fish (HW-36074). At Hanford, during the fall, the concentration of phosphorous-32 in whitefish flesh was 3600 times that in the river water (HW-48523 DEL).

Radionuclide activities in Columbia River fish in 1950 reached a peak in September. Values were two to four times those of 1949 (HW-21699 REV).

One hundred and thirty-one tissue samples from large fish (many species) were collected at Bonneville Dam and analyzed. The mean activity density was 2.4×10^{-5} μCi/g; maximum was 3.2×10^{-4} μCi/g; and 53 samples were below the reportable level of 5×10^{-6} μCi/g (HW-23093).

The concentration in Columbia River fish collected at Hanford in 1950 was 3.2×10^{-3} μCi/g in juvenile suckers (HW-36074).

Radionuclide concentrations in juvenile chinook salmon sampled from the Columbia River in May 1950 ranged from 8×10^{-5} μCi/g near Hanford to 5×10^{-5} μCi/g above McNary Dam, "about ten times the concentration of the older and larger migrant fish" (HW-17971 E).

"The first sturgeon (about 10 lbs) captured within the boundaries of the Reservation was taken on May 19, 1950. Radionuclide concentrations in its tissues were comparatively low (muscle 10^{-5} μCi/g, testes 10^{-4} μCi/g, feces 3×10^{-4} μCi/g)" (HW-17971 E).

The maximum concentration (beta) found in seven white sturgeon collected at Bonneville was 2×10^{-4} μCi/g. Thirty of the 39 samples analyzed from these fish were below the reportable limit of 5×10^{-6} μCi/g.

Differences in metabolic rates, food habits, life cycles, morphology, and the chemical composition of the tissues influenced the activity densities of specific organisms (HW-36074).

Maximum radionuclide concentrations in Columbia River fish were seen in the vicinity of RM 367 (Hanford) (HW-48523 DEL). Sites upstream were generally at background levels, and concentrations decreased with distance downstream. Variations in this pattern resulted from migratory habits of animals, short-term flucuations in reactor operations, the shifting of effluent channels in the river, and changes in the sites of effluent discharge (HW-36074).

The uptake of radionuclides in fish was controlled primarily by water temperature and the concentration of effluents in the river (HW-48523 DEL).

Suckers and chiselmouth were the most radioactive Columbia River fish species; bass and squawfish were the least (HW-23093).

During the first part of July 1950, high radionuclide levels were found in samples immediately below the 100-H area. These levels were up to 100 times those of the previous months. Some of the small fish contained as much as 63×10^{-3} μCi/g. Small fish from other areas ranged from 10^{-5} μCi/g above the reactor areas to 1.4×10^{-3} μCi/g at Hanford (HW-18473 E). Large fish were less radioactive. Food habits played a dominant role in the amount of radioactivity deposited in fish tissues. The maximum values for small fish were found in dace, which had been feeding almost exclusively on midgefly larvae. Small shiners, feeding largely on adult midges, were about one-third as radioactive as the dace. Small suckers, feeding on midge larvae and bottom algae, were intermediate in activity. Large fish collected at the same time were less radioactive. These high levels were apparently related to the effect of high river flows on effluent discharges and mixing (HW-18438; HW-21699 REV).

13.3.2 Shellfish

The maximum radionuclide concentrations in an *Anodonta* clams collected from Bonneville (RM 145.5) were 8.6×10^{-5} μCi/g in the viscera, 10^{-4} μCi/g in the gill, 4.7×10^{-5} μCi/g in the mantle, and 4.1×10^{-5} μCi/g in the soft parts (HW-36074).

Mussels were transplanted from Bonneville Dam to the Hanford Reach. As a result, the activity density in the visceral organs increased to about 10^{-4} μCi/g (HW-17971 E).

13.3.3 Waterfowl

In June 1950, to serve as a monitoring index of the possible hazards to wild waterfowl, a mixed colony of mallard and pekin ducks was established on the river at 100-F reactor (HW-18221 E).

The bones and thyroids of waterfowl usually had the highest activity densities due to the accumulation of phosphorous-32 and iodine-131, respectively, in those organs (HW-18645).

Radionuclide concentrations in tissues from pekin ducks in the 100-F colony increased in the month of August to maximum values of 9×10^{-3} μCi/g in bone and 8×10^{-3} μCi/g in the thyroid. These values exceeded the maximum permissible concentration (MPC) for phosphorous-32 and iodine-131 by factors of 7.5 and 2.0, respectively. Liver and pancreas samples also exceeded the MPC (HW-18740 E).

In September 1950, radionuclide concentrations in waterfowl from the 100-F colony were less than those seen in August, but bone samples still exceeded the MPC for phosphorous-32 by a factor of 2. Wild waterfowl showed a gain in thyroid activity, with a maximum value of 0.007 μCi/g, exceeding the MPC for iodine-131 by about two times (HW-19021 E).

Bone samples from four birds in the duck colony at 100-F in October 1950 all had higher activity densities than the MPC for phosphorous-32, with mallards being higher than pekins. The maximum activity density detected was 0.004 μCi/g (HW-19325 E).

Phosphorus-32 was the principal isotope present in waterfowl (HW-18645).

In October 1950 all waterfowl had thyroid activities below the MPC for iodine-131, except for a Canada goose from near 100-F, which had a level of 0.05 μCi/g in the thyroid, 12 times the MPC for ^{131}I (HW-19325 E).

The age of a bird had no significant effect on activity densities accumulated, except in bone (HW-18645).

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14.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1951

14.1 MEDIA SAMPLED

14.1.1 Fish

Fish from the Columbia, Snake, Yakima, and Walla Walla Rivers were collected and analyzed for radioactive contamination. Species collected included chinook salmon, mountain suckers, course-scaled (largescale) suckers, fine-scaled (bridgelip) suckers, shiners, squawfish, chubs (peamouth), dace, sticklebacks, sculpins (prickly and smooth), chiselmouths, bluegills, carp, smallmouth bass, largemouth bass, sockeye salmon, rainbow trout, Dolly Varden trout, whitefish, crappie, and steelhead trout (HW-36074; Robeck et al. 1954). Small fish were analyzed whole. Large fish were dissected, then analyzed. Routinely analyzed tissues included scales, muscle, bone, and liver. Additional tissues analyzed included ovaries, testes, kidneys, spleens, hearts, viscera, skin, and scales; feces and stomach and intestinal contents were also analyzed. Not all samples were analyzed for every constituent. For many species both juvenile and adult fish were analyzed (HW-36074; HW-48523; Robeck et al. 1954).

14.1.2 Shellfish

The viscera, gill, mantle, and soft parts of the Anodonta clam were analyzed for radionuclide contamination (HW-36074).

14.1.3 Waterfowl

Waterfowl analyzed included Canada geese and a variety of duck species. Tissues examined included bone, thyroid, and muscle (HW-20438 E; HW-21802 E; HW-23140 E; HW-25021). A special fecal study was performed on Canada geese (HW-23140 E).

14.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

14.2.1 Fish

Columbia River fish-sampling locations included Priest Rapids (RM 387-400), above the Hanford Works (RM 385), above Coyote Rapids (RM 383), Station B-1 (RM 381), Station D-2 (RM 375), Station H-1 (RM 372), Station H-2 (RM 369), Station F-1 (RM 367), Hanford (RM 362), Station 300 (RM 345), Richland (RM 339), Station P-1 (RM 331), Station P-2 (RM 329, in the vicinity of the Pasco water intake), above Kennewick (RM 330), below Pasco (RM 326), Station P-3 (RM 319), above the mouth of the Walla Walla River (RM 316), Juniper Canyon (RM 306), McNary-1 (RM 298, near Hat Rock, above the Dam), McNary 2-B (RM 285), Patterson (RM 278), and Bonneville (RM 145.5) (HW-36074, Robeck et al. 1954). (See Figures 4.1 to 4.4.)

Fish were also sampled from the Yakima River. Washington State collection sites included Kiona (RM 364), Enterprise (RM 343), and the Richland Highway bridge (RM 339). Fish from the Snake River were collected from Page (RM 342) and near the river mouth (RM 325). Walla Walla River samples were collected at the old highway crossing (RM 322) (Robeck et al. 1954). (See Figures 4.1 to 4.4.)

14.2.2 Shellfish

Clams (*Anodonta*) were collected from the Columbia River at Station Bonneville (RM 145.5) (HW-36074). (See Figure 4.3.)

14.2.3 Waterfowl

Waterfowl were collected from the 200 East area, 200 North area, and the Hanford vicinity (HW-23140 E; HW-21802 E). (See Figures 4.1 and 4.2.)

14.3 RADIONUCLIDES MEASURED/REPORTED

14.3.1 Fish

Analytical results were reported as gross beta activity per gram of tissue. Tables of data included monthly maximum and average values for fish caught at each sampling station (HW-36074), as well as concentrations in individual tissues from individual fish (HW-48523; Robeck et al. 1954; HW-36074). Some radionuclide concentrations were discussed, but values were determined from decay studies only.

Phosphorus-32 is the predominant radionuclide in fish from the Hanford vicinity (HW-36074; Robeck et al. 1954; HW-25021).

Rocky Mountain whitefish were the most important food/game fish caught in the Columbia River in the Hanford vicinity (HW-48523). In addition, salmon, steelhead, bass, sturgeon, carp, and suckers were popular with fishermen (HW-36074; Robeck et al. 1954).

Fish over ten grams were considered adults for counting purposes. Analysis size was two grams. When fish were less than two grams, several fish (up to six) were pooled for analysis (Robeck et al. 1954).

Radioactivity found in fish was predominantly from phosphorous-32, sodium-24, and traces of other longer-lived elements. The Columbia River has naturally low concentrations of phosphorus, an essential element. As a result, fish showed concentrations of this element 100,000 to 200,000 times that of the water. Although sodium is an essential element, it is readily available in the Columbia and sodium-24 was not concentrated in amounts proportionate to phosphorous-32. Also, since sodium-24 has a short half-life, it diminishes as it moves up the food chain (HW-25021).

Steelhead and salmon that spawn in the Columbia River generally contained insignificant levels of radioactivity because they feed very little during the spawning period (HW-36074).

Maximum concentrations of radioactivity in fish were found in scales, bones, and livers. Muscle, fat, and skin contained the least activity (HW-36074, Robeck et al. 1954, HW-48523).

Suckers, which eat large quantities of algae and other plant material, exhibited a higher concentration of radioisotopes in their muscle than did whitefish, which are primarily omnivorous (HW-48523).

Upstream of the Hanford Site, background levels of less than 10^{-5} μCi/g (beta) occur in aquatic organisms (HW-25021).

Maximum radioisotope concentrations were seen in the vicinity of RM 367 (Hanford) (HW-48523; HW-25021) and RM 362 (Hanford) (Robeck et al. 1954). Sites upstream were generally at background levels, and concentrations decreased with distance downstream. Variations in this pattern resulted from

migratory habits of animals, short-term fluctuations in reactor operations, the shifting of effluent channels in the river, and changes in the sites of effluent discharge (HW-36074). Rapid decreases in the downstream activity are also due to radioactivity decay, dispersion, removal by sedimentation, assimilation by living organisms, and dilution by tributary streams (HW-25021).

Seasonal variations in radionuclide concentrations in river organisms occurred due to fluctuations in water temperature and river levels (HW-25021, Robeck et al. 1954).

Differences in metabolic rates and the chemical composition of tissues influenced radionuclide concentrations in specific organisms as did food habits, life cycles, and morphology (HW-25021; HW-36074).

Radionuclides found in Columbia River fish included phosphorous-32, sodium-24, scandium-46, chromium-51, manganese-54, iron-59, cobalt-60, copper-64, zinc-65, arsenic-76, zirconium-niobium-95, cesium-137, and neptunium-239 (HW-48523).

Radionuclide concentrations in tissues from dead or nearly dead spawned out chinook salmon collected from the Columbia River shoreline were less than 10^{-5} μCi/g (HW-25021).

Zinc-65 was present in all whitefish tissues tested and greatly exceeded the concentration of phosphorous-32 in the gut and parts of the eye (HW-48523).

Average radioactivity concentrations in chinook salmon fry were comparable to concentrations in the young of other native fish species (HW-25021).

In January 1951 the 100-F Pile 21-day shutdown, as well as colder river water temperatures and slightly increased river flows, resulted in a decline in radionuclide activities in Columbia River fish. The maximum activity found in large fish in January was 7.8×10^{-6} μCi/g in the liver of a whitefish (HW-20161 E).

In February 1951 the average activity level in Columbia River juvenile fish (8×10^{-5} μCi/g) was about half of the January level (HW-20438 E).

Warmer water temperatures and the end of the spring runoff in July 1951 resulted in higher radionuclide concentrations in fish tissues for the period. Activities in small fish tripled to 10^{-3} μCi/g. In large fish a maximum concentration density of 1.9×10^{-3} μCi/g was found in the liver of a sucker. The concentration in the flesh was 4×10^{-4} μCi/g (HW-21802 E).

Colder temperatures in December 1951 caused a lowering of fish metabolic rates, resulting in lower radionuclide activities in fish tissues. The average value in small fish was 0.43×10^{-3} μCi/g (HW-23140 E).

The highest radionuclide activities for game fish flesh (2.7×10^{-4} μCi/g) were found near Hanford, downstream of the plant discharges (HW-25021).

The maximum radionuclide concentrations in whitefish collected at Hanford (Station 362) in August were 2200×10^{-6} μCi/g in scales, 760×10^{-6} μCi/g in bone, 660×10^{-6} μCi/g in the liver, and 140×10^{-6} μCi/g in muscle (HW-48523).

The maximum radionuclide concentration in juvenile fish sampled from Hanford Ferry Crossing (RM 362) was 9.05×10^{-3} μCi/g in suckers (Robeck et al. 1954).

14.3.2 Shellfish

The maximum activity levels obtained from an Anodonta clam collected at Station Bonneville (RM 145.5) were 14×10^{-6} μCi/g, wet weight, for the viscera; 130×10^{-6} μCi/g, wet weight, for the gills; 19×10^{-6} μCi/g, wet weight, for the mantle; and 370×10^{-6} μCi/g, wet weight, for the soft parts (HW-36074).

14.3.3 Waterfowl

The bones of ducks exposed to river water containing radioactive waste materials from Hanford had 10^5 times the amount of radioactivity found in the water (HW-25021).

In February 1951 the maximum activity density in a waterfowl bone was 0.001 μCi/g (HW-20438 E).

In July 1951 the maximum activity found in a duck from the 200 North area was 0.08 μCi/g in the bone. The principal isotope was strontium-89 (HW-21802 E).

A special onsite study was conducted to measure radioactivity in the fecal material of Canada geese. In July, thirty-five percent of the samples were found to be in the 200 to 300 d/m/g range. The maximum value obtained was 790 d/m/g (HW-23140 E).

In December 1951 readings in the tissues of resident ducks were as high as 125 d/m/g (HW-23140 E).

The maximum thyroid activity density in ducks from the 200 East Area was 0.083 μCi/g in December, 1951 (HW-23140 E).

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15.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1952

15.1 MEDIA SAMPLED

15.1.1 Fish

Fish from the Columbia, Yakima, Snake, and Walla Walla rivers were analyzed for radioactive contamination. Species collected included chinook salmon, fine-scaled (bridgelip) suckers, course-scaled (largescale) suckers, mountain suckers, shiners, squawfish, chubs (peamouth), dace, sticklebacks, bluegills, sculpins (prickly and smooth), smallmouth bass, largemouth bass, carp, sockeye salmon, rainbow trout, whitefish, chiselmouth, sunfish, blueback (sockeye) salmon, yellow perch, codfish, white crappie, and sturgeon (HW-36074, Robeck et al. 1954). Small fish were analyzed whole. Large fish were dissected, then analyzed. Routinely analyzed tissues included scales, muscle, bone, and liver. Additional tissues analyzed included ovaries, testes, kidney, spleen, heart, viscera, skin and scales; feces and stomach and intestinal contents were also analyzed. Not all samples were analyzed for every radionuclide. For many species both juvenile and adult fish were analyzed (HW-36074; HW-48523; Robeck et al. 1954).

15.1.2 Shellfish

Several varieties of freshwater clams were analyzed for radionuclide contamination. These included pea clams, *Anodonta*, and Sphaeridae (HW-36074; Robeck et al. 1954). The viscera and soft parts of the *Anodonta* clams were analyzed (HW-36074).

15.1.3 Waterfowl

Waterfowl analyzed included puddle ducks (mallards, pintails, teals, etc.), Canada geese, and American coots (HW-27104). Tissues analyzed included muscle, liver, bone; feces were also analyzed (HW-26720 E; HW-27104).

15.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

15.2.1 Fish

Columbia River fish-sampling locations included Priest Rapids (RM 387-400); above Hanford Works (RM 385); above Coyote Rapids (RM 383); Station B-1 (RM 381); Station D-1 (RM 377, at Wahluke Ferry); Station D-2 (RM 375); Station H-1 (RM 372); Station H-2 (RM 369); Station F-1 (RM 367); Hanford (RM 362); Station 300 (RM 345); Richland, Washington (RM 339); Station P-2 (RM 329, in the vicinity of Pasco, Washington, water intake); above Kennewick, Washington (RM 330); below Pasco, Washington (RM 326); Station P-3 (RM 319); above the mouth of the Walla Walla River (RM 316); Juniper Canyon (RM 306); McNary-1 (RM 298, near Hat Rock, above the Dam); McNary 2-B (RM 285); Patterson, Washington (RM 278); Bonneville Dam (RM 145.5); below Corbett, Oregon (RM 125); and Astoria, Oregon (RM 13) (HW-36074; Robeck et al. 1954). Further sampling was done at Beverly, Washington (RM 412); River Mile 403; the Ringold area (Washington) (RM 353); Richland, Washington (RM 340), and River Mile 293 (HW-48523).

Fish were also sampled from the Yakima River. Collection sites included Enterprise, Washington (RM 343), and the Richland Highway Bridge (RM 339). Fish from the Snake River were collected from Page at RM 342 and near the mouth of the Snake at RM 325. Walla Walla River samples were collected at the old highway crossing (RM 322) and at the US Highway 395 bridge (RM 318) (Robeck et al. 1954).

Additional fish samples were collected from Lake Roosevelt (behind Grand Coulee Dam) and the Bonneville Reservoir. Collection sites in the Bonneville Reservoir included locations above The Dalles, Oregon (RM 191); above Lyle, Washington (RM 182); below the White Salmon River (RM 167); above the Little White Salmon River (RM 163); Collins, Washington (RM 158); and below Stevenson, Washington (RM 150). All fish sampling done at Lake Roosevelt was done at River Mile 694 (2 miles below the mouth of the Colville River) and River Mile 597 (1 mile above Grand Coulee Dam) (Robeck et al. 1954).

15.2.2 Shellfish

The Sphaeridae clam was collected from Patterson, Washington (RM 278) (Robeck et al. 1954). The *Anodonta* clam was collected from Station Bonneville (RM 145.5) and the pea clam from Station F-1 (RM 367) (HW-36074).

15.2.3 Waterfowl

Waterfowl were sampled on the Site from Redox swamp and U swamp (pond) (HW-27104).

15.3 RADIONUCLIDES MEASURED/REPORTED

15.3.1 Fish

Analytical results were reported as gross beta activity per gram of tissue. Tables of data included monthly maximum and average values for fish caught at each sampling station (HW-36074), as well as concentrations in individual organs from individual fish (HW-48523; Robeck et al. 1954; HW-36074). Some radionuclide concentrations were discussed.

Phosphorus-32 was the predominant radionuclide in fish from the Hanford vicinity (HW-36074; Robeck et al. 1954).

