Radionuclides in Transport in the Columbia River From Pasco to Vancouver, Washington

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By W. L. HAUSHILD, H. H. STEVENS, JR., J. L. NELSON *and*
G. R. DEMPSTER, JR.

TRANSPORT OF RADIONUCLIDES BY STREAMS

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By W. L. HAUSHILD, H. H. STEVENS, JR., J. L. NELSON, and G. R. DEMPSTER, JR.

ABSTRACT

The radionuclide discharges in the cooling-water effluent of the reactors on the U.S. Atomic Energy Reservation at Hanford, Wash., were formed by neutron activation of: (1) impurities in the Columbia River water used to cool the reactors, (2) corrosion products from the reactor components, and (3) chemicals used in the water-treatment process. Until all the eight reactors that were cooled by once-through flow were shut down, their cooling-water effluents were the main source of dissolved and particulate radionuclides in the Columbia River. Concentrations and discharges of 13 dissolved and particulate radionuclides were observed at Pasco and Vancouver, Wash., for all or parts of the period from January 1964 to September 1966, and at Umatilla, Oreg., from May 1965 to September 1966.

A time-series analysis of concentrations and discharges of eight of the 13 particulate and dissolved radionuclides at Pasco and Vancouver showed a progressive decrease in the concentrations and discharges of many radionuclides during the study period. The decrease was mainly attributable to a decrease in the number of operating reactors. Concentrations and discharges of the radionuclides varied seasonally in separate patterns that were used to categorize the particulate and dissolved radionuclides into five classes. Concentrations of radionuclides in classes 1, 2, and 4 varied seasonally in accord with seasonal variations in dissolved parent materials in the river water used to cool the reactors. The seasonal variations of concentrations of class-3 radionuclides exhibited characteristics of dilution by the river discharge of a source with constant strength. Concentrations of class-5 radionuclides varied seasonally in close accord with the seasonal variation in water discharge at Vancouver, Wash.; this evidence indicates that, after transport far enough downstream, the variability in concentrations of many radionuclides in the Columbia River tended to lose dependency on its variability at the source and became dependent upon the variability in the water discharge. Specific activities of zinc-65 and chromium-51 at Vancouver varied inversely with concentration of suspended sediment.

Seasonal variations in the discharges of dissolved and particulate radionuclides depended on seasonal variations in their concentrations and the seasonal variation in the water discharge. For the generally anionic chromium-51 and the anionic and uncharged antimony-124, the ratio of dissolved-radionuclide discharge to the total discharge averaged 93 and 96 percent, respectively, at the river stations, and varied little in time at a river station or among the river stations. The average percentages dissolved for the generally cationic cobalt-58, cobalt-60, zinc-65, manganese-54, scandium-46, and iron-59 were generally much lower than that for the anionic radionuclides and depended on the radionuclide. The percentages dissolved for the cationic radionuclides generally varied greatly in time at a station and among the stations.

The hydrodynamic and sedimentation characteristics of the Columbia River and the chemical characteristics of the radionuclides were found to be important factors affecting the disposition of the radionuclides discharged at Pasco in the Pasco-Vancouver reach.

INTRODUCTION

Starting in 1944, the U.S. Atomic Energy Commission operated nuclear reactors at their Hanford Reservation near Richland, Wash. Water from the Columbia River was used to cool the reactors and was returned to the river through partly controlled releases. The last of eight reactors that were cooled by once-through flow shut down early in 1971; there are no plans to restart any of these eight reactors. A ninth reactor, which has a recirculating cooling system and, therefore, contributes very little radioactive material to the Columbia River, may be operated again. Because some of the dissolved and suspended materials in the cooling water were made radioactive when they were exposed to the neutron fluxes of the reactors, the cooling-water effluents introduced small quantities of radionuclides into the river. Once they entered the river, the radionuclides were dispersed in solution in the water, were fixed to organic and inorganic sediments, or were assimilated by aquatic biota. The water, sediment, and biota subsequently transported the radionuclides downstream or stored the radionuclides in place for variable periods of time. As a result, any investigation of the disposition of the radionuclides in the river system necessarily involved studies of their storage in the streambed sediments, their transport, and their decay during residence in the river.