Rocky Mountain whitefish were the most important food/game fish caught in the Columbia River in the Hanford vicinity (HW-48523). In addition, salmon, steelhead, bass, sturgeon, carp, and suckers were popular with fishermen (HW-36074; HW-28636; Robeck et al. 1954).

Fish over ten grams were considered adults for counting purposes. Analysis size was two grams. When fish were less than two grams, several fish (up to six) were pooled (Robeck et al. 1954).

Shiners collected from the Hanford vicinity contained phosphorous-32, sodium-24, copper-64, copper-67, arsenic-76, and elements from the rare earth group, zinc group, and calcium group (HW-36074).

Maximum radioisotope concentrations in fish were seen in the vicinity of RM 367 (Hanford) (HW-48523) and RM 362 (Hanford) (Robeck et al. 1954). Sites upstream were generally at background levels and concentrations decreased with distance downstream. Between Hanford and Richland radionuclide concentrations

in fish decreased rapidly; below Richland the rate of decrease was slower; and below McNary Dam it became very gradual (HW-28636). Variations in this pattern resulted from migratory habits of animals, short-term fluctuations in reactor operations, the shifting of effluent channels in the river, and changes in the sites of effluent discharge (HW-36074). An amount higher than background (1×10^{-6} μCi/g) was found at the mouth of the river at Astoria, Oregon (Robeck et al. 1954).

In December 1952 the activity values for small fish collected from the Columbia River at the Hanford Station averaged 1.4×10^{-3} μCi/g. The maximum activity level in large fish (4.7×10^{-3} μCi/g) was seen in the scales of a squawfish. This fish also contained 7.5×10^{-5} μCi/g in the muscle tissue. These values represented a decrease from November, probably due to a reduced river water temperature (HW-26720E).

Radioactivity levels in fish were dependent upon the fishes' rate of metabolism and the activity levels in the organisms on which they feed. Maximum radionuclide levels occurred during periods of low and high water temperatures, usually in late summer and the fall months (Robeck et al. 1954).

Maximum concentrations of radioactivity in Columbia River fish were found in scales, bone, and liver. Muscle, fat, and skin had the least (Robeck et al. 1954; HW-48523, HW-36074).

During the winter of 1952, approximately half of the whitefish sampled from Priest Rapids exhibited radionuclide concentrations equal to or greater than those occurring in fish caught immediately below the reactor areas. A concentration of 2.2×10^{-3} μCi/g in the muscle of one specimen from Priest Rapids was the maximum value found in an adult game fish sampled during the year (HW-28636).

A special study of Bonneville Reservoir was conducted between August 18 and 29, 1952. A maximum gross beta activity of 5200×10^{-7} μCi/g was found in a course-scaled sucker from RM 191 above The Dalles, Oregon (Robeck et al. 1954).

Steelhead and salmon had insignificant levels of radioactivity as adults returning to spawn because they do not feed during this time (HW-36074).

Suckers, which eat large quantities of algae and other plant material, exhibited a higher concentration of radioisotopes in their muscle than did whitefish, which are omnivorous (HW-48523).

In 1952 the maximum radionuclide concentration observed in shiners sampled at Station D-1 was 8400 x 10^{-6} μCi/g, wet weight (HW-36074).

Radionuclides reported in Columbia River fish included phosphorous-32, sodium-24, scandium-46, chromium-51, manganese-54, iron-59, cobalt-60, copper-64, copper-64, zinc-65, arsenic-76, zirconium-niobium-95, cesium-137, and neptunium-239 (HW-48523).

A special study of Lake Roosevelt was conducted, and analytical results were reported as alpha and beta activities in units of 10^{-7} μCi/g. The corrected counts for fish from Lake Roosevelt were generally below the minimum detectable limits as determined by 95% confidence levels (Robeck et al. 1954).

The maximum radionuclide concentration in whitefish scales from Hanford was 700 x 10^{-6} μCi/g, wet weight. Maximum concentration in the muscle was 210 x 10^{-6} μCi/g, wet weight (HW-48523).

Gross beta activities in fish from the Yakima River were higher at the Richland Highway Bridge (a maximum reading of 8010 x 10^{-7} μCi/g from a squawfish) than at Enterprise, Washington (maximum of 2640 x 10^{-7} μCi/g from shiners). Snake River fish had higher activity densities at the river's mouth (14,120 x 10^{-7} μCi/g from a sucker) than seventeen miles upstream at Page, Washington (25 x 10^{-7} μCi/g in shiners). Fish in the Walla Walla River had higher activity densities at the old highway crossing (1110 x 10^{-7} μCi/g from a squawfish) than at the U.S. Highway 395 bridge (165 x 10^{-7} μCi/g from a sucker) (Robeck et al. 1954).

The wide variation in concentrations of radioactive materials in whitefish at any given station was produced by migration patterns, biological variation, and differences in age and rate of food intake (HW-48523).

The maximum radionuclide concentration in whitefish scales from Priest Rapids was obtained in December and was 4,400 x 10^{-6} μCi/g, wet weight. The maximum concentration in whitefish muscle from the same location was 360 x 10^{-6} μCi/g, wet weight (HW-48523).

The effects of cooking on radioisotope concentrations in fish were discussed. In general, after cooking there was an increase in the concentration of radioisotopes in the scales and skin and a decrease in the muscle and bone (HW-48523).

15.3.2 Shellfish

The maximum radionuclide concentration in the Anodonta clam was sampled from Station Bonneville and was 300 x 10^{-6} μCi/g, wet weight, in the viscera (HW-36074).

A maximum concentration of 4,700 x 10^{-7} μCi/g was obtained in a clam (Sphaeridae) sampled at Patterson, Washington (Robeck et al. 1954).

The maximum concentration of radioisotopes from a pea clam collected from Station F-1 was 440 x 10^{-6} μCi/g (HW-36074).

15.3.3 Waterfowl

Canada geese, which occupied the Redox swamp approximately 50% of the year, had a maximum beta activity level of 700 d/m/g in muscle, 64,700 d/m/g in the feces, 4700 d/m/g in the bone, and 900 d/m/g in the liver (HW-27104).

One chronically exposed pintail (injured and confined to Redox swamp) had total beta activity levels of 5,000,000 d/m/g in feces, 87,900 d/m/g in bone, 42,000 d/m/g in the liver, and 17,200 d/m/g in the muscle (HW-27104; HW-26720E).

Alpha contamination in birds collected at Redox swamp was low. The maximum value was 480 d/m total alpha/g in the feces of the injured pintail duck. Ninety per cent of this amount was due to plutonium-239 (HW-27104).

Ten waterfowl utilizing Redox swamp part-time contained a mean beta contamination of 200 d/m/g. Thirty other waterfowl collected both on and off the Site had no appreciable amounts of radioactivity (HW-26720E).

Waterfowl chronically and periodically exposed to Redox swamp contained sufficient amounts of beta radioactivity to deliver whole-body irradiation rates of 100 to 250 mrep/hour (HW-27104).

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16.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1953

16.1 MEDIA SAMPLED

16.1.1 Fish

Columbia River fish were analyzed for radioactive contamination. Species collected included course-scaled (largescale) suckers, squawfish, shiners, prickly sculpins, chinook salmon, sticklebacks, smooth sculpins (*C. beldingii*), chub (peamouth), chiselmouth, sunfish, smallmouth bass, dace, whitefish, carp, fine-scaled (bridgelip) suckers, sturgeon, and flounder (Robeck et al. 1954). Other fish examined included rainbow trout, yellow perch, sockeye salmon, mountain suckers, crappie, largemouth bass, and blueback (sockeye) salmon (HW-36074). Small fish were analyzed whole. Larger fish were dissected, then analyzed. Tissues examined included muscle, liver, scales, bone, skin, ovaries, testes, kidney; stomach and intestinal contents were also analyzed (Robeck et al. 1954). Additional tissues analyzed included the heart, spleen, and viscera (HW-36074; HW-48523).

16.1.2 Shellfish

There was no information on shellfish collection and analyses in the reviewed documents.

16.1.3 Waterfowl

There was no information about waterfowl collections in the reviewed documents.

16.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

16.2.1 Fish

Columbia River sampling locations included sites above Trinidad (RM 445), above Vantage (RM 424), Beverly (RM 414), Priest Rapids (RM 400), above Coyote Rapids (RM 383), Hanford Ferry Crossing (RM 362), Richland (RM 339), below Pasco (RM 326), above McNary Dam (RM 297), and Patterson, Washington (RM 278); below Corbett (RM 125), and Astoria, Oregon (RM 13)

(Robeck et al. 1954). Other Columbia River sampling locations included a control station at Priest Rapids Dam (RM 387 and RM 396); Station B-1 (RM 381); Station D-1 (RM 377, Wahluke Ferry); Station H-1 (RM 372); Station H-2 (RM 369); Station F-1 (RM 367); Hanford (RM 362); the Ringold area (Washington) (RM 354); the 300 Area (RM 345); Richland, Washington (RM 339); Station P-3 (RM 319); McNary-1 (RM 298, near Hat Rock, above the Dam); McNary-2B (RM 285, below the Dam); Umatilla, Oregon (RM 291); near Alder Creek, Washington (RM 258); Biggs, Oregon (RM 208); Lyle Ferry (RM 181, Rowena Point, Oregon); Bonneville Dam (RM 145.5); Puget Island, Washington (RM 45, in the Cathlamet Channel); and Cape Disappointment, Washington (RM 0) (HW-36074; HW-48523).

16.3 RADIONUCLIDES MEASURED/REPORTED

Analytical results were reported as gross beta activity per gram of tissue, wet weight. Tables of data included monthly maximum and average values for fish caught at each sampling station (HW-36074), as well as concentrations in individual organs from individual fish (HW-36074; HW-48523; Robeck et al. 1954). Some isotope concentrations were discussed.

Fish over ten grams were considered adults for counting purposes. Analysis size was two grams. When fish were less than two grams, several fish (up to six) were pooled (Robeck et al. 1954).

Half of the whitefish caught at Priest Rapids during November and December had activity levels greater than, or equal to, levels in fish caught below the reactor areas (HW-30437).

Rocky Mountain whitefish were the most important food/game fish caught in the Columbia River in the Hanford vicinity (HW-48523). In addition, salmon, steelhead, bass, sturgeon, carp, and suckers were popular with fishermen (HW-36074; Robeck et al. 1954).

Maximum radioisotope concentrations in Columbia River fish were seen in the vicinity of RM 367 (Hanford) (HW-48523; HW-33366), and RM 362 (Hanford Ferry Crossing) (Robeck et al. 1954). Concentrations in fish collected upstream of the Site were generally at background levels and concentrations below the Site decreased with distance downstream. Variations in this pattern

resulted from migratory habits of animals, short-term fluctuations in reactor operations, the shifting of effluent channels in the river, and changes in the sites of effluent discharge (HW-36074). A measurable amount was found at the mouth of the river at Astoria, Oregon (Robeck et al. 1954).

Radionuclide levels in spawning steelhead and salmon were insignificant because these fish, when spawning, generally do not eat (HW-36074).

The effects of cooking on radionuclide concentrations were discussed. In general, after cooking there was an increase in the concentration of radionuclide in the scales and skin, and a decrease in the muscle and bone (HW-48523).

Maximum activities in whitefish from Priest Rapids during the first half of 1953 were found in a specimen caught in May. Results were 1.2×10^{-2} μCi/g for scales and 5.3×10^{-4} μCi/g for muscle (HW-30437).

Radionuclides found in Columbia River fish included phosphorous-32, copper-64, chromium-51, sodium-24, manganese-56, arsenic-76, zinc-65, iron-57, cobalt-60, scandium-46, zirconium-niobium-95, cesium-137, and neptunium-239 (HW-36074; HW-48523).

Radiophosphorous uptake was elevated because natural levels of stable phosphorus in the Columbia River are low (HW-33366).

The maximum radionuclide concentration in juvenile fish (shiners) collected at the Hanford Ferry Crossing was 9000×10^{-6} μCi/g; average activity was 1300×10^{-6} μCi/g. Maximum values for adult fish (suckers) were 5000×10^{-6} μCi/g for bone and 1100×10^{-6} μCi/g for muscle. Average values for adult fish were 1200×10^{-6} μCi/g for bone and 300×10^{-6} μCi/g for muscle (Robeck et al. 1954).

The maximum concentrations of phosphorous-32 in adult whitefish were found in the scales and liver. The maximum concentrations in juveniles were found in the scales and bone (HW-48523).

Radionuclide density in fish is dependent upon their rate of metabolism and the radioactivity in the organisms on which they feed. Maximum activity density levels occurred during low water stages and high water temperatures, usually in late summer and fall (Robeck et al. 1954).

Phosphorus-32 was the predominant radionuclide in fish in the Hanford vicinity (HW-36074; HW-33366; Robeck et al. 1954).

The maximum radionuclide concentration in whitefish scales from Priest Rapids was obtained in December and was 456 x 10^{-6} μCi/g, wet weight. The maximum concentration in whitefish muscle from the same location was obtained in October and was 63 x 10^{-6} μCi/g, wet weight (HW-48523).

Radioactive materials were concentrated in all parts of the body of fish. However, the activity levels were about ten times higher in scales, bone; and internal organs than in the edible parts such as the muscle or skin (Robeck et al. 1954).

Suckers, which eat large quantities of algae and other plant material, exhibited a higher concentration of radionuclides in their muscle than did whitefish, which are primarily omnivorous (HW-48523).

The maximum radionuclide concentration for shiners (minnows) sampled near Hanford in 1953 was 9 x 10^{-3} μCi/g, wet weight. Maximum values for the course-scaled sucker were 4 x 10^{-3} μCi/g, 0.7 x 10^{-3} μCi/g, 3 x 10^{-3} μCi/g, and 2.5 x 10^{-3} μCi/g, wet weight for scales, muscle, liver, and bone, respectively (HW-33366).

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HW-33366 Foster, R.F., J.J. Davis, and P.A. Olson. 1954. Studies on the Effect of the Hanford Reactors on Aquatic Life in the Columbia River. General Electric Company, Hanford Works, Richland, Washington.

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17.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1954

17.1 MEDIA SAMPLED

17.1.1 Fish

Columbia River fish were analyzed for radioactive contamination. Species collected included chinook salmon, shiners, squawfish, bluegill, dace, fine-scaled (bridgelip) suckers, course-scaled (largescale) suckers, mountain suckers, sculpins, carp, chiselmouth, chubs (peamouth), sticklebacks, largemouth bass, rainbow trout, sturgeon, cutthroat trout, sockeye salmon, whitefish, smallmouth bass, and steelhead trout (HW-36074). Small fish were analyzed whole. Larger fish were dissected, then analyzed. Tissues routinely examined included muscle, liver, scales and bone. Other tissues sampled occasionally included ovaries, testes, kidney, spleen, heart, viscera, skin, and scales; feces were also examined (HW-36074; HW-48523).

17.1.2 Shellfish

Clams were analyzed for radioisotope contamination. Only soft parts were examined, as their shells contained practically no radioactive material (HW-36074).

17.1.3 Waterfowl

Waterfowl were collected and analyzed for the Hanford environmental monitoring program. Individual species were not identified (HW-35917).

17.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

17.2.1 Fish

Columbia River fish were collected at two locations near Hanford, at Richland and Priest Rapids, and in the vicinity of McNary Dam (HW-35917). Further sampling was conducted at Priest Rapids (RM 387 and RM 396); Station B-1 (RM 381); Station D-1 (RM 377); Station D-2 (RM 375); Station H-1 (RM 372); Station H-2 (RM 369); Station F-1 (RM 367); Hanford, Washington (RM 362); the Ringold area (Washington) (RM 354); 300 Area (RM 345); Richland,

Washington (RM 339); McNary-1 (RM 298, near Hat Rock, above the dam); and McNary 2-B (RM 285, below the dam) (HW-36074). River Mile 293 was also sampled, as well as Priest Rapids at RM 391, Ringold (RM 353), and Richland, Washington (RM 340) (HW-48523).

17.2.2 Shellfish

Clams were sampled from McNary-1 (RM 298, above McNary) (HW-36074).

17.2.3 Waterfowl

Waterfowl were collected from the 200 West Area's "U" swamp (pond) (HW-34147-E).

17.3 RADIONUCLIDES MEASURED/REPORTED

17.3.1 Fish

Phosphorus-32 uptake was elevated because natural levels of stable phosphorous in the Columbia River are low (HW-33366).

Phosphorous-32 is considered to be responsible for 70% to 95% of the radioactivity in all river organisms, except plankton and sponge, in the vicinity of Hanford (HW-36074; HW-33366). The maximum concentration of phosphorous-32 in adult whitefish was found in the scales and liver. The maximum concentration in juveniles was found in the scales and bone (HW-48523).

Radionuclides found in Columbia River fish included phosphorous-32, copper-64, chromium-51, sodium-24, manganese-56, arsenic-76, zinc-65, iron-59, cobalt-60, scandium-46, zirconium-niobium-95, cesium-137, and neptunium-239 (HW-36074; HW-48523).

Copper-64 was responsible for 1% to 7.5% of the total beta emitters from shiners (HW-36074; HW-35917).

Sodium-24 made up 3 to 14% of the total radionuclide activity in samples analyzed at Hanford (HW-35917).

While the exposed surfaces of aquatic organisms absorb or adsorb significant amounts of radionuclides, greater accumulation occurs through

metabolic processes that concentrate the radioisotopes. Fish were found to obtain most of their radioactivity from their food sources, rather than directly from the water (HW-33366).

The concentrations of radionuclides in fish varied due to food habits; life cycles; and differences in metabolic rates, chemical composition of tissues, and morphology (HW-36074).

Calcareous tissues such as scales and bone were usually the most radioactive. Muscle and nervous tissue were least active (HW-33366).

The average dose rate received by shiners at Hanford in 1954 was 39.7 millirads/day, with a maximum of 117 millirads/day in the month of August (HW-36074).

Suckers, which eat large quantities of algae and other plant material, exhibited a higher concentration of radionuclides in their muscle than did whitefish, which are primarily omnivorous (HW-48523).

Rocky Mountain whitefish were the most important food/game fish caught in the Columbia River in the Hanford vicinity (HW-48523). In addition, steelhead, bass, salmon, sturgeon, carp, and suckers were popular with fishermen (HW-36074).

Analytical results were reported as gross beta in units of pCi/g, wet weight. Tables of data included monthly maximum and average values for fish caught at each sampling station (HW-36074), as well as concentrations in organs from individual fish (HW-36074; HW-48523). Some isotope concentrations were discussed, but values were determined from decay studies only.

Only trace amounts of radionuclides with half-lives less than 14 days were found in fish more than 20 miles downstream of the reactors (HW-35917).

Maximum radionuclide concentrations were seen in the vicinity of RM 367 (Hanford) (HW-48523; HW-33366). Sites upstream were generally at background levels, and concentrations decreased with distance downstream. Variations in this pattern resulted from migratory habits of animals, short-term fluctuations in reactor operations, the shifting of effluent channels in the river, and changes in the sites of effluent discharge (HW-36074).

Steelhead and salmon had insignificant levels of radioactivity as adults returning to spawn, because they do not feed during this time (HW-36074).

The effects of cooking on radionuclide concentrations were discussed. In general, after cooking there was an increase in the concentration of radionuclides in the scales and skin, and a decrease in the muscle and bone (HW-48523).

Forty-one percent of the whitefish caught at Priest Rapids between November 1953 and October 1954 had activities above background levels (HW-35917).

17.3.2 Shellfish

The soft parts of clams were analyzed for radionuclide contamination. Results were reported as average and maximum concentrations of gross beta in units of 10^{-6} μCi/g, wet weight (HW-36074).

Maximum radionuclide contamination values for clams were obtained in December, when the monthly maximum was 150 x 10^{-6} μCi/g, wet weight (HW-36074).

17.3.3 Waterfowl

The major contaminant found in waterfowl collected from the 200-W "U" swamp (pond) in December 1954 was cesium (HW-34147-E).

The average radionuclide concentrations in waterfowl from "U" swamp (pond) for the month of December were 2 x 10^{-2} μCi/g in muscle tissue and 1 x 10^{-2} μCi/g in liver tissue (HW-34147-E).

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HW-35917 Kornberg, H.A. 1955. Biology Research Annual Report, 1954. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-34147-E Parker, H.M. 1955. Radiological Sciences Department Report for Month of December, 1954. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-48523 Watson, D.G., and J.J. Davis. 1957. Concentration of Radioisotopes in Columbia River Whitefish in the Vicinity of the Hanford Atomic Products Operation. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

18.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1955

18.1 MEDIA SAMPLED

18.1.1 Fish

Columbia River fish were analyzed for radionuclide contamination. Species collected included shiners, mountain suckers, fine-scaled (bridgelip) suckers, course-scaled (largescale) suckers, squawfish, chubs (peamouth), sticklebacks, dace, sculpins, chinook salmon, smallmouth bass, rainbow trout, carp, chiselmouth, sturgeon, whitefish, largemouth bass, crappie, and steelhead trout (HW-36074). Small fish were analyzed whole. Larger fish were separated into various tissues, then analyzed. Tissues routinely examined included muscle, liver, scales, and bones. Other tissues sampled occasionally included ovaries, testes, kidney, spleen, heart, viscera, and skin; feces were also examined (HW-36074; HW-48523 DEL).

18.1.2 Shellfish

Columbia River clams were analyzed for radionuclide contamination. Only soft parts were examined, because the shells contained practically no radioactive material (HW-36074).

18.1.3 Waterfowl

Waterfowl examined for radionuclide contamination included mergansers, puddle ducks, and coots. Concentrations of phosphorous-32 in the bones of mergansers and puddle ducks were compared for seasonal fluctuations. Tissues examined in coots included bone, muscle, kidney, liver, egg yolk and albumin, and egg shell (HW-41500).

18.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

18.2.1 Fish

Locations of Columbia River fish sampling stations included control stations at Priest Rapids (RM 387 and RM 396); Station B-1 (RM 381); Station D-1 (RM 377); Station D-2 (RM 375); Station H-1 (RM 372); Station H-2

(RM 369); Station F-1 (RM 367); Hanford (RM 362); the Ringold area (Washington) (RM 354); Richland, Washington (RM 339); McNary-1 (RM 298, above McNary); and McNary 2-B (RM 285) (HW-36074). River Mile 293 was also sampled, as well as Priest Rapids at RM 391, Ringold at RM 353, and Richland at RM 340 (HW-48523).

Most fish-sampling areas on the river included fast-water areas with cobblestone bottoms. However, a few slow-water areas were included for comparison (HW-36074).

18.2.2 Shellfish

Columbia River clams were sampled at McNary-1 (RM 298, above McNary) (HW-36074).

18.2.3 Waterfowl

Waterfowl were collected along the Columbia River within the Hanford reservation boundaries (HW-41500).

18.3 RADIONUCLIDES MEASURED/REPORTED

18.3.1 Fish

Two new reactors, 105-KW and 105-KE, were placed into operation in early 1955 (HW-43529; HW-41500).

In the Columbia River near Hanford, phosphorous-32 was considered to be responsible for 70% to 95% of the radioactivity in all river organisms except plankton and sponge. The radionuclides responsible for activities in plankton and sponge were not identified (HW-36074).

The maximum concentration of phosphorous-32 in adult Columbia River whitefish was found in the scales and liver. The maximum concentration in juveniles was found in the scales and bone (HW-48523).

Radionuclides found in Columbia River fish included phosphorous-32, copper-64, chromium-51, sodium-24, manganese-56, arsenic-76, zinc-65, iron-59, cobalt-60, scandium-46, zirconium-niobium-95, cesium-137, and neptunium-239 (HW-36074; HW-48523).

Copper-64 is responsible for 1% to 7.5% of the total beta emitters in Columbia River shiners (HW-36074).

The concentrations of radioisotopes in fish vary due to food habits; life cycles; and differences in metabolic rates, chemical composition of tissues, and morphology (HW-36074).

Analytical results for Columbia River fish were reported as gross beta in units of pCi/g, wet weight. Tables of data included monthly maximum and average values for fish caught at each sampling station (HW-36074) as well as concentrations in individual organs from individual fish (HW-36074; HW-48523). Some radionuclide concentrations were discussed, but values were determined from decay studies only.

Rocky Mountain whitefish were the most important food/game fish caught in the Columbia River in the Hanford vicinity (HW-48523). In addition, steelhead, bass, salmon, sturgeon, carp, and suckers were popular with fishermen (HW-36074).

Suckers, which eat large quantities of algae and other plant material, exhibited a higher concentration of radionuclides in their muscle than did whitefish, which are primarily omnivorous (HW-48523).

The average dosage rate received by shiners at Hanford in 1955 was 37.4 millirads/day, with a maximum of 137 millirads/day during the month of August (HW-36074).

The effects of cooking on radionuclide concentrations in fish were discussed. In general, after a fish was cooked, there was an increase in the concentration of radionuclides in the scales and skin, and a decrease in the muscle and bone (HW-48523).

In 1955, during the period when radionuclide contamination levels were highest (October-December), the concentration of radionuclides in the flesh of whitefish caught at sport-fishing areas near Priest Rapids and Ringold averaged 2×10^{-4} μCi/g and 3×10^{-4} μCi/g, respectively. Maximum contamination levels were 7×10^{-4} μCi/g and 8×10^{-4} μCi/g, respectively. Within the boundaries of Hanford, an average of 4×10^{-4} μCi/g of flesh was seen in fish collected near RM 367 during the same time period (HW-36074).

Maximum radioisotope concentrations in fish were found in the vicinity of RM 367 (Hanford) (HW-48523). Sites upstream were generally at background levels, and concentrations decreased with distance downstream. Variations in this pattern resulted from migratory habits of animals, short-term fluctuations in reactor operations, the shifting of effluent channels in the river, and changes in the sites of effluent discharge (HW-36074).

At Hanford, during the fall, the concentration of phosphorous-32 in whitefish was 3600 times that of Columbia River water (HW-48523).

The maximum concentration of phosphorous-32 in shiners was about 160,000 times that of Columbia River water. During August through October, the concentration of beta emitters in shiners from Hanford averaged 470 times that of the water (HW-36074).

Zinc-65 was present in all whitefish tissues but greatly exceeded the phosphorous-32 concentrations in the gut and parts of the eye (HW-48523).

Steelhead and salmon have insignificant levels of radioactivity as adults returning to spawn, as they do not feed during the spawning period (HW-36074).

18.3.2 Shellfish

The soft parts of clams were analyzed for radionuclide contamination. Results were reported as average and maximum concentrations of gross beta in units of 10^{-6} μCi/g, wet weight (HW-36074).

Maximum radionuclide contamination values were obtained in September, when the monthly maximum was 200 x 10^{-6} μCi/g, wet weight (HW-36074).

18.3.3 Waterfowl

Waterfowl within the Hanford reservation exhibited a seasonal pattern of phosphorous-32 in bone, with peak periods in May and September. Soft tissues often contained concentrations similar to those found in bone (HW-41500).

Maximum radionuclide contamination was usually found in birds whose diets included aquatic insects (HW-41500).

Coots and other waterfowl inhabiting onsite waste ponds contained an average concentration of 0.6 μCi/g of total beta activity in all edible muscle and 1.7 μCi/g in the skeleton (HW-41500).

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HW-36074 Davis, J.J., D.G. Watson, and C.C. Palmiter. 1956. Radiological Studies of the Columbia River Through December, 1955. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-41500 Kornberg, H.A. 1956. Biology Research Annual Report, 1955. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-43529 Rostenbach, R.E. 1956. Columbia River Survey, 1954-1955. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-48523 Watson, D.G., and J.J. Davis. 1957. Concentration of Radioisotopes in Columbia River Whitefish in the Vicinity of the Hanford Atomic Products Operation. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

19.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1956

19.1 MEDIA SAMPLED

19.1.1 Fish

Species collected as part of the routine Hanford environmental sampling program included Rocky Mountain whitefish, minnows (shiners), and suckers (HW-48523; HW-45999; HW-46451; HW-47091; HW-47740). Large fish were either analyzed whole or dissected, then analyzed. Tissues routinely examined included bone, liver, scales, and muscle. Other tissues occasionally tested included kidney, ovaries, testes, heart, spleen, and skin; feces were also occasionally examined (HW-48523).

19.1.2 Shellfish

No information is available at this time.

19.1.3 Waterfowl

Coots, diving ducks, and puddle ducks were collected as part of the routine Hanford waterfowl sampling program. Tissues analyzed included bone and soft tissue (HW-45999; HW-46451; HW-47091; HW-47740). Diving ducks, river ducks, mergansers, and coots were examined in a special study to determine the effects of different food habits on radionuclide contamination (HW-47500).

19.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

19.2.1 Fish

Routine Columbia River fish collection locations included Hanford, 100-H, Priest Rapids, McNary, Ringold, and Richland, Washington. Not all stations were sampled each month (HW-45999; HW-46451; HW-47091; HW-47740). Sampling locations in other studies included Priest Rapids (RM 391 and RM 396); Station F-1 (RM 367); Hanford (RM 362); Ringold (RM 354); Trinidad (RM 441); Vantage (RM 423); Beverly (RM 412); River Mile 403, McNary Dam (RM 285 and 295), and Richland (all Washington) (RM 340) (HW-48523).

Additionally, approximately 1200 samples were collected along the Washington and Oregon coasts and from the Atlantic coast near Cape Cod.

19.2.2 Waterfowl

Waterfowl were collected from the 221-U swamp, 200-East waste swamp, and the Columbia River in the vicinity of Hanford (HW-45999; HW-46451; HW-47091; HW-47740; HW-47500).

18.3 RADIONUCLIDES MEASURED/REPORTED

18.3.1 Fish

Fish collections were reported monthly beginning in September when the Biology Department started issuing monthly reports.

Rocky Mountain whitefish was the most important food/game fish caught in the Columbia River in the Hanford vicinity (HW-48523).

The upstream migration of whitefish resulted in a ten-fold increase in contamination levels in whitefish sampled from Priest Rapids in November (HW-47091).

Phosphorus-32 is responsible for 60% to 90% of the total concentration of radionuclides in Columbia River fish and invertebrates (HW-48523).

The contamination levels of Columbia River fish in September 1956 were twice that of September 1955 (HW-45999).

Because of the inclusion of bony tissues and gut contents in the analyzed samples, shiners, which were analyzed whole, had a higher concentration of radionuclides than both whitefish and sucker flesh (HW-48523).

During November 1956 the concentration of radioisotopes in Columbia River fish collected near Hanford was three times that of November 1955 (HW-47091).

New gamma ray spectrometric analyses showed the presence of substantial quantities of zinc-65, chromium-51, manganese-56, iron-59, sodium-24, scandium-46, cobalt-60, and copper-64 in whitefish sampled at Hanford (HW-48523).

In September and December 1956 concentrations of radionuclides in small fish were twice what they were in 1955 during the same months (HW-45999, HW-47740).

The average fall values for whitefish muscle in 1956 were 5 x 10^{-4} μCi/g for Ringold and 6 x 10^{-4} μCi/g for areas within the Hanford reservation (HW-48523).

Suckers, which eat large quantities of algae and other plant material, exhibited a higher concentration of radionuclides in their muscle than did whitefish, which are primarily omnivorous (HW-48523).

The effects of cooking on radionuclide concentrations in Columbia River fish were discussed. In general, after cooking there was an increase in the concentration of radionuclides in the scales and skin, and a decrease in the muscle and bone (HW-48523).

At Hanford, during the fall, the concentration of phosphorous-32 in whitefish was 3600 times that of the Columbia River water (HW-48523).

The maximum concentration of phosphorous-32 in adult whitefish was found in the scales and liver. The maximum concentration in juveniles was found in scales and bone (HW-48523).

Elevated activities were seen in fish caught up to thirty miles upstream of 100-B (HW-48523).

Zinc-65 was present in all whitefish tissues but greatly exceeded phosphorous-32 concentrations in the gut and in parts of the eye (HW-48523).

Results for samples collected as part of the routine Hanford monitoring program were reported as average and maximum μCi of radionuclide per gram of tissue (HW-47091; HW-47740; HW-46451; HW-45999). Other analytical results were reported as gross beta in units of pCi/g, wet weight, and tables of data were presented (HW-48523).

19.3.2 Waterfowl

Contamination levels for waterfowl from the 221-U swamp in October were one-third the levels for 1955. The October values for puddle ducks from the Columbia River area were fifteen times those of 1955 (HW-46451).

During the June to August period, merganser food preference shifted from large to small fish, resulting in an increase in phosphorous-32 concentration (HW-47500).

Results for waterfowl samples collected from the 221-U swamp as part of the routine Hanford sampling program were reported as average and maximum μCi of fission products per gram of tissue (HW-47091; HW-47740; HW-46451; HW-45999).

Diving ducks consumed more insects than coots or river ducks and exhibited a greater uptake of strontium-90, cesium-137, and ruthenium-106 (HW-47500).

Waterfowl collected from the 222-U swamp in December 1956 contained radionuclide concentrations similar to those seen in December 1955 (HW-47740).

Radionuclide levels in puddle ducks collected from 200-East Area waste swamp in November 1956 were about one-third that of similar samples collected from the 221-U swamp during the same month (HW-47091).

During the final quarter of 1956, when the bird populations utilizing the waste ponds stabilized, the tissue concentrations of fission products in diving ducks were six times those of coots and five times those of river ducks (HW-47500).

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HW-45999 Kornberg, H.A. 1956. Biology Monthly Report, September 1956. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

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HW-47091 Kornberg, H.A. 1956. Biology Monthly Report, November 1956. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-47740 Kornberg, H.A. 1957. Biology Monthly Report, December 1956. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-47500 Kornberg, H.A. 1957. "Role of Food Habits in Wildlife Contamination at Hanford." Biology Research Annual Report, 1956. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

HW-48523 Watson, D.G., and J.J. Davis. 1957. Concentration of Radioisotopes in Columbia River Whitefish in the Vicinity of the Hanford Atomic Products Operation. General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

20.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1957

20.1 MEDIA SAMPLED

20.1.1 Fish

Several species of Columbia River fish were analyzed for radionuclide contamination. These included whitefish (HW-63654 REV; HW-48741 D; Davis et al. 1958; Davis 1958), suckers (Davis et al. 1958; HW-63654), minnows (HW-48741 D; Davis et al. 1958), shiners, salmon and sculpins (Davis 1958), squawfish, and sturgeon (Davis et al. 1958). Tissues analyzed in the suckers included bone, scales, spleen, liver, kidney, gut, heart, ovaries, retina, blood, brain, muscle, skin, fat, and lens. All tissues were analyzed for zinc-65 and phosphorous-32. Most were analyzed for copper-64, sodium-24, and Chromium-51. Bone and scale tissue was analyzed for strontium-89-90. Gut tissue was analyzed for iron-59, and cesium-137 concentrations in muscle tissue were monitored (Davis et al. 1958).

20.1.2 Shellfish

No information was located.

20.1.3 Waterfowl

Ducks and geese sampled from the Hanford region during the fall hunting season included the Barrow goldeneye duck (Davis et al. 1958), coots, diving ducks, puddle ducks, and mergansers (HW-48741 D). Tissues examined included bone, pancreas, liver, spleen, testes, flesh, kidney, heart, gut, lungs, blood, fat, and feathers (Davis et al. 1958).

20.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

20.2.1 Fish

Columbia River fish-collection sites included Hanford, Priest Rapids, Ringold (HW-63654; HW-48741 D), and Dot Island Station (a location near the reactors) (Davis et al. 1958). (See Figures 4.1 and 4.2.)

20.2.2 Shellfish

No information was located.

20.2.3 Waterfowl

Waterfowl were collected from 221-U Swamp (HW-48741 D) and along the Columbia River within the Hanford reservation (HW-63654 REV; Healy et al. 1958). The Barrow goldeneye was collected at Dot Island in November (Davis et al. 1958).

20.3 RADIONUCLIDES MEASURED/REPORTED

20.3.1 Fish

Radionuclides found in Columbia River large-scale suckers included, in order of diminishing abundance, phosphorous-32, sodium-24, zinc-65, manganese-56, arsenic-76, copper-64, strontium-80, and cesium-137. Over 90% of the radionuclide contamination was phosphorous-32, which deposited principally in hard tissues (bone, scales), but was also present in visceral organs and muscle (HW-63654 REV). Radioactive phosphorus in bone samples was 4.64×10^{-2} μCi/g (wet weight), while zinc-65 concentrations were highest in the retina and iris (2.81×10^{-3} μCi/g, wet weight, in the retina). Lowest phosphorous-32 concentrations were in the fat and muscle (Davis et al. 1958).

Suckers were the most radioactive species of large fish in the Columbia River (Davis et al. 1958).

The peak period for radioactive contamination in fish was during August, September, and October, when water temperature and metabolic rates were at their highest. Lowest concentrations were in winter (Davis et al. 1958, HW-63654 REV).

"No detrimental effects have been indicated on fish or other aquatic organisms due to the radioactive materials in the river, despite reconcentration by factors of 10^5 in certain biota in the food chain" (HW-54243 REV).

Levels of phosphorous-32 in whitefish in 1957 were equivalent to levels seen in 1956. Concentrations of phosphorous-32 in small fish in 1957 were three times greater than levels found in 1956 (HW-48741 D).

The differences in radionuclide composition of different species could have been attributed to the position in the food web, life cycles, intra-specific differences in metabolism, chemical composition of tissues, and morphology (Davis et al. 1958).

The calculated dose rate of radioactivity to shiners during the fall was about 0.7 rad per day, which is "in the order of ten per cent of the safe level for fish" (HW-54243 REV).

In the Hanford Reach, Columbia River plankton were about three times more radioactive than the fish, but 50 miles downstream and beyond, the fish were more radioactive (Davis et al. 1958).

Whitefish were considered to be the fish species contributing the most to human exposure because of their relatively high accumulation of radio-nuclides, and because they were easily caught in the fall when the tissue content of radioactive materials was highest (HW-63654).

Ringold was the closest public fishing area downriver from the reactors (HW-63654 REV).

Concentrations of phosphorous-32 in shiners from near Hanford were 165,000 times that of the water (Davis et al. 1958).

The concentration of phosphorous-32 in the flesh of whitefish collected near Hanford in August 1957 was 1×10^{-3} μCi/g, wet weight (HW-63654 REV).

As salmon pass through the Hanford region on their spawning migration, they do not feed, because of their life-cycle stage. Consequently, they do not accumulate significant amounts of radioactive material. Salmon fry and shiners collected in Richland in the spring of 1957 had an average beta activity of 4×10^{-4} μCi/g. A young salmon caught 360 miles downstream from Hanford at the river mouth in September 1956 had an average concentration of 1×10^{-4} μCi/g in the muscle (wet weight) (Davis 1958).

Concentrations of zinc-65 in whitefish during late summer 1957 were about 1/20 of the observed levels for phosphorous-32, while the maximum permissible intake rate for zinc-65 was five times greater. Therefore, zinc-65 only contributed a small fraction of the exposure received by people from the consumption of fish (HW-63654 REV).

Whitefish flesh contained concentrations of phosphorous-32 high enough to result in recommendations for restrictions on certain process operations, especially during the fall months when river flow was low and fish metabolism was high (HW-54243 REV).