In 1962, the U.S. Geological Survey and the General Electric Co.[1], each in cooperation with the U.S. Atomic Energy Commission, initiated an investigation of the disposition of radioactivity in the 310-mile reach of the Columbia River between the reactors on the Hanford Reservation and the head of the river's estuary (Longview, Wash.). The purposes of the investigations were to: (1) quantify the transport and storage of radionuclides within the river system, (2) determine the effects of the hydrodynamic and sedimentation characteristics of the river system on the transport and storage of radionuclides, (3) furnish specific information and data on the disposition of radionuclides in the river for use in related studies of radionuclides in the Columbia River estuary and adjacent ocean, and (4) provide generalized information and relations that might be useful in evaluating the disposition of radionuclides in other rivers.

The Geological Survey determined radionuclide, water, and sediment discharges; defined physical, chemical, and mineralogical properties of sediments; conducted reconnaissance surveys to determine the spatial distribution of radionuclides in deposited sediment; and characterized waterflow and sediment movement. General Electric and, later, Battelle Northwest provided detailed laboratory analysis of the radionuclide content of water and sediment samples, conducted laboratory research on radionuclide-sediment interactions, and aided in a survey of radionuclides in streambed sediments between the reactors and McNary Dam. The staffs of the organizations cooperated closely to cordinate the technical program of the investigations.

As an outgrowth of their continuing research of analytical methods, on January 1, 1964, General Electric altered the laboratory procedures and began analyzing water and suspended-sediment samples with a newly developed multidimensional counting system (Perkins, 1965) in place of the high-resolution, anticoincidence counting system that was originally used (Perkins and others, 1960). Application of the new equipment and techniques permitted the concentrations of additional radionuclides to be measured and improved the accuracy of the overall analysis.

Because of the improvement in analytical procedures, some of the relations based on radionuclide content that are defined by data obtained after January 1, 1964, do not coincide exactly with similar relations for data collected before that date. To avoid minor discrepancies, data that were obtained from July 1962 through September 1963 and that have already been presented and treated in an earlier report (Haushild and others, 1966) are not considered here; however, unpublished basic data from October 1963 through December 1963 at Pasco and Vancouver, Wash., and from October 1963 through September 1964 at Hood River, Oreg., are given in table 18.

Results of the investigation considered in this report are based on concentrations and discharges of radionuclides in the Columbia River observed at Pasco, Wash., Umatilla, Oreg., and Vancouver, Wash., during the period January 1964 through September 1966 which is designated as the study period in this report. Data for eight radionuclides were obtained for the entire period and were used in the interpretation and analysis of radionuclide concentrations and discharges. The eight radionuclides were chromium-51, zinc-65, scandium-46, iron-59, manganese-54, antimony-124, cobalt-58, and cobalt-60. Some data are also reported for phosphorus-32, barium-140, zirconium-95–niobium-95, ruthenium-106, and cesium-137; however, analyses of these data are not part of this report because the radionuclides either are principally from "fallout" or their concentrations were observed during only part of the record period. Two other reports (Perkins and others, 1966; Nelson, Perkins, Nielsen, and Haushild, 1966) present information that pertains to parts of this same body of data and to aspects of the investigation not included in this report.

Specifically, this report presents information on the spatial and temporal variations in concentrations and discharges of radionuclides in the Columbia River, The variations, in turn, are related to the hydrodynamic and sedimentation characteristics of the Columbia River, the physical-chemical properties of the radionuclides, and the variations in concentrations of parent materials in the cooling-water effluent. Also, a classification of particulate and dissolved radionuclides, which is based on the seasonal variations in concentrations and discharges of these radionuclides, is presented. Finally, principles of continuity and conservation-of-mass are applied to facilitate a discussion of the disposition of the radionuclides in the reach between Pasco and Vancouver, Wash.

ACKNOWLEDGMENTS

The interest and counsel of Walter G. Belter, chief; and Harold Bernard and I. Craig Roberts, staff engineers, Environmental and Sanitary Engineering Branch, Division of Reactor Development and Technology, U.S. Atomic Energy Commission, were beneficial in establishing goals and providing direction for the study.

Dr. Julian M. Nielsen, director, and staff members of the Radiological Sciences Department, Battelle

1 After the spring of 1965, Battelle Northwest, Pacific Northwest Laboratory (a division of Battelle Memorial Institute), assumed the responsibilities for the part of the investigation that had been assigned to General Electric Co.

Northwest, Pacific Northwest Laboratory, Hanford, Wash., helped design field investigational procedures to maximize benefits and efficiency of sampling programs while not overtaxing capabilities of the radiochemical laboratory to analyze the samples. Dr. Nielsen and his staff are to be complimented for improving techniques and methods of determining the concentrations of specific radionuclides and for maintaining high quality control on the analysis of samples.