Data were tabulated for whitefish flesh caught in public fishing areas above and below the reactors. Maximum values reported for fish below the reactors was 1.5×10^{-3} μCi/g in November and October. Maximum values for fish above the reactors was 3.3×10^{-4} μCi/g in October (Healy et al. 1958).

20.3.2 Shellfish

Zinc-65 is the radionuclide which has been detected in the greatest amounts in marine organisms, particularly oysters, at considerable distances from the river mouth (HW-63654 REV).

20.3.3 Waterfowl

Tissues examined from the Barrow goldeneye were all analyzed for phosphorous-32. Most were examined for zinc-65, and some tissues were analyzed for scandium-46, chromium-51, cobalt-60, and copper-64 (Davis et al. 1958).

The concentration of phosphorous-32 in the muscle of some ducks, which were killed along the Columbia River within the Hanford reservation, was similar to that in fish (HW-63654 REV).

A waterfowl collected in the vicinity of Hanford "may have accumulated a concentration of phosphorous-32 in the muscle to 75,000 times its concentration in the river water" (Davis et al. 1958).

Ducks from the Hanford reservation swamps were analyzed for fission products, and values were reported in μCi of fission products/g tissue. Maximum concentrations were seen in bone ($2\text{-}5 \times 10^{-3}$ μCi of fission products/g). Contamination of bone in February 1957 was one tenth that of February 1956. Soft tissue contamination was one-third of 1956 values (HW-48741 D).

Ducks and geese banded in the Hanford region were sighted in areas extending from Alberta and British Columbia to California and Oklahoma (Davis 1958).

The radionuclide content in waterfowl from the Columbia River area below the reactors depends on the food habits of the birds and the geographic areas of the river in which they feed (Davis et al. 1958).

The greatest concentration of phosphorous-32 in juvenile waterfowl occurred in the pancreas and skeleton, but in the adult birds the greatest concentration occurred in the muscle (Davis et al. 1958).

The Barrow goldeneye duck usually contains higher contamination levels in their tissues than other species, due to the fact that this group feeds almost entirely on aquatic insect larvae and other invertebrates from the river bottom (Davis et al. 1958).

Monthly values were reported for edible flesh from ducks caught on the Hanford reservation. Maximum values were seen in September (5×10^{-3} μCi/g) (Healy et al. 1958).

Flesh from ducks collected along the Columbia River within the Hanford reservation was analyzed. Maximum values were found in diving ducks (4×10^{-3} μCi/g). Bone values, while about three times higher than flesh values, were not reported (HW-48741 D).

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21.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1958

There were no fish, shellfish, or waterfowl data discussed in the reviewed documents. It appears as though these organisms were not collected by Hanford environmental-monitoring personnel during 1958.

22.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1959

22.1 MEDIA SAMPLED

22.1.1 Fish

Fish sampled from the Columbia River included minnows (usually shiners but also juvenile cyprinids) and adult whitefish (muscle tissue) (HW-64371; HW-65500). The redside shiner was considered the biological indicator of radiation contamination in Columbia River biota during 1959. Whitefish were the representative game fish (HW-65500).

Marine species from near the mouth of the Columbia River were collected and analyzed. Species included starry flounder, octopi, smelt, white perch, and chinook salmon (HW-SA-2857; HW-63654 REV; HW-65500; HW-64371).

22.1.2 Shellfish

Marine shellfish collected included oysters (fresh and canned), burrowing clams, razor clams, crabs, steamer clams, mixed clams, and bay mussels (HW-64371; HW-65500; HW-63654 REV).

Dungeness crabs, bay mussels, Pacific oysters, razor clams, and Japanese littleneck clams were collected near the month of the Columbia River. Both the shell and the soft tissues were analyzed (HW-SA-2857).

22.1.3 Waterfowl

Ducks collected from the Columbia River included diving ducks and river ducks (HW-65500). More specific identifications were not provided.

22.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

22.2.1 Fish

Samples of minnows were collected near the reactors (10 fish in January and 10 in December), from the Priest Rapids area (10 in February and 2 in October) and from the Ringold area (10 in February, 11 in March, 24 in April,

16 in May, 10 in June, 10 in July, 19 in August, and 10 in October) (HW-64371).

Whitefish were collected from the Priest Rapids area (3 fish in February, 13 in October, and 5 in December); from near the reactors (3 in February, 12 in November, and 14 in December); and from the Ringold area (1 in October and 4 in December). A single whitefish sample was also collected near the mouth of the Yakima River (HW-65500).

In April, ocean fish were collected from Kalaloch, Washington (smelt) and Ilwaco, Washington (chinook salmon, starry flounder) (HW-64371).

22.2.2 Shellfish

Samples of oysters (locally purchased) were obtained from Washington State growers in November and December (HW-64371).

Additional samples were also purchased locally. Points of origin for these samples included Japan, New Jersey, Mississippi, Louisiana, and several Washington state locations (HW-64371).

Pacific Ocean shellfish were collected in April from both the Washington and Oregon coasts, and soft tissues were analyzed for zinc-65. Sampling locations (and specific organisms) included Coos Bay, Oregon (burrowing clams); Lewis State Park, Oregon (razor clams); Long Beach, Washington (razor clams); Kalaloch, Washington (razor clams); Willapa Bay, Washington (oysters and steamer clams); Sequim, Washington (mixed clams, oysters, and crabs); and Ilwaco, Washington (crabs) (HW-64371; HW-63654 REV).

Mussels (*Mytilus*) were collected from various coastal locations in April. Organisms were collected from Coos Bay, Boiler Bay, and Seaside, Oregon; Ilwaco, Willapa Bay, Kalaloch and Dungeness, Washington; and Juneau and Kachemak Bay, Alaska (HW-69500).

22.2.3 Waterfowl

Ducks were collected from the Columbia River near Pasco, Washington (1 duck in January), near the reactors (1 bird in January) and from the Ringold area (8 birds in January and 9 in October) (HW-64371).

22.3 RADIONUCLIDES MEASURED/REPORTED

22.3.1 Fish

The dominant radionuclide accumulated by Columbia River fish was phosphorous-32 (HW-65500).

Total beta was measured in whitefish collected from the Columbia River during the last quarter of the year. The maximum monthly mean for whitefish flesh collected within the boundaries of the Hanford site was 0.001 μCi/g. The maximum monthly mean for whitefish collected at the public fishing area just below Priest Rapids Dam was seen in October (0.0007 μCi/g) (HW-65500).

Total beta was measured in a single whitefish sampled from near the mouth of the Yakima River. The estimated mean concentration in flesh, based on levels in scales, was on the order of 0.0006 μCi/g. This indicated that whitefish from the Columbia River were moving into the lower reaches of the Yakima River (HW-65500).

Reported maximum concentrations of phosphorous-32 in whitefish ranged from 0.0039 μCi/g (wet weight) near the reactors in November to 0.00012 μCi/g (wet weight) near the reactors in February (HW-64371).

Minnows (shiners) were collected and analyzed for phosphorous-32. The maximum concentrations of phosphorous-32 in whole fish ranged from 0.021 μCi/g (wet weight) in October at Ringold to 0.000026 μCi/g (wet weight) in February at Priest Rapids (HW-64371).

Flesh from fish collected from Kalaloch, Washington, and Ilwaco, Washington, was checked for zinc-65 levels. The highest concentration was seen in smelt collected at Kalaloch (0.000014 μCi/g). Other concentrations ranged from 0.000013 μCi/g in the flounder to 0.0000012 μCi/g in one of the salmon (HW-64371).

Concentrations of gross beta, chromium-51, and zinc-65 (μCi/g) in salmon and flounder collected at the mouth of the Columbia River were tabulated (HW-63654 REV).

The species of fish most popular with sportsmen in the Hanford vicinity included steelhead trout, bass, Rocky Mountain whitefish, salmon, crappie, and sturgeon (HW-63654 REV).

22.3.2 Shellfish

Concentrations of various radionuclides were measured in locally purchased oysters. Analyses were done primarily on soft tissues, but the shells from one location were also sampled. The specific radionuclides analyzed for included strontium-89, strontium-89, scandium-46, potassium-40, zinc-65, zirconium-niobium-95, cesium-137, ruthenium-103+106, iodine-131, chromium-51, and cerium 141+144. Many of the results were below the reporting limit, including strontium-89 and strontium-90. Highest results were for zinc-65 and ranged from 0.000039 to 0.000067 μCi/g (HW-64371).

The soft tissues from another group of locally purchased oysters were analyzed for zinc-65 only. Samples were either canned or fresh and originated from locations in both the western and eastern United States and in Japan. The concentrations in Washington state samples ranged from 0.0000041 to 0.000063 μCi/g. The concentration range for the other samples was 0.00000003 to <0.00000014 μCi/g (HW-64371).

Concentrations of zinc-65 in the soft tissues of the Washington and Oregon coast shellfish collected in April ranged from 0.000046 μCi/g in Willapa Bay, Washington, oysters to 0.00000045 μCi/g in Coos Bay, Oregon, burrowing clams (HW-64371).

Gamma emitters were measured in the soft tissues of mussels collected from various coastal locations in April. Tissues were analyzed for cerium-141+144, chromium-51, ruthenium-103+106, manganese-54, cesium-137, zinc-65, and zirconium-niobium-95. All but chromium-51 occur in both world wide fallout and in Hanford effluents. Chromium-51 is not found in fallout. In almost all cases, the highest constituent concentrations were seen at Ilwaco, Washington (HW-69500).

Representative concentrations of radioisotopes in Pacific coast shellfish and crabs are given in HW-63654 REV. Tissues were analyzed for gross beta, chromium-51, and zinc-65.

22.3.3 Waterfowl

An aerial survey of the waterfowl population in the Hanford area was conducted in 1958. This survey determined that there were about 200 resident

ducks on the Hanford site during the summer months. By November, duck populations had increased to around 150,000. Similar numbers of ducks were seen in 1959 (HW-65500).

Phosphorus-32 was the predominant radionuclide found in duck flesh although measurable amounts of sodium-24, zinc-65, and strontium-90 were also found (HW-65500).

Flesh from ducks collected along the Columbia River near Pasco, Ringold, and the Hanford reactors was analyzed for phosphorous-32. The maximum concentration was seen in a diving duck collected at Ringold in January (0.0029 μCi/g wet weight). Maximum concentrations for all birds sampled ranged from 0.000056 μCi/g at both Ringold and Pasco to 0.0029 μCi/g at Ringold (HW-64371).

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23.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1960

23.1 MEDIA SAMPLED

23.1.1 Fish

Muscle tissue was sampled from large Columbia River fish, while small fish were analyzed whole. Species collected as part of the routine Hanford environmental sampling program included whitefish, shiners, carp, chiselmouth, squawfish, course-scale (largescale) suckers, yellow perch, fine-scale (bridgelip) suckers, chub (peamouth), sturgeon, minnows (whole fish, usually shiners but also small cyprinids), salmon (adult and juvenile), largemouth bass, smallmouth bass, black catfish, channel catfish, and pumpkinseed (HW-68435).

Levels of zinc-65 were measured in samples of tuna, salmon, sardines, anchovies, codfish, herring, and halibut obtained from local markets (HW-63824).

23.1.2 Shellfish

Oysters from Willapa Bay, Washington, were collected for the Hanford environmental monitoring program (HW-68435).

Marine organisms sampled included Pacific oysters, bay mussels, razor clams, and Japanese littleneck clams. Both shell and soft parts were analyzed. Dungeness crabs were also sampled (HW-SA-2857).

Levels of zinc-65 were measured in samples of oysters, crabs, clams, and shrimp obtained from local markets. Some oyster samples were fresh, and some were canned. In one case oysters were obtained from canned stew (HW-63824).

23.1.3 Waterfowl

Samples from approximately 600 ducks and geese were obtained during the 1960 waterfowl hunting season from local hunters and scanned for radionuclides. Species collected included mallard, green-winged teal, American shoveler, northern American coot, American common merganser, surf scooter, bufflehead, barrow goldeneye, American common goldeneye, lesser Canada goose, American pintail, and northern ruddy (HW-68435).

23.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

23.2.1 Fish

Routine Columbia River fish-collection locations included Ringold, Hanford, Richland, near Priest Rapids, near the reactors, Burbank (all Washington), and McNary Dam area (HW-68435, HW-69500).

23.2.2 Shellfish

Shellfish were collected near the shoreline from Willapa Bay, Washington (36 miles north of the Columbia River mouth) (HW-69500, HW-SA-2857); Ilwaco, Washington (at the river mouth) (HW-69500, HW-SA-2857); Long Beach, Washington (6 miles north of the river mouth) (HW-SA-2857); Seaside, Oregon (HW-SA-2857); Coos Bay, Oregon; Juneau, Alaska; and Kachemak Bay, Alaska (HW-69500).

The origins of the fresh and canned oysters obtained from local markets included Willapa Bay, Washington; South Bend, Washington; Seattle, Washington; the Gulf of Mexico, New Orleans, Louisiana; Biloxi Mississippi; Port Norris, New Jersey; Japan; and the West Coast (HW-63824).

23.2.3 Waterfowl

Waterfowl were sampled from Hanford; Burbank, Washington; the Separations Plant swamp; and the river near the reactors (HW-69500).

23.3 RADIONUCLIDES MEASURED/REPORTED

23.3.1 Fish

Radionuclides found in Columbia River fish, in order of diminishing importance, included phosphorous-32, sodium-24, zinc-65, manganese-56, arsenic-76, copper-64, strontium-90, and cesium-137. Over 90% of the radioactive material found was phosphorous-32, which deposits in the bones, scales, and visceral organs. Muscle was found to be one of the least contaminated body parts (HW-63654 REV). Not all samples were analyzed for every constituent.

Concentrations of phosphorous-32 were reported in units of 10^{-3} $\mu c/g$, wet weight (HW-68435).

The species of fish most popular with sportsmen in the vicinity of the Hanford project included steelhead trout, bass, Rocky Mountain whitefish, salmon, crappie, and sturgeon (HW-63654 REV).

Minnows (shiners) serve as indicator organisms and were collected at monthly intervals at Hanford (HW-69500).

There were eight production reactors operating during this time period (HW-68435).

The seasonal maximum average concentration of phosphorous-32 in whitefish muscle sampled at Ringold was $3 \times 10^{-3} \mu Ci/g$ and was seen during the fall months (HW-68435).

Except for suckers, whitefish usually have the highest concentration of radionuclides in fish (HW-68435).

Radionuclide accumulation is dependent on the feeding habits of fish. Seasonal variance occurs due to the rate of feeding, which is related to temperature (HW-63654 REV). Whitefish, suckers, and chiselmouth have the highest concentrations of total beta emitters (HW-69500).

Radionuclide concentrations in minnows this year were 2.5 times greater than in 1959 and 2 times greater than in 1958. Whitefish activity was also greater this year. Fish caught near Richland had beta concentrations similar to fish caught at Hanford, and some fish collected near Priest Rapids had high activity levels, indicating some upstream movement (HW-69500).

Whitefish were considered to contribute the most to human exposure because they are known to accumulate radionuclides released from the Site, and they were easily caught during the fall when tissue concentrations of radioactive materials were highest (HW-63654 REV).

"From the observed seasonal trends in the concentration of phosphorous-32 during 1960 it is estimated that a consumption of 10 lbs of fresh whitefish over a twelve month period would result in an intake of about 5 μCi of phosphorous-32" (HW-68435).

23.3.2 Shellfish

Willapa Bay, Washington, was the closest commercial oyster-producing area north of the Columbia River mouth (HW-63654 REV).

"Approximately one-half of the oysters produced on the West Coast are grown at Willapa Bay, Washington" (HW-63824).

The average concentration of zinc-65 in six samples of Willapa Bay oysters was about 50 pCi/g of soft tissue (HW-68435).

Zinc-65 was the radionuclide of greatest biological importance in Pacific Ocean shellfish due to its abundance in the soft tissues (HW-SA-2857).

The source of zinc-65 in marine shellfish was probably Hanford. Deposits of ruthenium and zirconium were probably from fallout. The source of cerium and manganese contamination was uncertain (HW-SA-2857).

Concentrations of zinc-65 in West Coast oysters was higher than those from other locations in the world that have been measured (HW-63824).

"Although the ^{65}Zn [zinc-65] concentration in oysters from Willapa Bay is relatively high compared with those from other locations, it represents a very small portion of the allowable concentration" (HW-63824).

Cobalt-60 was detected in oyster samples from Willapa Bay (HW-63824).

The gamma emitters chromium-51, neptunium-239, zinc-65, manganese-54, zirconium-niobium-95, ruthenium-103+106, and cerium-141+144 have been measured in brown algae, mussels, and oysters collected near the mouth of the Columbia River (HW-SA-2857).

23.3.3 Waterfowl

A new rapid-scanning method developed for the analysis of waterfowl determined that 40% to 45% of the waterfowl measured were above background levels and contained radionuclides common to the reactor effluents in the Columbia River but not occurring in worldwide fallout (HW-69500).

Concentrations of total beta emitters, predominantly phosphorous-32, in the flesh of waterfowl during November 1960 were six to eight times greater than observed in 1959 (HW-69500).

The maximum average concentration of phosphorous-32 in waterfowl was $4.6 \times 10^{-3} \mu Ci/g$ and was found in a green winged teal sampled from the Columbia River in the vicinity of the Hanford Site in December (HW-68435).

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24.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1961

24.1 MEDIA SAMPLED

24.1.1 Fish

Large and small fish were collected from the Columbia River for radionuclide analyses. Muscle tissue was removed from larger fish for analyses while smaller fish were usually analyzed whole. Species collected as part of the routine Hanford environmental sampling program included whitefish, course-scaled (largescale) suckers, fine-scale (bridgelip) suckers, shiners, squawfish, crappie, perch, chub (peamouth), chiselmouth, carp, smallmouth bass, brown trout, sturgeon, salmon, rainbow trout, steelhead, channel catfish, and bluegill. Shiners were generally analyzed whole, as were some squawfish and perch (HW-71999).

Starry flounder, rock greenling, buffalo sculpin, Pacific tomcod, blackcod, blacktail snailfish, Dover sole, English sole, filamented rattail, perch, rex sole, rock fish, sand sole, river and surf smelt, and staghorn sculpin were collected from the North Head (north jetty at the river mouth) of the Columbia River and other Washington and Oregon coastal locations between Cape Flattery and Coos Bay, Oregon. Whole fish were analyzed for radionuclide content. Collections took place between 1961 and 1963 in both coastal and offshore waters (UWFL-86).

24.1.2 Shellfish

Marine organisms sampled included Willapa Bay oysters (HW-71999) and soft-shelled clams (Toombs and Culter 1968).

Between 1961 and 1963, University of Washington personnel collected shellfish along the coasts of Washington and Oregon and analyzed them for radionuclide content. Species collected included empire clams, mud clams, razor clams, various crabs, mussels, limpets, snails, and shrimp, as well as other invertebrates (UWFL-86).

24.1.3 Waterfowl

During the 1961 waterfowl hunting season, the Hanford environmental-sampling program obtained approximately 3400 waterfowl from local hunters for radionuclide analysis. Additional birds were collected by Hanford monitoring personnel at locations onsite. Collected species included mallard, teal, shoveler, scaup, ruddy duck, pintail, old squaw, widgeon, wood duck, American golden eye, Barrow golden eye, gadwall, bufflehead, canvasback, merganser, ring neck, white wine scooter, coot, lesser Canada geese, white-fronted geese, cackling geese, basin Canada geese, lesser snow geese, snow geese and Ross' geese. Waterfowl heads were analyzed from offsite birds, while both head and muscle were analyzed from onsite birds (HW-71999).

A special study was performed to investigate waterfowl dispersion. Six hundred and one waterfowl were collected from local hunters during the 1960-61 hunting season within a 50 mile radius of Hanford. Analyses were performed on 6 species of river or pond ducks, 4 species of diving ducks, 1 species of merganser, and three varieties of geese. Two thirds of the birds analyzed were mallards (HW-72500).

24.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

24.2.1 Fish

Routine Columbia River fish-collection locations included Hanford, Richland, near Priest Rapids, Ringold, Burbank, and McNary Dam, Washington (HW-71999).

Sampling locations for the University of Washington study included the Washington locations of Cape Flattery, Hoh Head, Kalaloch, Copalis Rocks, Ocean Shores, Grays Harbor, Westport, Grayland Beach, Willapa Bay, Long Beach, and North Head. Oregon locations included Iredale, Seaside, Cannon Beach, Barview, Tillamook Bay, Agate Beach, Yaquina Bay, and Coos Bay. It was not clear if fish were obtained from all of these locations (UWFL-86).

24.2.2 Shellfish

University of Washington shellfish sampling locations are described above.

Oyster samples were collected from Willapa Bay, Washington (HW-71999).

Soft-shell clams were collected from Tillamook Bay, Oregon (Toombs and Culter 1968).

24.2.3 Waterfowl

Waterfowl for the Hanford environmental sampling program were obtained from local hunters in Washington State (Benton City, Bepo North Pond, Burbank area, Byron Pond, Connell, Eureka area, Finley, Horse Heaven area, Ice Harbor, Kahlotus, Kennewick, Kiona, Mabton, McNary, Mesa, Othello, Page, Pasco, Patterson, Pot Holes area, Prosser, Richland, Richland "Y," Ringold, Roza, Scootney area, Toppenish, Touchet, Twin Bridges, Twin Lakes, Walla Walla, Wallula, West Richland, and Yakima), Oregon (Sauvie Island, Summer Lake), Idaho (Boise), and California (Fresno, Sacramento Valley, and Tule Lake). Onsite locations included the 200-E and 200-W swamps, the lower Columbia River area from Hanford Ferry downstream to the project boundary, and the upper Columbia River area from Hanford Ferry to the project boundary (HW-71999).

24.3 RADIONUCLIDES MEASURED/REPORTED

24.3.1 Fish

Fish collected as part of the Hanford environmental sampling program were analyzed for total beta, phosphorous-32, zinc-65, scandium-46, neptunium-239, arsenic-76, and chromium-51. Concentrations were reported in units of $\mu\mu$Ci/g. Not all samples were analyzed for all constituents (HW-71999).

The concentration of phosphorous-32 in whitefish varied with the seasons and reached a maximum in late fall (HW-70552).

Except for suckers, whitefish usually had the greatest concentration of radioactive materials. The bulk of this material was phosphorous-32, which deposits primarily in the bone but also in the flesh (HW-71999).

The average seasonal concentrations of phosphorous-32 and zinc-65 found in whitefish muscle collected between Ringold and Richland were 8 x 10^{-4} μCi/g and 8 x 10^{-5} μCi/g, respectively (HW-71999).

Ringold was the closest fishing area available to the public downstream from the reactors (HW-71999).

Zinc-65 levels in muscle samples of Pacific Ocean fish decreased with distance from the mouth of the Columbia River. The rate of decrease was greater to the south than to the north (UWFL-86).

24.3.2 Shellfish

Willapa Bay oysters were analyzed for scandium-46, potassium-40, zinc-65, zirconium-niobium-95, cesium-137, ruthenium-103+106, iodine-131, chromium-51, cerium-141+144, and phosphorous-32 (HW-71999).

Zinc-65 was the only radionuclide originating from Hanford reactor effluents that was found in sufficient abundance beyond the mouth of the Columbia River to be of radiological interest (HW-71999).

Oysters from Willapa Bay were sampled regularly and analyzed for zinc-65. The average concentration of zinc-65 in 17 samples involving 34 pints of oysters was 8 x $10^{-5}$$\mu$Ci/g (HW-71999).

Soft-shell clams were monitored for zinc-65 (0.4 pCi/g drained weight) (Toombs and Culter 1968).

24.3.3 Waterfowl

Waterfowl collected as part of the Hanford environmental-sampling program were analyzed for beta and phosphorous-32. Concentrations were reported in units of $10^{-5}$$\mu$Ci/g (HW-71999).

Waterfowl collected as part of the special dispersion study were first scanned for gross gamma, principally due to zinc-65, and those containing more than 25 cpm were then chemically processed and analyzed for phosphorous-32 (HW-72500).

The maximum concentration of phosphorous-32 found in a sample obtained through the Hanford environmental sampling program was 2.6 x $10^{-3}$$\mu$Ci/g (HW-71999).

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25.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1962

25.1 MEDIA SAMPLED

25.1.1 Fish

Muscle samples were collected from large Columbia River fish. Species collected included whitefish, bass, carp, chiselmouth, squawfish, course-scaled (largescale) suckers, fine-scaled (bridgelip) suckers, sturgeon, steelhead, chub (peamouth), perch, trout, salmon, crappie, channel cat, catfish, bullhead, brown trout, bluegill, and rainbow trout (HW-76526; Toombs and Culter 1968). A reasonable effort was made to collect five fish for each sample (HW-76526; HW-75076). Samples of steelhead, sturgeon, trout and salmon were analyzed when caught. There was no special effort to sample these fish on a routine basis (HW-76526; HW-75076).

Starry flounder, rock greenling, buffalo sculpin, Pacific tomcod, blackcod, blacktail snailfish, Dover sole, English sole, filamented rattail, perch, Rex sole, rock fish, sand sole, river and surf smelt and staghorn sculpin were collected from the North Head (north jetty at the river mouth) of the Columbia River and other Washington and Oregon coastal locations between Cape Flattery, Washington, and Coos Bay, Oregon. Whole fish were analyzed for radionuclide content. Collections took place between 1961 and 1963 in both coastal and offshore waters (UWFL-86).

25.1.2 Shellfish

Marine organisms sampled by the state of Oregon included Willapa Bay oysters (HW-76526), soft-shelled clams, razor clams, Dungeness crabs, mussels, oysters, and snails. Many of the shellfish samples were purchased from commercial growers (Toombs and Culter 1968). Early in 1962, monitoring personnel at Hanford made arrangements to have two pounds of oysters shipped to Hanford from Willapa Bay every two weeks for analyses (HW-75076).

Between 1961 and 1963, University of Washington personnel collected shellfish along the coasts of Washington and Oregon and analyzed them for radionuclide content. Species collected included empire clams, mud clams,

razor clams, various crabs, mussels, limpets, snails, and shrimp, as well as other invertebrates (UWFL-86).

25.1.3 Waterfowl

During the 1962 waterfowl hunting season, about 102 ducks were shot by hunters in Washington and Oregon and submitted to Hanford for radionuclide analyses. An additional 88 birds were collected from the swamps and ponds onsite. Species collected included mallard, golden eye, pintail, teal, brant, gadwall, widgeon, shoveler, old squaw, coot, Canada goose, merganser, ruddy duck and bufflehead. Both the heads and muscle tissues from birds collected onsite were analyzed but the tissues analyzed from offsite birds were not specifically identified (HW-76526).

25.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

25.2.1 Fish

Routine Columbia River fish-sampling locations for the Hanford monitoring program in 1962 included Priest Rapids, Coyote Rapids, Hanford, Ringold, Richland, Burbank, and McNary Dam (all Washington) (HW-76526).

Sampling locations for the University of Washington study included the Washington locations of Cape Flattery, Hoh Head, Kalaloch, Copalis Rocks, Ocean Shores, Grays Harbor, Westport, Grayland Beach, Willapa Bay, Long Beach, and North Head. Oregon locations included Iredale, Seaside, Cannon Beach, Barview, Tillamook Bay, Agate Beach, Yaquina Bay, and Coos Bay. It was not clear if fish were obtained from all of these locations (UWFL-86).

25.2.2 Shellfish

University of Washington shellfish sampling locations are described above.

The Hanford environmental-monitoring program collected shellfish from Willipa Bay, Washington (HW-76526).

Collection sites for the State of Oregon included:

Willapa Bay, Washington:	oysters
Tillamook Bay, Oregon:	oysters, soft-shelled clams, Dungeness crabs
Seaside Beach, Oregon:	razor clams
Astoria, Oregon:	Dungeness crabs
Yaquina Bay, Oregon:	Dungeness crabs
Cannon Beach, Oregon:	mussels
The Nehalem River Jetty, Oregon:	mussels, snails
Yaquina Bay/Agate Beach, Oregon:	mussels, oysters

(Toombs and Culter 1968)

25.2.3 Waterfowl

Waterfowl contributed by offsite hunters were collected at Dayton, Mesa, Prosser, Sunnyside, and Patterson Ferry, Washington. Several birds were also harvested at Umapine, Oregon. Samples collected by Hanford monitoring personnel were obtained at Hanford, Richland, the lower Columbia River, the upper Columbia River, Gable swamp (pond), Redox swamp, and U-Plant swamp (pond) (HW-76526). The upper Columbia River extends from 100-B to Hanford, and the lower Columbia River extends from Hanford to Richland (HW-75076).

25.3 RADIONUCLIDES MEASURED/REPORTED

25.3.1 Fish

There were eight production reactors operating in 1962.

Many samples of fish were collected and analyzed during 1962 for both onsite and offsite studies.

Except for suckers, whitefish generally had the highest radionuclide concentrations (HW-76526).

The frequency of sampling whitefish in the Ringold to Richland area was changed from monthly to twice monthly in January (HW-73366).

On any given day, the range in phosphorous-32 concentrations in whitefish muscle frequently extended over one or two orders of magnitude (HW-SA-2688).

The annual average concentrations of phosphorous-32 and zinc-65 in whitefish caught between Ringold and Richland was 0.00035 μCi/g and

0.00006 μCi/g, respectively. Most phosphorous-32 deposited in the bone, but some was also found in muscle tissues (HW-76526).

The muscle tissues from most fish caught as part of the 1962 Hanford environmental monitoring program were analyzed for phosphorous-32, cobalt-60, potassium-40, zinc-65, cobalt-58, cesium-137, and total beta (HW-76526).

Results for 1207 fish samples analyzed in 1962 as part of the Hanford environmental program were reported in tables (HW-76526).

Highest phosphorous-32 concentration in bass muscle in 1962 (1600 pCi/g) was seen at Ringold in September (HW-76526).

The concentration of phosphorous-32 in the muscle of a channel catfish caught at McNary in August was 2200 pCi/g HW-76526).

Zinc-65 levels in muscle samples of Pacific Ocean fish decreased with distance from the mouth of the Columbia River. The rate of decrease was greater to the south than to the north (UWFL-86).

25.3.2 Shellfish

Willapa Bay Oysters collected for the Hanford monitoring program were monitored for potassium-40, zinc-65, zirconium-niobium-95, cesium-137, ruthenium-103+106, cerium-praseodymium-144, phosphorous-32, cobalt-58, and cobalt-60 (HW-76526). Not all samples were analyzed for every constituent.

Results (pCi/g) for the 27 oyster samples (totaling 54 lbs) analyzed in 1962 as part of the Hanford environmental program were tabulated. The average concentrations of zinc-65 and phosphorous-32 were 0.000094 μCi/g and 2.9×10^{-6} μCi/g, respectively. These were the only two radionuclides found in enough quantity to be of interest (HW-76526).

Soft-shelled clams, razor clams, Dungeness crabs, mussels, oysters and snails were monitored for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Tables of results were given and included collection dates, sample locations, organisms, and nuclide concentrations. Additional information provided included summary tables listing maximum, minimum, and average values (Toombs and Culter 1968).

Zinc-65 and phosphorous-32 were the only radionuclides of Hanford origin abundant enough beyond the mouth of the Columbia River to be of interest radiologically. Oysters were found to contain more zinc-65 than other common seafood organisms (HW-76526).

The highest concentrations of zinc-65 and chromium-51 in the soft tissues of mussels collected at North Head by the University of Washington were 140 pCi/g, wet weight, and 47 pCi/g wet weight, respectively (UWFL-86).

25.3.3 Waterfowl

Total beta and phosphorous-32 data were reported. One out of every 17 birds analyzed contained phosphorous-32 concentrations greater than the detection limit of 5×10^{-5} μCi/g (wet wt). The highest phosphorous-32 concentration (11×10^{-5} μCi/g) was seen at Mesa, Washington, where a total of 25 waterfowl were collected. Other sample locations and bird totals included Dayton, Washington (3 birds); Patterson Ferry (1 bird); Prosser, Washington (22 birds); Sunnyside, Washington (47 birds); and Umapine, Oregon (4 birds) (HW-76526).

One-third of the waterfowl sampled onsite contained concentrations of phosphorous-32 greater than the detection limit. The highest phosphorous-32 concentration seen in muscle tissue onsite (1.8×10^{-3} μCi/g) was found in a golden eye collected from the lower river in December. A total of 48 waterfowl were sampled from the lower river in 1962. Other onsite sampling sites and collection totals included Hanford (9 birds), Richland (1 bird), upper river (17 birds), Gable swamp (6 birds), Redox Swamp (2 birds), and U Plant swamp (5 birds) (HW-76526).

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26.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1963

26.1 MEDIA SAMPLED

26.1.1 Fish

Muscle tissues were collected from Columbia River fish as a part of the routine Hanford environmental-sampling program. Species sampled included whitefish, suckers, squawfish, chiselmouth, steelhead, carp, sturgeon, bass, bullhead, crappie, perch, ling, catfish, bluegill, and salmon (HW-80991).

Chinook salmon were analyzed as part of the Oregon State Board of Health Environmental Radiological Survey (Toombs and Culter 1968).

Starry flounder, rock greenling, buffalo sculpin, Pacific tomcod, blackcod, blacktail snailfish, Dover sole, English sole, filamented rattail, perch, Rex sole, rock fish, sand sole, river and surf smelt, and staghorn sculpin were collected from the North Head (north jetty at the river mouth) of the Columbia River and other Washington and Oregon coastal locations between Cape Flattery, Washington, and Coos Bay, Oregon. Whole fish were analyzed for radionuclide content. Collections took place between 1961 and 1963 in both coastal and offshore waters (UWFL-86).

26.1.2 Shellfish

Twenty-six oyster samples from Willapa Bay, Washington, were analyzed as part of the Hanford environmental-sampling program (HW-80991).

Marine organisms sampled as part of the Oregon Radiological Survey included soft-shell clams, razor clams, Dungeness crabs, mussels, oysters, and snails (Toombs and Culter 1968).

Between 1961 and 1963, University of Washington personnel collected shellfish along the coasts of Washington and Oregon and analyzed them for radionuclide content. Species collected included empire clams, mud clams, razor clams, various crabs, mussels, limpets, snails, and shrimp, as well as other invertebrates (UWFL-86).

26.1.3 Waterfowl

Ducks and geese were collected from local hunters during the 1963 waterfowl hunting season as part of the routine environmental sampling program. Muscle tissue and bird heads were analyzed for radionuclide contamination. Waterfowl species included mallard, teal, shoveler, widgeon, golden eye, Canada geese, pintail, ruddy duck, coot, merganser, Asian geese, lesser geese, scaup, Pacific loon, blue teal, gadwall, and a cackler (HW-80991).

Waterfowl sampled as part of the Oregon environmental radiological survey included ruddy and mallard ducks (Toombs and Culter 1968).

26.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

26.1.1 Fish

Routine Columbia River fish collection locations included Priest Rapids, Hanford, Ringold, Burbank, Richland, McNary, and Coyote Rapids, Washington (HW-80991). Chinook salmon were sampled at Woody Island, below The Dalles, Oregon (Toombs and Culter 1968).

Sampling locations for the University of Washington study included the Washington locations of Cape Flattery, Hoh Head, Kalaloch, Copalis Rocks, Ocean Shores, Grays Harbor, Westport, Grayland Beach, Willapa Bay, Long Beach, and North Head. Oregon locations included Iredale, Seaside, Cannon Beach, Barview, Tillamook Bay, Agate Beach, Yaquina Bay, and Coos Bay. It was not clear if fish were obtained from all of these locations (UWFL-86).

26.2.2 Shellfish

Oysters were collected from Willapa Bay, Washington, as part of the Hanford environmental sampling program (HW-80991).

University of Washington shellfish sampling locations are described above.

Dungeness crabs were collected from Tillamook Bay, Astoria, and Yaquina Bay, Oregon. Sites for oyster collection included Coos Bay and Tillamook Bay,

Oregon. Mussels were sampled from Yaquina Bay, Cannon Beach, and Nehalem River Jetty, Oregon. Soft-shell clams and horse clams were collected from Tillamook Bay, Oregon. Razor clams were collected from Seaside Beach, Oregon, and snails were obtained at Nehalem River Jetty, Oregon (Toombs and Culter 1968).

26.2.3 Waterfowl

Waterfowl were collected from both onsite and offsite locations. Many of the offsite samples were obtained from local area hunters during the hunting season. Two hundred and ninety-nine waterfowl were harvested from offsite locations, including Benton City, Chandler, Connell, Gibbon, Mesa, Ringold, Othello, Prosser, Richland, Scootney Reservoir, Yakima, and the Potholes, Washington. Additional samples were collected from the Yakima and Columbia Rivers. One hundred eighty-six waterfowl were sampled from onsite locations, including East Swamp, West Swamp, Hanford, and the Upper and Lower Columbia River. (HW-80991). The upper Columbia River extends from 100-B to Hanford, and the lower Columbia River extends from Hanford to Richland (HW-75076).

Waterfowl for the Oregon Environmental Radiological Survey were obtained at Tillamook Bay, Oregon (Toombs and Culter 1968).

26.3 RADIONUCLIDES MEASURED/REPORTED

26.3.1 Fish

Fish collected as part of the Site environmental program were analyzed for total beta, phosphorous-32, cobalt-60, potassium-40, zinc-65, cobalt-58, and cesium-137. Concentrations were tabulated and reported in units of pCi/g. (HW-80991).

Chinook salmon collected from the Columbia River below The Dalles, Oregon, were monitored for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51 Concentrations were reported in pCi/g drained weight. Tables of data were provided and included collection date, sample location, organism, and nuclide concentrations. Additional information included summary tables listing maximum, minimum, and average concentration

values. Not all samples were analyzed for every constituent (Toombs and Culter 1968).

There were eight production reactors operating during 1963 (HW-80991).

Seasonal variations in the concentrations of radionuclides in fish were affected by the amount of material released from the reactors, water temperature, feeding habits, and metabolism of the various fish species, and the flow rate of the river (dilution factor) (HW-80991).

The average phosphorous-32 concentration found in whitefish sampled downstream from the reactors was 420 pCi/g. The maximum concentration found was 2800 pCi/g (HW-80991).

The average zinc-65 concentration found in whitefish sampled downstream from the reactors was 38 pCi/g. The maximum activity found was 120 pCi/g obtained in a sample from Ringold (HW-80991).

Zinc-65 levels in muscle samples of Pacific Ocean fish decreased with distance from the mouth of the Columbia River. The rate of decrease was greater to the south than to the north (UWFL-86).

26.3.2 Shellfish

Oysters obtained from Willapa Bay were analyzed for potassium-40, zinc-65, cesium-137, phosphorous-32, cobalt-58, and cobalt-60. Concentrations were reported in units of pCi/g (HW-80991).

Shellfish collected for the Oregon Environmental Radiological Survey were analyzed for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Concentrations were reported in units of pCi/g, drained weight (Toombs and Culter 1968).