The supervision, guidance, and assistance provided by L. B. Laird, G. L. Bodhaine, P. C. Benedict, Alfred Clebsch, Jr., and Robert Schneider, U.S. Geological Survey, were invaluable. Especially appreciated is the assistance of the many other Geological Survey personnel who aided in some phase of the project; D. W. Hubbell and J. L. Glenn specifically provided constructive criticism of project plans, invaluable technical advice, and review of reports throughout the study.

THE RIVER SYSTEM

The Columbia River flows some 1,230 miles from Columbia Lake, British Columbia, elevation 2,654 feet, to the Pacific Ocean. In its upper part, the river flows through British Columbia and eastern Washington, and in its lower part, it forms the boundary between Washington and Oregon.

The Columbia River above Pasco drains rugged mountainous-to-hilly terrains, the northern Cascade Range and northern Rocky Mountains (Fenneman, 1931), and the lower-lying Columbia Plateau (fig. 1). River miles shown in figure 1 are based on those compiled by the Hydrology Subcommittee, Columbia Basin Inter-Agency Committee (1962, 1965). The mountainous-to-hilly terrains are underlain by granitic, metamorphic, and sedimentary rocks (Huntting and others, 1961; Ross and Forrester, 1947); the plateau is underlain by volcanic rocks. The Snake River, which enters the Columbia River below Pasco (fig. 1), also drains plateau and hilly-to-mountainous terrains underlain by rock types similar to those in the Columbia River basin above Pasco. From about the mouth of the Snake River to near the mouth of the Sandy River, the Columbia River and its tributaries drain chiefly continental volcanic rocks (Huntting and others, 1961; Wells, 1961). From the Sandy River to the mouth of the Columbia River near Astoria, Oreg., the drainage is from marine sedimentary rocks and intercalated submarine flows (Wells, 1961).

The Cascade Range divides the Columbia River basin into two climatologically dissimilar regions (Highsmith, 1957). East of the mountains, the climate is semiarid and either modified continental or comparatively continental; west of the mountains, the climate is mild and is semimarine in the protected western lowlands to marine at the mouth of the Columbia River and along the Pacific Coast. The annual precipitation in the Columbia River basin ranges from more than 100 inches at higher altitudes in the Cascade and Coast Ranges (fig. 1) to less than 10 inches on the plateaus. West of the Cascade Range, especially in protected western lowlands such as the Willamette Valley, precipitation is distributed seasonally with cool, wet winters and warm, dry summers; east of the range, the sparse precipitation falls about equally during the cold winters and hot summers (Highsmith, 1957).

The downstream order of major tributaries of the Columbia River along the study reach are the Snake, Umatilla, John Day, Deschutes, Klickitat, Sandy, Willamette, Lewis, Kalama, and Cowlitz Rivers (fig. 1). The Snake and Willamette Rivers are by far the major contributors of water and sediment to the Columbia River; other contributors, in approximate order of importance, are the Deschutes, John Day, Umatilla, Klickitat, and Sandy Rivers between Pasco and Vancouver, and the Cowlitz, Lewis, and Kalama Rivers downstream from Vancouver.

The flow in the Columbia River and its major tributaries is controlled and regulated by dams. The water discharge and sediment movement in these rivers are affected by the storage and controlled release of water from reservoirs for power production, flood control, irrigation, water-temperature control, channel maintenance, and indirectly, at least, the dilution of wastes. Figure 1 shows the location of dams within the study reach. The construction of the John Day Dam on the Columbia River was completed in 1967 and had only a local and minor effect on flow during the data-collection period. Below Bonneville Dam, tides affect the flows in the Columbia River and in the lower reaches of its tributaries.

Santos (1965) reported that the water of the Columbia River is a calcium magnesium bicarbonate type and that the dissolved-solids content ranges from 84 to 128 mg/l (milligrams per liter) at McNary Dam, and from 72 to 163 mg/l at The Dalles, Oreg. (1952–59 record). Data in Santos' report show that the average dissolved-solids content of water in tributaries below The Dalles is generally less than one-half of the average content in Columbia River water at The Dalles.

Radionuclide, water, and sediment data were collected from stations at Pasco, Wash. (Pasco), Umatilla, Oreg. (Umatilla), and Vancouver, Wash. (Vancouver), on the Columbia River. The parenthesized names used in this report are for these locations.