Oysters generally contain higher concentrations of zinc-65 than other marine organisms. Average phosphorous-32 and zinc-65 activities for the 26 soft-tissue samples collected as part of the Hanford environmental sampling program were 4 pCi/g and 80 pCi/g, respectively (HW-80991).

The maximum zinc-65 activity found in oysters from Tillamook Bay in 1963 was 27.9 pCi/g (Toombs and Culter 1968).

The highest concentration of zinc-65 found in soft-shell clams in 1963 was 2.9 pCi/g. The maximum reading obtained in 1963 for razor clams was 15.3 pCi/g (Toombs and Culter 1968).

Dungeness crabs sampled during 1963 from Astoria, Oregon, had a maximum zinc-65 concentration of 27.2 pCi/g. The maximum concentration of zinc-65 found in mussels from the Nehalem River Jetty, Oregon, was 31.7 pCi/g (Toombs and Culter 1968).

Many of the Dungeness crab and oyster samples were obtained from commercial growers (Toombs and Culter 1968).

26.3.3 Waterfowl

Waterfowl collected for the Oregon Environmental Radiological Survey were analyzed for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Concentrations were reported in units of pCi/g, drained weight (Toombs and Culter 1968).

Both muscle and head samples were obtained from waterfowl collected within the Hanford reservation. Head specimens only were analyzed from offsite birds. Beta readings and phosphorous-32 concentrations were obtained and reported in units of pCi/g (HW-80991).

Less than 10% of offsite waterfowl contained concentrations of phosphorous-32 greater than the detectable level of 50 pCi/g of flesh wet weight, and only one sample was greater than 500 pCi/g (540 pCi/g). Approximately one-half of the birds sampled onsite contained detectable quantities of phosphorous-32, and thirty-seven of these birds contained more than 500 pCi/g. The maximum concentration found was 4800 pCi/g (HW-80991).

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27.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1964

27.1 MEDIA SAMPLED

27.1.1 Fish

Muscle tissues from Columbia River fish were analyzed as part of the routine Hanford environmental sampling program. Species collected included whitefish, bass, bullheads, catfish, crappie, perch, suckers, sturgeon, trout, carp, steelhead, bluegill, and king (chinook) salmon (BNWL-90). Liver, gills, and viscera were analyzed from chinook salmon collected from the lower Columbia River as part of the Oregon Environmental Radiological Survey (Toombs and Culter 1968).

27.1.2 Shellfish

Marine samples included the soft tissues of Willapa Bay oysters (BNWL-90), soft-shell clams, razor clams, Dungeness crabs, mussels, oysters, and snails (Toombs and Culter 1968).

27.1.3 Waterfowl

During the 1964 waterfowl hunting season, samples from approximately 71 ducks were obtained from local hunters for radionuclide analyses as part of the Hanford environmental sampling program. One hundred and forty-seven samples were obtained within Hanford boundaries for use in the study. Waterfowl species included mallard, teal, widgeon, pintail, gadwall, golden eye, Canada geese, merganser, lesser geese, coot, lesser scaup, green wing teal, scaup, ruddy duck, and shoveler. Waterfowl heads were analyzed from offsite birds, while both head and muscle were analyzed from onsite birds (BNWL-90).

27.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

27.2.1 Fish

Routine Columbia River fish-collection locations included Priest Rapids, Coyote Rapids, Hanford, Ringold, Richland, Burbank, Island View (a station located near the confluence of the Yakima and Columbia Rivers), and McNary Dam (BNWL-90). In addition, chinook salmon samples were collected below The Dalles, Oregon, at Woody Island, as part of the Oregon Environmental Radiological Survey (Toombs and Culter 1968).

27.2.2 Shellfish

Pacific oysters were collected at Willapa Bay, Washington, as part of the Hanford environmental sampling program (BNWL-90).

Dungeness crabs were collected from Tillamook Bay and Astoria, Oregon. Mussels were collected from Cannon Beach, Nehalem River Jetty, and Yaquina Bay/Agate Beach, Oregon. Sites for oyster collection included Tillamook Bay and Yaquina Bay/Agate Beach, Oregon. Soft-shell clams were collected at Tillamook, Oregon; razor clams were collected at Sunnyside Beach, Oregon; and snails were collected at Nehalem River Jetty, Oregon (Toombs and Culter 1968).

27.2.3 Waterfowl

Waterfowl were sampled on the Hanford reservation from Gable swamp (pond), B swamp (pond), S swamp, U swamp (pond), Redox swamp, 300 Area pond and the upper and lower Columbia river. The upper Columbia River extends from 100-B to Hanford and the lower Columbia River extends from Hanford to Richland (HW-75076). Offsite birds were obtained from local hunters and were harvested from Othello, Benton City, Bailies Ranch (between Mesa and Othello), and the Yakima River (all Washington) (BNWL-90).

27.3 RADIONUCLIDES MEASURED/REPORTED

27.3.1 Fish

Fish collected as part of the Site environmental program were analyzed for total beta, phosphorous-32, cobalt-60, potassium-40, zinc-65, cobalt-58, and cesium-137. Concentrations were reported in units of pCi/g. Tables of results were provided. Not all samples were analyzed for all constituents (BNWL-90).

High radionuclide concentrations in whitefish normally occurred in fall months. However, below-normal river flow rates during spring 1964 and below-normal river temperatures during fall 1964 resulted in peak concentrations during the first half of the year (BNWL-90).

Sport fish caught by local fishermen were the most significant source of Hanford-produced radionuclides to people (HW-80649).

Previous radionuclide exposure estimates were based on whitefish consumption. Surveys indicated that bass and crappie were eaten in larger quantities than whitefish (HW-80649).

N-Reactor and eight production reactors were operating this year. Reactor 105-DR was shut down permanently on December 30, 1964 (BNWL-90).

The potential intake of phosphorous-32 may have been reduced in whitefish samples that were smoked, because of the storage time before consumption (BNWL-90).

Annual average radionuclide concentrations in Columbia River whitefish during 1964 were 470 pCi/g and 37 pCi/g for phosphorous-32 and zinc-65, respectively (BNWL-90).

Chinook salmon were monitored for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51 as part of the Oregon Environmental Radiological Survey. Results were reported in units of pCi/g drained weight. Tables of data were provided. Included were collection dates, sample locations, organisms, and radionuclide concentrations. Additional information was provided in the form of data summary tables listing maximum, minimum, and average values for all organisms analyzed (Toombs and Culter 1968).

In an effort to determine the distribution of zinc-65 in the chinook salmon, the viscera, the meat posterior to the gills, the liver, and the gills were analyzed separately using gamma spectrometry. Results indicate the highest concentrations of zinc-65 were associated with the viscera (27.6 pCi/g)(Toombs and Culter 1968).

27.3.2 Shellfish

Willapa Bay oysters were analyzed for potassium-40, zinc-65, cesium-137, phosphorous-32, cobalt-58, and cobalt-60. Concentrations were reported in units of pCi/g (BNWL-90).

Shellfish collected for the Oregon Environmental Radiological Survey were analyzed for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Concentrations were reported in units of pCi/g drained weight (Toombs and Culter 1968).

Oysters generally contained higher concentrations of zinc-65 than other common seafood organisms. Average phsophorous-32 and zinc-65 activities for the 24 samples collected as part of the Site environmental sampling program were 4 pCi/g and 56 pCi/g, respectively. Maximum concentrations were 16 pCi/g and 86 pCi/g, respectively (BNWL-90).

"Although there is considered to be a ^{65}Zn [zinc-65] residual in the oceans of the world as the result of fallout from nuclear weapons testing, the concentrations in crab samples collected from the southern coastal area of Alaska were below the detection limit of 0.2 pCi/g for ^{65}Zn. This indicates that most of the observed ^{65}Zn activity in the Oregon coastal environment originates from the Hanford reactors" (Toombs and Culter 1968).

Concentrations of zinc-65 in Willapa Bay oysters were relatively stable for 1963 and 1964 at approximately 100 pCi/g. However, the level of phosphorous-32 fluctuated by more than a factor of ten during the course of a year, with the maximum occurring in the late spring and early summer and the minimum in the fall. This cycle was comparable to both the oceanographic data on the transport of Columbia River water to Willapa Bay and the metabolic rate as affected by temperature (HW-80649).

The maximum zinc-65 activity found in oysters from Tillamook Bay was 23.4 pCi/g (Toombs and Culter 1968).

The highest concentration of zinc-65 found in soft-shell clams was 2.1 pCi/g. The maximum reading obtained for razor clams was 23.8 pCi/g (Toombs and Culter 1968).

Dungeness crabs had a maximum zinc-65 concentration of 20.7 pCi/g, and mussels had a maximum concentration of 20.2 pCi/g (Toombs and Culter 1968).

27.3.3 Waterfowl

Waterfowl collected as part of the Hanford environmental sampling program were analyzed for phosphorous-32, zinc-65, potassium-40, and cesium-137. Concentrations were reported in pCi/g. Both muscle and head samples were evaluated from birds collected within the Hanford reservation. Only head specimens were analyzed from offsite birds (BNWL-90).

Less than 10% of the waterfowl contributed by hunters offsite contained levels of phosphorous-32 greater than the detectable level of 50 pCi/g of flesh (wet weight). The highest concentration found for offsite birds was 650 pCi/g (BNWL-90).

Approximately one-third of the waterfowl specimens collected in the Hanford environs contained detectable levels of phosphorous-32, and about one in ten contained 500 pCi/g or more. The maximum concentration for onsite specimens was 1700 pCi/g of flesh (BNWL-90).

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28.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1965

28.1 MEDIA SAMPLED

28.1.1 Fish

Several species of Columbia River fish were sampled and analyzed for radionuclide contamination. Species collected included mountain whitefish, bass, steelhead, salmon, carp, trout, suckers, sturgeon, catfish, crappie, perch, blue gill, shad, squawfish, and chiselmouth (BNWL-316 APP). Chinook salmon were sampled also (Toombs and Culter 1968). Fish tissues analyzed included muscle (BNWL-316 APP), viscera, and muscle posterior to the gills (Toombs and Culter 1968).

28.1.2 Shellfish

Marine organisms sampled included oysters, mussels, Dungeness crabs, snails, razor clams, and soft-shell clams (Toombs and Culter 1968). In addition, Pacific coast oysters were sampled as part of the routine Hanford environmental sampling program (BNWL-316 APP).

Clams were collected from the Columbia River below the reactors (BNWL-SA-623).

28.1.3 Waterfowl

Waterfowl sampled for radionuclide contamination included golden eye, coot, ruddy duck, bufflehead, mallard, green-wing teal, Canada geese, and lesser geese (BNWL-316 APP; BNWL-CC-913). Muscle tissue and heads were analyzed.

28.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

28.2.1 Fish

Routine Columbia River fish collection locations included Priest Rapids, Hanford, Ringold, Richland, Burbank, McNary, and Coyote Rapids (all Washington) (BNWL-316 APP). Lower Columbia River fish were sampled at Woody

Island, and a few fish were sampled from the Willamette River at Sauvies Island and Oregon City, Oregon (Toombs and Culter 1968).

28.2.2 Shellfish

Oysters were collected from Willapa Bay, Washington, as part of the routine Hanford environmental-sampling program (BNWL-316 APP). Oysters, Dungeness crabs, and soft-shell clams were collected from Tillamook Bay, Oregon (62 miles south of the Columbia River). Razor clams were sampled at Seaside Beach, Oregon, 28 miles south of the river mouth. Dungeness crabs were collected from Astoria, Oregon, 13.7 miles from the mouth of the Columbia River. Mussels were collected from Nehalem River Jetty (50 miles south of the mouth of the river), Cannon Beach (35 miles south), and Yaquina Bay-Agate Beach, Oregon (140 miles south of the river mouth). Oysters were also collected at Yaquina Bay-Agate Beach, Oregon (Toombs and Culter 1968).

28.2.3 Waterfowl

Waterfowl were collected from Redox swamp, U swamp (pond), B swamp (pond), Gable swamp (pond), Ringold, the upper river (the area within the plant boundary from Vernita Bridge to Hanford), and the lower river (the area within the plant boundary from Hanford to the 300 Area) (BNWL-316 APP; BNWL-CC-913).

28.3 RADIONUCLIDES MEASURED/REPORTED

28.3.1 Fish

Fish sampled as part of the routine sampling program were analyzed for phosphorous-32, cobalt-60, potassium-40, zinc-65, cobalt-58, and cesium-137. Results were reported in units of pCi/g and given in table form (BNWL-316 APP).

H and F reactors were shut down permanently on April 27, 1965, and June 25, 1965, respectively (BNWL-316).

Fish acquired all of the radionuclides present in the Columbia River water, but phosphorous-32 and zinc-65 accumulated the most significant amounts in the flesh. For radionuclides to accumulate, fish must feed for several weeks on organisms that have concentrated the nuclides (BNSA-53).

The concentrations of the two principal radionuclides present in fish, phosphorous-32 and zinc-65, vary depending on the species and the season of the year (BNWL-165).

Whitefish is the sportfish that usually contains the greatest concentration of phosphorous-32 (BNWL-316, BNWL-165).

Marine and anadromous species such as salmon have relatively low radionuclide concentrations because they feed mainly in the ocean and only return to the Columbia River to spawn (BNSA-53).

The most important radionuclides were zinc-65, phosphorous-32, and chromium-51. Of these, zinc-65 was the most widely distributed due to its long half-life and the ability of organisms to concentrate it (Toombs and Culter 1968).

There was a pronounced decrease in zinc-65 concentrations in fish tissues during the summer due to the greater dilution of reactor effluents by increased river flow during the freshet period of late spring and early summer (BNWL-SA-623).

In 1965, the highest concentration of zinc-65 found in a chinook salmon collected by Toombs and Culter (1968) was found in the viscera of a fish sampled from the Columbia River at Woody Island (13.6 pCi/g).

In largescale suckers, northern squawfish, and chiselmouth, concentrations of zinc-65 were greater in eye tissues than in the gastrointestinal (G.I.) tract. However, carp had greater zinc-65 concentrations in the G.I. tract, and in whitefish the eye and the G.I. tract had nearly equal amounts (BNWL-SA-623).

The average concentrations of phosphorous-32 and zinc-65 in whitefish sampled downstream from the reactors during 1965 were 200 pCi/g and 27 pCi/g of flesh, respectively (BNWL-316).

Levels of phosphorous-32 measured during the first half of 1965 were lower than observed in 1964 or 1963 (BNWL-165).

Samples from approximately 100 whitefish were collected 18 km upstream from the reactors in January and December 1965. In January, 70% contained measurable amounts of zinc-65; in December, 60%. The average concentrations

of zinc-65 in the eye and G.I. tract in January were 780 and 1100 pCi/g wet weight, respectively. In December the concentrations were 1060 and 1400 pCi/g, wet weight, respectively (BNWL-SA-623).

28.3.2 Shellfish

Oysters contained higher concentrations of zinc-65 than other seafood organisms (BNWL-316, BNWL-165, Toombs and Culter 1968).

Zinc-65 and phosphorous-32 were the only two radionuclides originating from Hanford that were found in significant abundance beyond the mouth of the Columbia River (BNWL-316; BNWL-165).

Shellfish collected for the environmental sampling program were analyzed for phosphorous-32, sodium-24, chromium-51, manganese-56, copper-64, zinc-65, and lanthanum-140 (BNWL-SA-623).

Marine shellfish collected for the Oregon Environmental Radiological Survey were analyzed for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Results were reported as pCi/g drained weight (Toombs and Culter 1968).

Clams were collected from the Columbia River below the reactors. The soft parts and shells were analyzed for radiological contaminants. From 1964 to 1965 the sodium-24 concentrations decreased, while lanthanum-140 concentrations increased. Zinc-65 levels decreased in the shell and increased in the soft parts. Chromium-51 concentrations decreased in the soft parts and increased in the shell (BNWL-SA-623).

Concentrations of zinc-65 in crab samples collected from the southern coastal area of Alaska were below the detection limit of 0.2 pCi/g, indicating that radioactivity from samples obtained from the Oregon coast was due to Hanford reactors and not fallout from nuclear weapons testing (Toombs and Culter 1968).

The annual average concentration of zinc-65 in oyster samples caught at Willapa Bay, Washington, decreased since 1963, while potassium-32 concentrations remained at the same level. Average phosphorous-32 and zinc-65 concentrations found in oysters in 1965 were 4 and 40 pCi/g, respectively (BNWL-316).

Fission product radionuclides, primarily ruthenium-103 and ruthenium-106, zirconium-niobium-95, and, occasionally, cerium-141 and cerium-144 were observed, due to worldwide atmospheric fallout, and found to be highest in soft-shell clams (Toombs and Culter 1968).

Twenty-six oyster samples were collected at Willapa Bay, Washington, during 1965. Maximum zinc-65 and phosphorous-32 concentrations were 110 pCi/g and 9.2 pCi/g, respectively (BNWL-316 APP).

Many of the Pacific coast shellfish samples were purchased from commercial growers (Toombs and Culter 1968).

28.3.3 Waterfowl

Radionuclides analyzed in waterfowl included phosphorous-32, zinc-65, and cesium-137 (BNWL-CC-913), as well as potassium-40 (BNWL-316 APP).

Not all organisms were analyzed for every radionuclide.

Ninety-eight waterfowl were analyzed during 1965. Seventy-five birds had flesh concentrations of phosphorous-32 amounting to less than 50 pCi/g, wet weight. Twenty samples were greater than 50 but less than 500 pCi/g, and 3 samples were greater than 500 pCi/g. The maximum concentration of phosphorous-32 in birds collected from the Columbia River was 950 pCi/g (BNWL-316).

For the 27 waterfowl collected onsite during 1965, the maximum phosphorous-32 concentration observed in muscle was 300 pCi/g. This was found in a ruddy duck collected from U swamp in February. The maximum concentration of zinc-65 found in waterfowl muscle collected onsite (12 pCi/g) was obtained from a golden eye duck from Gable swamp in March. The maximum cesium-137 concentration in muscle (310 pC/g) was obtained from a coot sampled from Gable swamp in March. The maximum phosphorous-32 concentration in waterfowl heads (1000 pCi/g) was seen in a mallard duck obtained from Gable swamp in February (BNWL-CC-913).

Waterfowl, as a potential source of radionuclide contamination, are of less significance than fish because they cannot be harvested in such large numbers by individuals and because of the "dilution" factor by large flights of migrating birds (BNWL-316).

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29.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1966

29.1 MEDIA SAMPLED

29.1.1 Fish

Muscle tissue was sampled from Columbia River fish. Fish sampled for the Hanford environmental program (and analytical totals) included whitefish (479), trout (17), white sturgeon (30), carp (79), bass (25), catfish (88), perch (90), steelhead (14), crappie (26), bluegill (3), suckers, and shad (7) (BNWL-439 APP).

Many fish were collected and analyzed for another Hanford study addressing the radioecology of the Columbia River. Muscle tissues, gut contents and carcasses of large fish were analyzed. Ocassionally, an entire large fish was also analyzed. Small fish were analyzed whole, without their gut contents. Species collected included sturgeon, chinook salmon, coho salmon, steelhead, whitefish, largescale suckers, carp, redside shiners, squawfish, chiselmouth, peamouth, dace, yellow perch, smallmouth bass, sculpin, threespine stickleback, shad, and burbot (BNWL-1377, Part II).

Fish collected from the lower Columbia River by Oregon researchers included sturgeon, chinook salmon, and salmon (Toombs and Culter 1968).

29.1.2 Shellfish

Willapa Bay oysters were collected as part of the Hanford Environmental Monitoring Program (BNWL-439 APP). Other marine organisms sampled included soft-shell clams, cockle clams, butter clams, razor clams, Dungeness crabs, mussels, oysters, and snails (Toombs and Culter 1968).

Crayfish were also collected and analyzed (BNWL-1377, Part II).

29.1.3 Waterfowl

Waterfowl were collected routinely by Hanford environmental monitoring personnel at both onsite and offsite locations. Heads and muscle tissue were analyzed for birds collected onsite. Only the heads of birds collected offsite were evaluated. Species collected included mallard, golden eye,

merganser, widgeon, gadwall, green-winged teal, coot, Canada geese, and lesser Canada geese (BNWL-439 APP).

29.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

29.2.1 Fish

Fish were collected from the Columbia River at Priest Rapids, Coyote Rapids, Hanford, Ringold, Richland, Island View, Burbank, and McNary Dam (all Washington) (BNWL-439 APP). Additional collections were made from the lower Columbia at Bonneville; Corbett, Oregon; and Woody Island (Toombs and Culter 1968).

Samples of large fish collected for the radioecology study were gill-netted at White Bluffs. All other samples for this study were collected near the 100-F Area, about 13.5 miles downstream of the nearest reactor effluent outfall (BNWL-1377, Part I).

29.2.2 Shellfish

Oysters were collected at Willapa Bay, Washington (BNWL-439 APP). Other marine sampling locations included the following:

Tillamook Bay, Oregon:	soft-shelled clams, cockle clams, Dungeness crab, oysters
Coos Bay, Oregon:	butter clams, cockle clams
Seaside Beach, Oregon:	razor clams
Astoria, Oregon:	Dungeness crab
Cannon Beach, Oregon:	mussels
Nehalem River Jetty, Oregon:	mussels, snails
Yaquina Bay/Agate Beach, Oregon:	mussels, oysters

(Toombs and Culter 1968)

29.2.3 Waterfowl

Waterfowl were collected from the upper river (100-B to Hanford), lower river (Hanford to Richland), Burbank, McNary, Mesa, Othello, Eltopia, Wallula, Island View, and Patterson (BNWL-439 APP).

29.3 RADIONUCLIDES MEASURED/REPORTED

29.3.1 Fish

Fish were also collected throughout the year, and tables of results (pCi/g) were given for all of the species sampled at each location. Approximately 860 samples of fish tissue were analyzed this year as part of the Hanford Environmental Studies (BNWL-439 APP).

There was an abnormal release of radioiodine to the Columbia River on February 11, 1966 (BNWL-439).

Fish sampled as part of the Hanford Environmental Program were analyzed for phosphorous-32, cobalt-60, potassium-40, zinc-65, cobalt-58, and cesium-137. Results were reported in pCi/g. Results for each radionuclide were not reported for every fish sampled (BNWL-439 APP).

Marine fish from the lower Columbia and Willamette Rivers were monitored for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Tables of results were reported for all organisms collected (pCi/g, drained weight) (Toombs and Culter 1968).

Fish collected for the Hanford radioecology study were analyzed for phosphorous-32, cesium-137, cerium-praseodymium-144, scandium-46, cobalt-60, chromium-51, manganese-54, iron-59, zinc-65, neptunium-239, ruthenium-106 rhodium, zirconium-niobium-95, barium-lanthanum-140, barium-140, and lanthanum-140. Results were reported in pCi/g for wet weights, dry weights, and ash weights (BNWL-1377, Part II).

Of the more significant radionuclides in the Columbia River at Richland, Washington, the relative proportions were as follows: chromium-51 constituted nearly half; copper-64, neptunium-239, and arsenic-76 made up most of the remainder; and minor amounts included about 1% phosphorous-32, 2% zinc-65, and < 1% iodine-131 (BNWL-SA-601).

Because of a labor strike, all reactors were shut down from early July to late August. Consequently, phosphorous-32 concentrations in fish during the fall months were lower than in 1965. Levels of zinc-65, however, remained about the same. The reason for this was probably the recycling of materials from the river bottom. Average phosphorous-32 and zinc-65 concentrations in

Columbia River fish caught downstream of the reactors during 1966 were 110 pCi/g and 23 pCi/g, respectively (BNWL-439).

"Those individuals who probably ingest the largest amounts of ^{32}P [phosphorous-32] are fishermen who claim to eat bass, crappie, and perch as often as 3 to 5 times per week" (BNWL-439).

The average concentration of phosphorous-32 in whitefish during the first six months of 1966 was 100 pCi/g (BNWL-391).

Whitefish were the gamefish that usually contained the highest concentration of phosphorous-32. They also could be caught during winter months when other game fish were difficult to collect. "Therefore, data from whitefish are used as trend indicators, even though whitefish are not the most significant source of radionuclides for the local population" (BNWL-391).

29.3.2 Shellfish

Willapa Bay oysters were collected in all months. Samples were analyzed for potassium-40, zinc-65, cesium-137, and phosphorous-32. Results for 26 samples are available (pCi/g) (BNWL-439 APP).

Other marine shellfish from the lower Columbia and Willamette Rivers were monitored for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Tables of results were reported (pCi/g, drained weight) (Toombs and Culter 1968).

"Oysters have been found to contain higher concentrations of ^{65}Zn [zinc-65] than any other common seafoods" (BNWL-391).

"Phosphorous-32 and ^{65}Zn [zinc-65] are the only two radionuclides of Hanford origin that are found in sufficient quantity beyond the mouth of the Columbia to be of radiological interest" (BNWL-391).

The shutdown of the reactors due to the labor strike in August had very little effect on Willapa Bay oysters. Annual average concentrations of zinc-65 had been decreasing over the previous 3 years while phosphorous-32 levels had remained about the same. Average concentrations for the year were 28 pCi/g of zinc-65 and 2.9 pCi/g of phosphorous-32 (BNWL-439).

29.3.3 Waterfowl

Waterfowl muscle and/or head samples were analyzed for phosphorous-32, potassium-40, zinc-65, and cesium-137. Results were reported in pCi/g (BNWL-439 APP).

"One hundred twenty-four waterfowl samples collected in the Hanford environs during 1966 had concentrations of phosphorous-32 less than 50 pCi/g of flesh (wet weight), 51 samples were above 50 pCi/g but less than 500 pCi/g, and the remaining 10 samples were greater than 500 pCi/g. The maximum concentration was 2900 pCi/g of ^{32}P [phosphorous-32]" (BNWL-439).

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30.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1967

30.1 MEDIA SAMPLED

30.1.1 Fish

Muscle tissue, gut contents, and carcasses of Columbia River fish were analyzed for radionuclide content in several studies conducted by both Hanford environmental monitoring personnel and offsite laboratories. A wide variety of fish were collected for the onsite studies. These included whitefish, bass, catfish, crappie, perch, carp, bluegill, squawfish, suckers, bullhead, sturgeon, shad, steelhead, and salmon (BNWL-983-APP; BNWL-1377). Redside shiners, chiselmouth, and burbot were also collected as part of the Hanford studies (BNWL-1377). Salmon and sturgeon were collected by offsite laboratories (Toombs and Culter 1968).

30.1.2 Shellfish

Willapa Bay oysters were collected for the Hanford environmental-monitoring program (BNWL-1377). Shellfish collected and analyzed by Toombs and Culter included Pacific coast razor clams; oysters; mussels; dungeness crab; soft-shell, butter, and cockle clams; and snails. Analyses were done on soft tissues.

30.1.3 Waterfowl

Ducks and geese were collected on and around the Hanford Site by environmental monitoring personnel. Radionuclide concentrations in bird heads and muscle were reported (BNWL-665, BNWL-CC 1197-6). Species collected at various surface-water locations on and near the site included mallards (101 birds), merganser (5 birds), widgeon (9 birds), coot (24 birds), lesser scaup (3 birds), green-wing teal (2 birds), gadwall (1 bird), golden eye (5 birds), shoveler (1 bird), teal (2 birds), goose (1 bird), lesser Canada Geese (2 birds), and Canada geese (4 birds) (BNWL-983-APP; BNWL-665).

30.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

30.2.1 Fish

Routine collections of Columbia River fish were made at Priest Rapids, Coyote Rapids, Ringold, Burbank, Island View (near the confluence of the Yakima and Columbia Rivers) and Hover-Finley (all Washington) (BNWL-983-APP). Other Columbia River collection sites included near 100-F, near White Bluffs (BNWL-1377), and Woody Island (Toombs and Culter 1968). Additional fish were collected from the Willamette River at Oregon City and at Sauvies Island, Oregon (Toombs and Culter 1968).

30.2.2 Shellfish

Oysters collected for the Hanford monitoring program were obtained at Willapa Bay, Washington (BNWL-983-APP).

Toombs and Culter collected Pacific coast organisms at the following locations:

Tillamook Bay, Oregon:	soft-shell clams, cockle clams, Dungeness crabs, oysters
Seaside Beach, Oregon:	razor clams
Astoria, Oregon:	Dungeness crabs
Cannon Beach, Oregon:	mussels, snails
Nehalem River Jetty, Oregon:	mussels, snails
Yaquina Bay/Agate Beach, Oregon:	mussels, oysters

30.2.3 Waterfowl

Hanford environmental personnel collected waterfowl from upper and lower Columbia River areas (relative to Hanford reactor discharges); Othello, Washington; Burbank, Washington; U-Swamp (pond), Gable Swamp (pond), B Swamp (pond), and Redox Swamp (BNWL-983-APP; BNWL-665).

30.3 RADIONUCLIDES MEASURED/REPORTED

30.3.1 Fish

Five or six Hanford reactors were operating during most of this study. One of these was 100-N, which had a closed primary cooling loop (BNWL-1377).

D reactor was shut down in June and "the Redox separations plant was also retired from routine operation" in 1967 (BNWL-983).

Analytical results reported for fish collected as part of the routine Hanford sampling program included phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, and cesium-137. Results were reported in units of pCi/g (BNWL-983-APP). Fish tissues collected for other Hanford studies were analyzed for cerium-praseodymium-144, scandium-46, chromium-51, manganese-54, iron-59, neptunium-239, ruthenium-rhodium-106, zirconium-niobium-95, barium-lanthanum-140, barium-140, and lanthanum-140 (BNWL-1377).

Fish samples collected by Toombs and Culter were analyzed for potassium-40, zinc-65, zirconium-niobium-95, ruthenium-103+106, and chromium-51. Results were reported in units of pCi/g, drained weight.

"Data accumulated from whitefish sampling are used as trend indicators, even though whitefish are not the most significant source of radionuclides for the total population" (BNWL-665).

The average concentration of phosphorous-32 in whitefish during the first six months of 1967 was 100 pCi/g (BNWL-665).

The average concentration of phosphorous-32 in Columbia River whitefish collected downstream of the reactor areas during 1967 was 260 pCi/g (BNWL-983).

30.3.2 Shellfish

"Zinc-65 and ^{32}P [phosphorous-32] are the only radionuclides in the reactor effluent that are found in significant abundance in food organisms beyond the mouth of the Columbia River to be of radiological interest. Oysters have been found to contain higher concentrations of zinc-65 than other common seafoods" (BNWL-983).

The annual average concentrations of zinc-65 and phosphorous-32 in Willapa Bay oysters were 30 pCi/g and 3.3 pCi/g, respectively. Other results reported included potassium-40 and cesium-137 (BNWL-983).

Results reported for the Pacific coast shellfish collected by Toombs and Culter included potassium-40, zinc-65, zirconium-niobium-95,

ruthenium-103+106, and chromium-51. Results were reported in units of pCi/g, drained weight.

30.3.3 Waterfowl

"The average concentration of ^{32}P [phosphorous-32] in the muscle of waterfowl collected at the Hanford site during 1967 was about 160 pCi/g. The maximum concentration was 2800 pCi/g, the highest concentration found in local ducks since 1963" (BNWL-983).

"About 30% of the game bird meals consumed by local hunters were reported to be birds shot within about 5 km of the Columbia River between Ringold and McNary Dam. Analyses showed that birds collected beyond this distance contained little if any radioactivity of Hanford origin" (BNWL-983).

Results reported for head and muscle samples collected as part of the Hanford environmental-monitoring program included phosphorous-32, potassium-40, cesium-137, and zinc-65. Results were reported in units of pCi/g (BNWL-983-APP).

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31.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1968

31.1 MEDIA SAMPLED

31.1.1 Fish

Muscle samples were removed from Columbia River fish. Species collected as part of the routine Hanford environmental sampling program included whitefish (168 samples), bass (50 samples), catfish (170 samples), crappie (135 samples), carp (168 samples), and perch (157 samples) (BNWL-1341 APP).

31.1.2 Shellfish

The Hanford environmental-monitoring program routinely collected oysters from Willapa Bay, Washington (BNWL-1341).

31.1.3 Waterfowl

Head and muscle samples were obtained from ducks and geese collected in and around the Hanford site. Birds analyzed as part of the routine Hanford environmental surveillance program included mallards (54 birds), golden eyes (4 birds), mergansers (1 bird), green-winged teals (3 birds), lesser Canada geese (15 birds), and Canada geese (4 birds) (BNWL-1341 APP).

31.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

31.2.1 Fish

Whitefish were collected at Priest Rapids, Ringold, Island View (near the confluence of the Yakima and Columbia Rivers), and Burbank (all Washington). Other fish species collected for the routine Hanford monitoring program were obtained at Island View, Burbank, and Hover-Finley, Washington (BNWL-1341 APP).

31.2.2 Shellfish

Oysters were collected at Willapa Bay, Washington (BNWL-1341).

31.2.3 Waterfowl

Waterfowl were collected from an onsite pond and from the Columbia River near the site. Specific locations included Hanford, Savage Island, White Bluffs, and Gable swamp (pond) (all Washington) (BNWL-1341 APP; BNWL-CC-2026).

31.3 RADIONUCLIDES MEASURED/REPORTED

31.3.1 Fish

Columbia River fish samples collected for the Hanford environmental-sampling program were analyzed for phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, and cesium-137. Results for each constituent were not reported for every fish. Concentrations were reported in units of pCi/g, wet weight (BNWL-1341 APP).

The Columbia River fish eaten most frequently were crappie, perch, and bass BNWL-706). The maximum estimate of consumption of these fish by fishermen was 200 meals per year. "The average percentage of the maximum catch by species was 73% crappie, 16% bass, and 11% perch." The maximum individual's estimated intakes of radionuclides from eating these panfish during 1968 were 1.0 μCi phosphorous-32 and 0.4 μCi zinc-65 (BNWL-1341).

31.3.2 Shellfish

"Zinc-65 and ^{32}P [phosphorous-32] are the only radionuclides in the reactor effluent that are found in sufficient abundance in food organisms beyond the mouth of the Columbia River to be of radiological interest. Oysters have been found to contain higher concentrations of ^{65}Zn [zinc-65] than other common seafoods" (BNWL-1341).

Analytical results were reported for phosphorous-32, potassium-40, zinc-65, and cesium-137. Results were reported in pCi/g, wet weight (BNWL-CC-2026).

The annual average concentrations of zinc-65 and phosphorous-32 in Willapa Bay oysters in 1968 were 25 pCi/g and 3.3 pCi/g, respectively (BNWL-1341).

31.3.3 Waterfowl

Results reported for waterfowl heads and muscle tissue included phosphorous-32, potassium-40, zinc-65, and cesium-137. Concentrations were reported in units of pCi/g, wet weight (BNWL-1341; BNWL-CC-2026).

"The average concentration of ^{32}P [phosphorous-32] in muscle of waterfowl collected at the Hanford site for the environmental-monitoring program during 1968 was about 53 pCi/g for ducks and 1.4 pCi/g for geese. The maximum concentration in waterfowl during 1968 was 450 pCi/g" (BNWL-1341).

There were 137 waterfowl collected from the Columbia River in 1968. The highest river bird concentration of cesium-137 (8.5 pCi/g) was seen in a bird caught from Savage Island. Maximum concentrations of phosphorous-32 and zinc-65 in game birds collected from locations adjacent to the Columbia River during December were 490 pCi/g and 12 pCi/g, respectively. Maximum concentrations in ducks collected at Gable swamp were 130 pCi phosphorous-32/g, 2.9 pCi zinc-65/g, and 500 pCi cesium-137/g (BNWL-CC-2026).

"About 30% of the game bird meals consumed by local hunters were reported to be birds shot within about 5 km of the Columbia River between Ringold and McNary Dam" (BNWL-1341).

The eastern side of the Columbia River, north of Ringold, is open to hunters during hunting season. During 1968 this area was visited by 1537 hunters (BNWL-1341).

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32.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1969

32.1 MEDIA SAMPLED

32.1.1 Fish

Muscle tissue was sampled from Columbia River fish. Species (and approximate collection totals) collected as part of the routine Hanford environmental sampling program included whitefish (125), bass (52), catfish (194), crappie (133), perch (236), and carp (136) (BNWL-1505). Bass (4), sturgeon (1), and perch (4) were collected as part of a special study conducted in October (BNWL-CC-2363). Some composite samples were also analyzed. Equal weights of muscle tissue from five fish of the same species were composited (BNWL-1505 APP).

32.1.2 Shellfish

The Hanford environmental-sampling program collected oysters at Willapa Bay, Washington. The soft tissues were monitored for radionuclide contamination (BNWL-1505).

32.1.3 Waterfowl

Ducks and geese were collected from various locations in and around the Hanford site during the hunting season. Muscle tissue and bird heads were analyzed for radionuclide contamination. Animals analyzed included mallards (12 heads, 34 muscle), mergansers (1 head, 7 muscle), goldeneyes (2 heads, 2 muscle), ruddy ducks (2 heads, 3 muscle), buffleheads (3 heads, 3 muscle), green winged teals (2 heads, 4 muscle), lesser Canada geese (10 heads, 11 muscle), other geese (1 muscle), mallard cross (1 head, 2 muscle), and a Canada goose (1 muscle) (BNWL-1505 APP).

32.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

32.2.1 Fish

Routine Columbia River fish-collection locations included Ringold, Island View, Burbank, and Hover, Washington. The most popular fishing locations were at Burbank, Hover, and Island View, Washington (BNWL-1505; BNWL-1505 APP). Fish taken for the special study in October were obtained from Hanford slough (BNWL-CC-2363).

32.2.2 Shellfish

All oyster samples were from Willapa Bay, Washington.

32.2.3 Waterfowl

Waterfowl were sampled on or near the Site from the 100-K Trench, White Bluffs, Hanford, Redox swamp, Gable Mountain swamp (pond), Savage Island, 300 Area, Ringold, and 100-D.

32.3 RADIONUCLIDES MEASURED/REPORTED

32.3.1 Fish

Fish collected as part of the Site environmental program were analyzed for various radionuclides. Results for sodium-24, phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, and cesium-137 were reported, but not all samples were analyzed for all constituents. Concentrations were reported in units of pCi/g, wet weight. Samples were collected in all months, but all species were not caught at each sampling location each month (BNWL-1505 APP). The fish collected as part of the special study in October were analyzed for many of the same radionuclides (BNWL-CC-2363).

The Columbia River fish eaten most frequently were crappie, perch, and bass (BNWL-1019).

"From the standpoint of exposure dose resulting from eating Columbia River fish, the radionuclide of greatest significance is ^{32}P [phosphorous-32]" (BNSA-45).

"Zinc-65 does not significantly contribute to the exposure dose from eating Columbia River fish" (BNSA-45).

"The concentration of a radionuclide in several samples from a selected species of fish taken from a given sampling location on any given date will display a wide variance about their mean" (BNSA-45).

Whitefish are the sports fish that contained the highest levels of radionuclides and could be collected during winter months when other sports fish were difficult to sample (BNWL-1505).

Factors influencing radionuclide concentrations in fish included season, river flows, water temperature, reactor operating conditions, catch location and fish species (BNSA-45).