WATER AND SEDIMENT DISCHARGES

Average annual water discharge for 88 years of record for the Columbia River at The Dalles, Oreg., was about

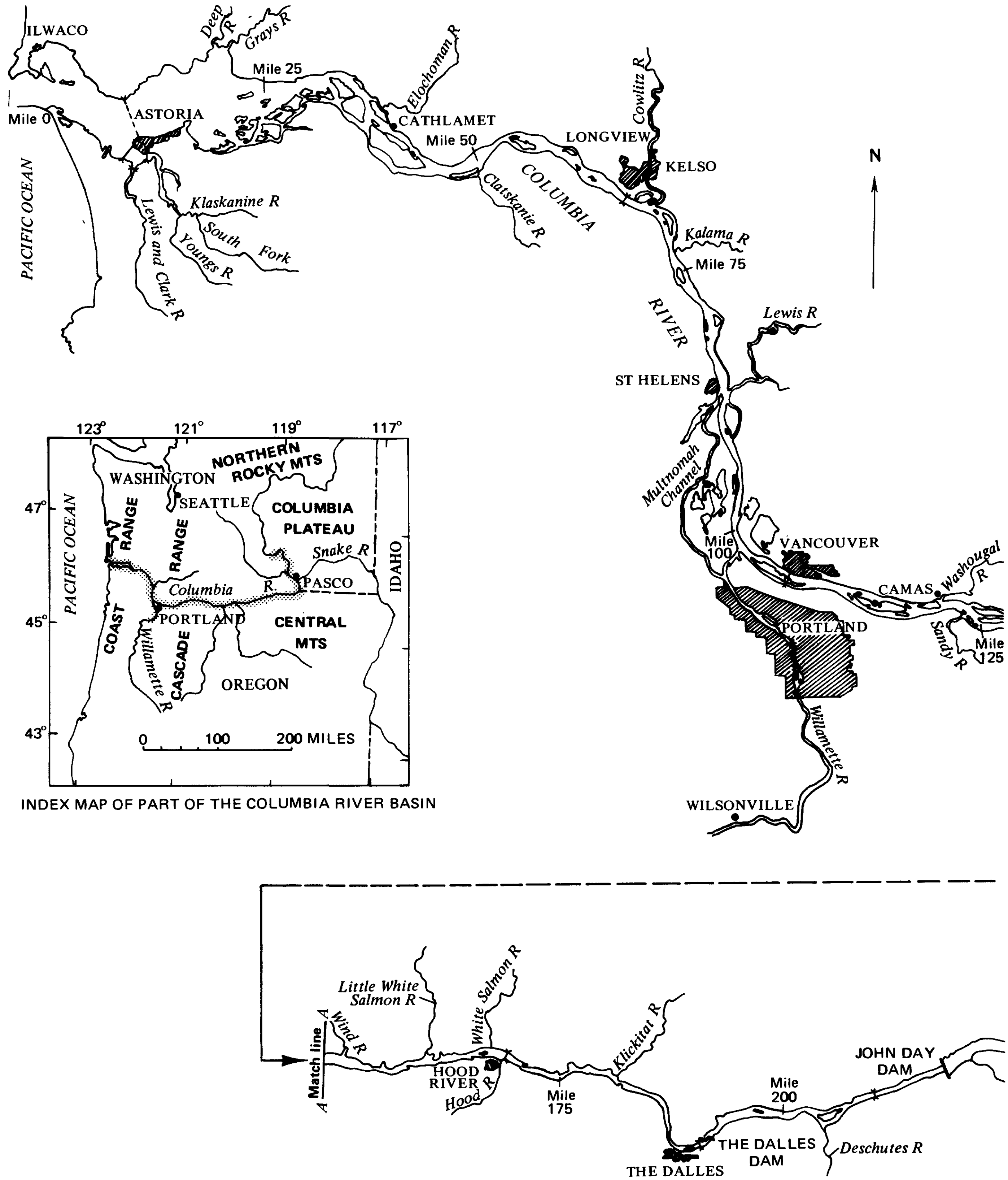
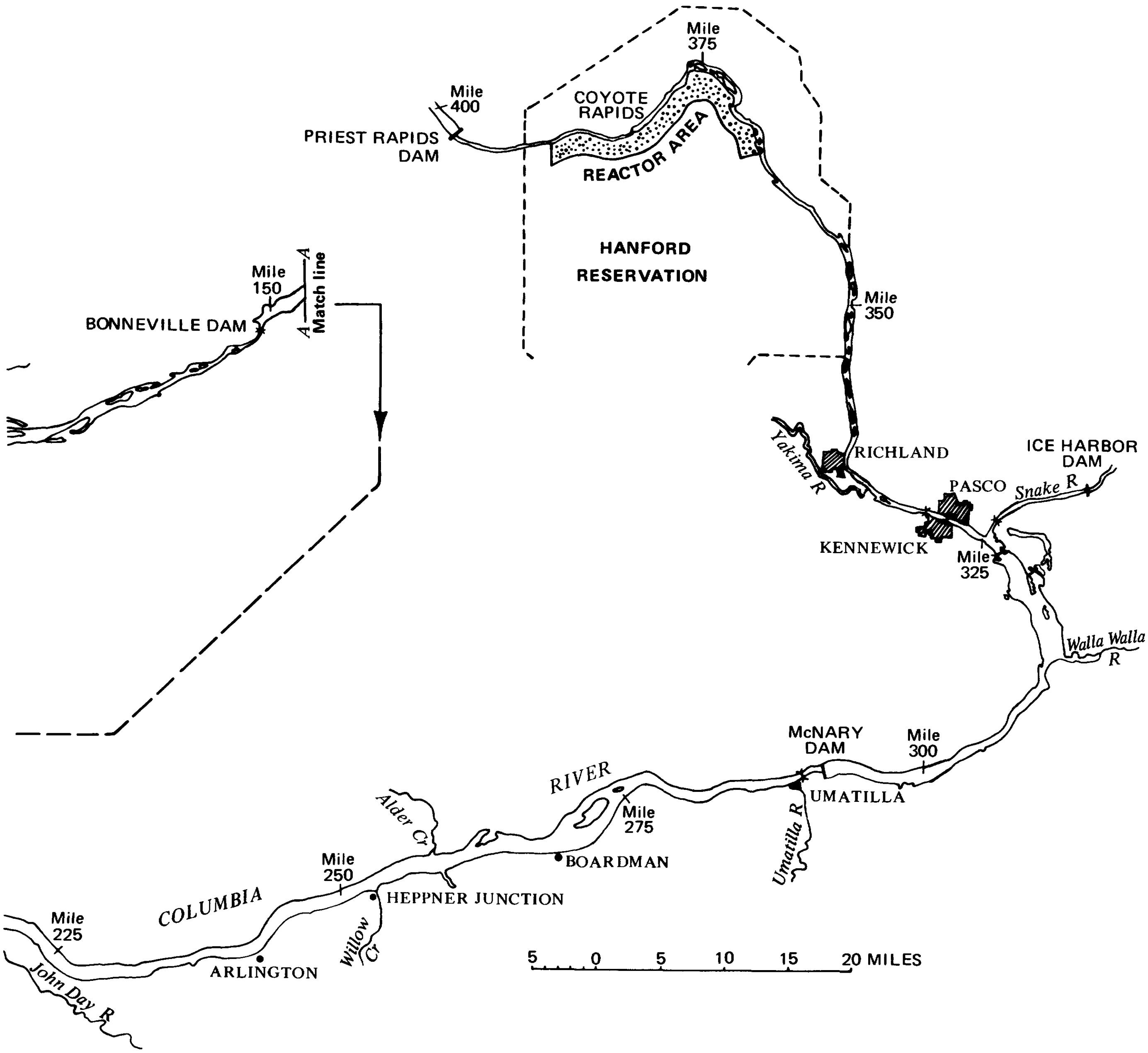