32.3.2 Shellfish

During 1969, 21 oyster samples were collected from Willapa Bay, Washington. Soft tissues were analyzed for phosphorous-32, potassium-40, zinc-65, cesium-137, and concentrations were reported in units of pCi/g, wet weight. Samples were collected every month during the year (BNWL-1505 APP).

"Zinc-65 and ^{32}P [phosphorous-32] were the only radionuclides in the reactor effluent that are found in sufficient abundance in food organisms beyond the mouth of the Columbia River to be of radiological interest. Oysters have been found to contain higher concentrations of ^{65}Zn [zinc-65] than other common seafoods." The annual average concentrations in oysters in 1969 were 19 pCi zinc-65/g and 2.8 pCi phosphorous-32/g (BNWL-1505).

32.3.3 Waterfowl

Waterfowl collected on or near the Hanford site by site personnel were monitored for concentrations of phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, cesium-134, and cesium-137. Some of the ducks from the 100-K trench were also analyzed for sodium-24, scandium-46, chromium-51, cerium-praseodymium-144, and zirconium-95 (BNWL-1505 APP).

"The average of the monthly average concentrations of ^{32}P [phosphorous-32] in the muscle of waterfowl collected on the river within the Hanford project for the environmental monitoring program during hunting seasons in 1969 was 72 pCi/g for 46 ducks and 3.6 pCi/g for 12 geese. The maximum concentration in such waterfowl during 1969 was 510 pCi ^{32}P

[phosphorous-32]/g, which is not significantly different from the maximum observed in 1968 for birds collected in the same area" (BNWL-1505).

"In addition to the birds collected on the river, nine waterfowl were sampled from swamps and a trench within the plant boundaries. Seven of the samples were collected from swamps receiving low-level liquid wastes near the chemical separations areas. The muscle of these birds contained on the average 34 pCi ^{32}P [phosphorous-32]/g and <1 pCi ^{65}Zn [zinc-65]/g. The predominant radionuclide in birds utilizing these swamps, ^{137}Cs [cesium-137], was detected in concentrations ranging from 70 to 420 pCi/g and averaging 300 pCi/g" (BNWL-1505).

The concentration of phosphorous-32 in a bird collected at the 100-K trench in December was about 110,000 pCi/g (BNWL-1019).

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33.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1970

33.1 MEDIA SAMPLED

33.1.1 Fish

Various tissues were sampled from Columbia River fish. Most samples were analyzed individually, but sometimes equal-sized muscle samples from 5 different fish were composited for analyses. Species collected as part of the routine Hanford environmental-sampling program included whitefish (125 individual and 5 composite samples), bass (29 individual and 8 composite samples), catfish (127 individual and 13 composite samples), crappie (91 individual and 17 composite samples), perch (69 individual and 12 composite samples), carp (8 individual and 2 composite samples), and suckers (4 individual and 1 composite samples) (BNWL-1669 ADD).

Concentration data for juvenile redside shiners, largescale suckers, chiselmouth, and squawfish were reported graphically in another Hanford study. Samples were primarily whole fish (shiners) or muscle tissue, but squawfish and sucker carcasses and sucker gut contents were also examined (BNWL-1377).

A limited study of whitefish was conducted from May to November (BNWL-B-71).

33.1.2 Shellfish

The Hanford environmental-sampling program collected oysters at Willapa Bay, Washington. The soft tissues were monitored for radionuclide contamination (BNWL-1669 ADD).

Clams, crabs, oysters, and shrimp were collected at Ilwaco, Washington, in October (BNWL-SA-4206).

33.1.3 Waterfowl

Ducks and geese were collected from various locations in and around the Hanford site during the 1970 hunting season. Muscle tissue was analyzed for radionuclide contamination. Birds analyzed as part of the routine Hanford surveillance program during 1970 included Mallards (71 birds), Green Winged teals (2 birds), mergansers (4 birds), ruddy duck (1 bird), goldeneye

(1 bird), lesser Canada geese (4 birds), and Canada honkers (14 birds) (BNWL-1669 ADD).

Between December 29, 1969, and April 20, 1970, fourteen ducks were collected at onsite trenches. Birds collected included gadwalls, mallard-gadwall crosses, widgeons, mallards, coots, and goldeneyes. Waterfowl collected at other onsite surface water locations included, in addition to the birds listed above, buffleheads, ruddy ducks, a green-winged Teal, a wood duck, and a mallard duckling (BNWL-C-96).

33.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

33.2.1 Fish

Routine Columbia River whitefish sampling areas included Ringold, White Bluffs to Ringold, White Bluffs to 100-K, White Bluffs, and Hanford, Washington. Bass, catfish, crappie, and perch were taken at Island View, Burbank, and Hover, Washington. Suckers were collected at Hover, Washington, and carp were obtained at Island View, Washington (BNWL-1669 ADD).

Additional Hanford fish samples were obtained near 100-F (small fish) and 11 km downstream of the nearest reactor (large fish) (BNWL-1377).

Whitefish collected for the limited study between May and November were obtained from the river between 100-K and White Bluffs, between White Bluffs and Ringold, and between Ringold and Richland (BNWL-B-71).

33.2.2 Shellfish

Oysters were obtained from Willapa Bay, Washington (BNWL-1669 ADD). Other Pacific coast organisms were collected at Ilwaco, Washington (BNWL-SA-4206).

33.2.3 Waterfowl

Routine duck and geese samples were collected at Hanford, Savage Island, 100-D, the river at 100-N, and White Bluffs, Washington (BNWL-1669 ADD). Throughout the year, other birds were taken on or near the Site at 100-K

trench, 100-N trench, 100-F trench, B swamp (pond), Gable swamp (pond), Redox swamp, T swamp, U swamp (pond), and the 300 Area pond (BNWL-C-96).

33.3 RADIONUCLIDES MEASURED/REPORTED

33.3.1 Fish

Analytical results reported for fish collected as part of the routine Hanford sampling program included sodium-24, phosphorous-32, potassium-40, cobalt-60, cobalt-58, zinc-65, and cesium-137. Not all samples were analyzed for all constituents. Concentrations were reported in units of 10^{-6} μCi/g, wet weight (BNWL-1669 ADD). Other fish were also monitored for chromium-51, manganese-54, iron-59, zirconium-niobium-95, and scandium-46. Results for these fish were reported (graphically) in units of mean pCi/g, dry weight (BNWL-1377).

A comparison with past data showed that concentrations in fish collected near the reactors in 1970 constituted a smaller source of exposure than fish sampled below Ringold in previous years. The average concentration of phosphorous-32 and iron-65 in whitefish taken between 100-K and White Bluffs during this study were 24 and 6 pCi/g, respectively (BNWL-B-71).

The Columbia River fish eaten most frequently were crappie, perch, and bass (BNWL-1019).

"The average percentage of the maximum annual consumption by species was 73% crappie, 16% bass and 11% perch." The average concentration of phosphorous-32 in such a mixture of pan fish was about 5 X 10^{-6} μCi/g. The zinc-65 concentration averaged 2 X 10^{-6} μCi/g (BNWL-1699).

33.3.2 Shellfish

Willapa Bay oysters were analyzed for phosphorous-32, potassium-40, zinc-65, and cesium-137. Samples were collected monthly (BNWL-1669 ADD). Samples collected at Ilwaco, Washington, were analyzed for zinc-65 (BNWL-SA-4206).

"Zinc-65 and ^{32}P [phosphorous-32] are the only radionuclides from Hanford reactor effluents that have been found in sufficient abundance in seafoods collected beyond the mouth of the Columbia River to be of significance to

human radiation exposure. Oysters have been found to contain higher concentrations of ^{65}Zn [zinc-65] than other common seafoods" (BNWL-1699).

The annual average concentrations of zinc-65 and phosphorous-32 in oysters for 1970 were 1.3×10^{-5} and 0.6×10^{-7} μCi/g, respectively (BNWL-1699).

33.3.3 Waterfowl

Waterfowl collected during routine sampling were analyzed for phosphorous-32, sodium-24, potassium-40, cobalt-58, cobalt-60, zinc-65, and cesium-137. Concentrations were reported in units of 10^{-6} μCi/g, wet weight (BNWL-1669 ADD). Other birds collected onsite were analyzed for scandium-46, chromium-51, manganese-54, iron-59, strontium-90, ruthenium-103, ruthenium-106, and cerium-praseodymium-144 (BNWL-C-96). Results for every constituent were not reported for all birds.

Spring and fall waterfowl migrations can result in a large (200,000) temporary influx of birds to the area. Some birds remain in the area year round (BNWL-1699).

Of the 15 waterfowl collected at the 100-K and 100-N trenches between December 29, 1969, and April 20, 1970, seven contained phosphorous-32 concentrations in muscle greater than 5 times the maximum concentration found in any other birds collected during 1968 or 1969 (maximum of 140,000 pCi/g, wet weight) (BNWL-C-96). The K and N trenches were covered with screen in the spring of 1970 to prevent further access by waterfowl (BNWL-B-71).

Concentrations of phosphorous-32 and zinc-65 in ducks were lower in 1970 than in earlier years. The average concentrations of zinc-65 and phosphorous-32 in duck muscle were about 1.2 and 9.6 pCi/g, respectively. Seventy-nine ducks were collected. Lower concentrations were probably the result of the shutdown of the KW reactor on February 1, 1970, and the extended shutdowns of the KE reactor during the year (BNWL-B-71, Part 2). There were only two reactors operating during 1970: N-Reactor and 100-KE (BNWL-SA-3455). The maximum phosphorous-32 concentration seen in duck muscle was 1.7×10^{-4} μCi/g (BNWL-1699).

The average concentrations of phosphorous-32 and zinc-65 in goose muscle in 1970 were 14 and 5.3 pCi/g, respectively. Seventeen geese were sampled (BNWL-B-71).

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34.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1971

34.1 MEDIA SAMPLED

34.1.1 Fish

Muscle tissue was sampled from a few Columbia River fish during 1971. Fewer fish were collected this year than in 1970 because the last of the Hanford reactors with once-through cooling (KE reactor) was permanently shut down in January 1971. Hanford environmental personnel routinely collected muscle tissue from whitefish (34 samples, 20% of which were composites), crappie (5 individual fish, 2 composite) and perch (7 individual fish). Composite samples consisted of equal weights of muscle from five fish (BNWL-1683 ADD; BNWL-1683).

34.1.2 Shellfish

Washington coast oysters were collected for the routine Hanford environmental sampling program (BNWL-1683). Tissues from Pacific coast clams, crabs, oysters, and shrimp were also analyzed (BNWL-SA-4206).

34.1.3 Waterfowl

Routine Hanford waterfowl collections primarily included ducks and geese. The livers of some birds collected on site were monitored for radionuclide contamination, but most samples were of muscle tissue. Most samples were analyzed individually, but sometimes equal-sized muscle samples from five different birds were composited for analysis. Species routinely collected (and approximate collection totals) included mallards (95 individual samples and 6 composite samples), green-winged teal (6 birds), golden eye (3 birds), ruddy duck (3 birds), widgeon (1 bird), pintail (1 bird), redhead (1 bird), scaup (1 bird), gadwall (2 birds), coots (3 birds), and 1 blue-winged teal. A total of 14 individual and 3 composite geese samples were also analyzed. Sixteen of the samples were Canada geese and one was a lesser Canada goose (BNWL-1683 ADD).

34.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

34.2.1 Fish

Routine Columbia River fish-sampling locations included Island View, Burbank, and Hover, Washington. Whitefish were also collected from the Columbia downstream of the reactors (BNWL-1683-ADD).

34.2.2 Shellfish

Oysters obtained for the Hanford environmental sampling program were collected at Willapa Bay, Washington (BNWL-1683). Other Pacific coast organisms were collected at Ilwaco, Washington (BNWL-SA-4206).

34.2.3 Waterfowl

Waterfowl were obtained from onsite and offsite surface-water locations. Onsite locations included U-swamp, Redox swamp, Gable swamp, B-swamp, 300 Area pond, 100-F trench, and from the 100 Areas (BNWL-B-228, BNWL-1683 ADD). Columbia River sampling locations for ducks included Ringold, White Bluffs, 100-D, Savage Island, Hanford and 100-F. Geese were collected from the Columbia River, at 100-F, 100-D, Hanford, White Bluffs, Savage Island, and 100-N (all Washington locations) (BNWL-1683 ADD; BNWL-B-228).

34.3 RADIONUCLIDES MEASURED/REPORTED

34.3.1 Fish

Analytical results reported for Columbia River whitefish collected downstream of the reactors included sodium-24, phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, and cesium-137. Both crappie and perch were analyzed for phosphorous-32, potassium-40, zinc-65, and cesium-137, but results for perch also included cobalt-58 and cobalt-60. Results were tabulated and reported in units of 10^{-6} μCi/g, wet weight (BNWL-1683 ADD).

"Historically, whitefish were the fish species caught and consumed locally that usually contained the greatest concentrations of radioactive material, although pan fish species were of greater significance as a source of human exposure due to the difference in quantities consumed" (BNWL-1683).

"Phosphorous-32 concentrations in whitefish dropped to less than the analytical limit of 10^{-6} μCi/g within a month after shutdown of the KE reactor" (BNWL-1683).

Average concentrations of phosphorous-32 and zinc-65 in Columbia River whitefish collected from May through November between 100-K and White Bluffs were 24 and 6 pCi/g, respectively. Concentrations in fish sampled near the reactors were equivalent to concentrations in fish collected downstream of the reactor areas (BNWL-B-71, PART 1).

34.3.2 Shellfish

"Zinc-65 and ^{32}P [phosphorous-32] are the only radionuclides from Hanford reactor effluents that have been found in sufficient abundance in food organisms beyond the mouth of the Columbia River to be of significance to human radiation exposure" (BNWL-1683).

"For 1971, the concentration of ^{32}P [phosphorous-32] was so low that negligible quantities of ^{32}P were found in Willapa Bay oysters" (BNWL-1683).

Normally, because of changes in ocean currents, the seasonal minimum concentration of phosphorous-32 in Willapa Bay oysters occurred in late summer (BNWL-1683).

Concentrations of zinc-65 in Ilwaco, Washington, shellfish were as follows: clams (1.5 pCi/g), crabs (3.7 pCi/g), oysters (10.7 pCi/g), and shrimp (0.48 pCi/g) (BNWL-SA-4206).

Results were reported for 12 Willapa oyster samples. Phosphorous-32 concentrations were reported for three samples. Results for potassium-40, zinc-65, and cesium-137 were reported for all samples. Data were tabulated and reported in units of μCi/g, wet weight (BNWL-1683 ADD).

34.3.3 Waterfowl

"About 30% of the game bird meals consumed by local hunters were reported to be birds shot within about 5 km of the Columbia River between Ringold and McNary Dam" (BNWL-1683).

"About 30% of all gamebirds taken locally were ducks and geese" (BNWL-1683).

"The average ^{137}Cs [cesium-137] concentration was much lower in the river waterfowl (89 birds) than the swamp and pond waterfowl (20 birds) indicating that the river waterfowl do not frequent the 200 area swamps and ponds" (BNWL-B-228).

Analytical results reported for routinely collected waterfowl muscle samples included sodium-24, phosphorous-32, cobalt-58, cobalt-60, potassium-40, zinc-65, strontium-90, and cesium-137. Results were reported in units of 10^{-6} μCi/g, wet weight. Livers from ducks captured onsite were also analyzed for uranium, plutonium-239, and americium-241. Plutonium-239 results were reported for all liver samples, but uranium and americium-241 were only reported for one location each (BNWL-B-228; BNWL-1683 ADD).

Fish samples were analyzed for sodium-24, phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, and cesium-137. Oysters were monitored for phosphorous-32, potassium-40, zinc-65, and cesium-137. Not all fish samples were analyzed for every constituent. Results for all organisms were reported in tables in units of pCi/g, wet weight (BNWL-1683-ADD).

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35.0 FISH, SHELLFISH, AND WATERFOWL RADIONUCLIDE CONTAMINATION SUMMARY FOR 1972

35.1 MEDIA SAMPLED

35.1.1 Fish

Muscle samples were taken from Columbia River fish. Fish species collected included whitefish, bass, sturgeon, catfish, steelhead, and bluegill (BNWL-1727 ADD).

35.1.2 Shellfish

Soft tissues were taken from Willapa Bay oysters (BNWL-1727).

35.1.3 Waterfowl

Over 100 waterfowl were collected from ponds and trenches on the Hanford Site and from the Columbia River within the Hanford boundary (BNWL-1727). Species collected included mallards, blue-winged teals, green-winged teals, mergansers, golden eyes, shovelers, 1 old squaw, coots, Canada geese, and lesser Canada geese (BNWL-1727 ADD).

35.2 SAMPLING LOCATIONS

For geographic sites and sampling locations, see Figures 4.1 to 4.6.

35.2.1 Fish

Columbia River fish were collected at Ringold, Burbank, Richland, and Coyote Rapids, Washington (BNWL-1727 ADD).

35.2.2 Shellfish

Pacific oysters were obtained from Willapa Bay, Washington (BNWL-1727).

35.2.3 Waterfowl

Sampling locations for waterfowl collected from the Columbia River included 100-F, 300 Area, 100-H, Hanford, White Bluffs, and 100-K. Onsite pond and trench locations included T-swamp, the 300 Area pond, B-swamp (pond), 100-F trench, Honey Hill pond (probably Westlake), Redox pond, Gable pond, and U-swamp (pond) (BNWL-1727 ADD).

34.3 RADIONUCLIDES MEASURED/REPORTED

34.3.1 Fish

Columbia River fish samples were analyzed for sodium-24, phosphorous-32, potassium-40, cobalt-58, cobalt-60, zinc-65, strontium-90, and cesium-137. Results were reported in units of μCi/g, wet weight (BNWL-1727).

Whitefish were collected monthly at Ringold in 1972. The remainder of the fish samples were sampled in July and September (BNWL-1727).

Average zinc-65 and phosphorous-32 concentrations in 21 whitefish sampled in 1972 were 0.4 pCi/g and 0.62 pCi/g, respectively. Maximums were 1.8 pCi/g for phosphorous-32 and 0.92 pCi/g for zinc-65 (BNWL-1727).

"Historically, whitefish were the fish species caught and consumed locally that usually contained the greatest concentrations of radioactive material, although pan fish species were of greater significance as a source of human exposure due to the difference in quantities consumed" (BNWL-1727).

35.3.2 Shellfish

Routinely sampled oysters were collected in all months except March, October, November, and December (BNWL-1727 ADD).

Willapa Bay oysters were monitored for potassium-40, zinc-65, and cesium-137 (BNWL-1727 ADD). Some yearly maximum and minimum values for oysters were reported in units of pCi/g (BNWL-1727; BNWL-1727 ADD).

"Zinc-65 and ^{32}P [phosphorous-32] are the only radionuclides from Hanford reactor effluents that have been found in sufficient abundance in seafoods collected beyond the mouth of the Columbia River to be of significance to human radiation exposure" (BNWL-1727).

Routine analysis for phosphorous-32 in Willapa Bay oysters was discontinued following the shutdown of KE reactor. Zinc-65 levels for nine oyster samples averaged 1.7 pCi/g in 1972 (BNWL-1727).

35.3.3 Waterfowl

On average, radionuclide concentrations were similar in ducks and geese. Zinc-65 and cobalt-60 averaged less than 0.1×10^{-6} μCi/g and 0.15×10^{-6} μCi/g, respectively. Phosphorous-32 was not routinely measured (BNWL-1727).

Uranium and plutonium were measured in livers of ducks collected from onsite ponds. Data were reported in units of pCi/g, wet weight (BNWL-1727 ADD).

Cesium-137 levels were much lower in river waterfowl than in waterfowl collected from the onsite ponds and trenches (BNWL-B-278).

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