FIGURE 1.—Columbia River study area.



194,000 cfs (cubic feet per second); maximum discharge was 1,240,000 cfs in 1894, and the minimum observed discharge was 35,000 cfs in 1937. Present-day (1964–66) minimum daily water discharges are about 80,000 cfs at The Dalles (U.S. Geol. Survey, 1964a, b; 1965a, b; 1966a, b). The hydrographs in figure 2 show that water discharges during the study period usually were low from September to April and generally were high from May to August (annual-flood period). The annual discharge maximum occurred in June. Runoff from rainfall and (or) snowmelt increased water discharges in some winters; daily discharges at The Dalles of 364,000 cfs for December 25, 1964, and 314,000 cfs for January 31, 1965, were near-record seasonal maximums.

Graphs in figures 3 and 4 show total sediment discharges and suspended-sediment concentrations that were observed during the study period at the Columbia River stations. The annual cycle of water and sediment discharges for the Columbia River is typical of regulated streams whose storage capacity in reservoirs is less than the annual runoff. The graphs show that suspended-sediment concentrations and total sediment discharges as well as water discharges were generally low and relatively constant from September to late April or early May, increased to maximums by mid-June, and

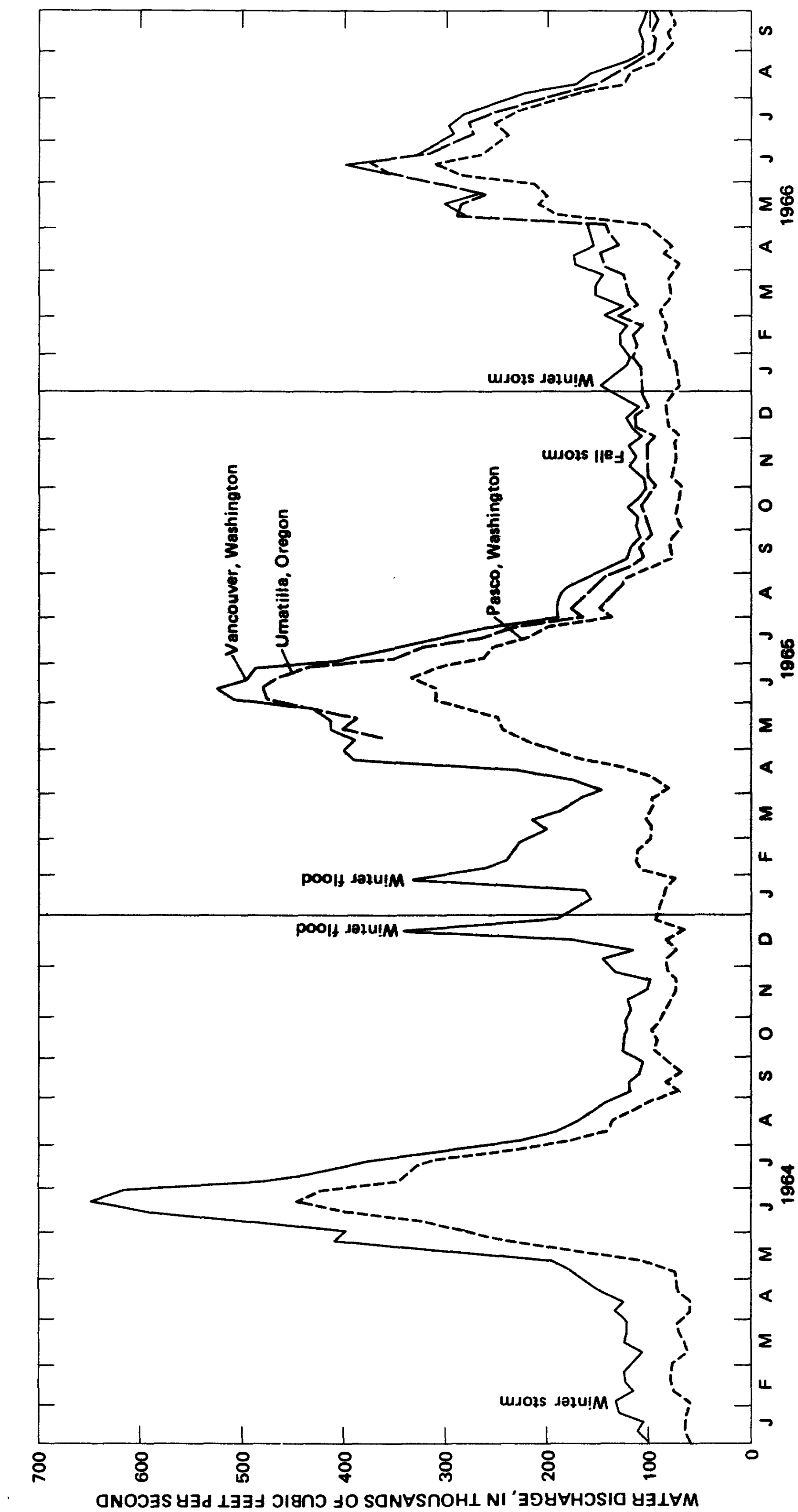


FIGURE 2.—Mean weekly water discharges at Columbia River stations.

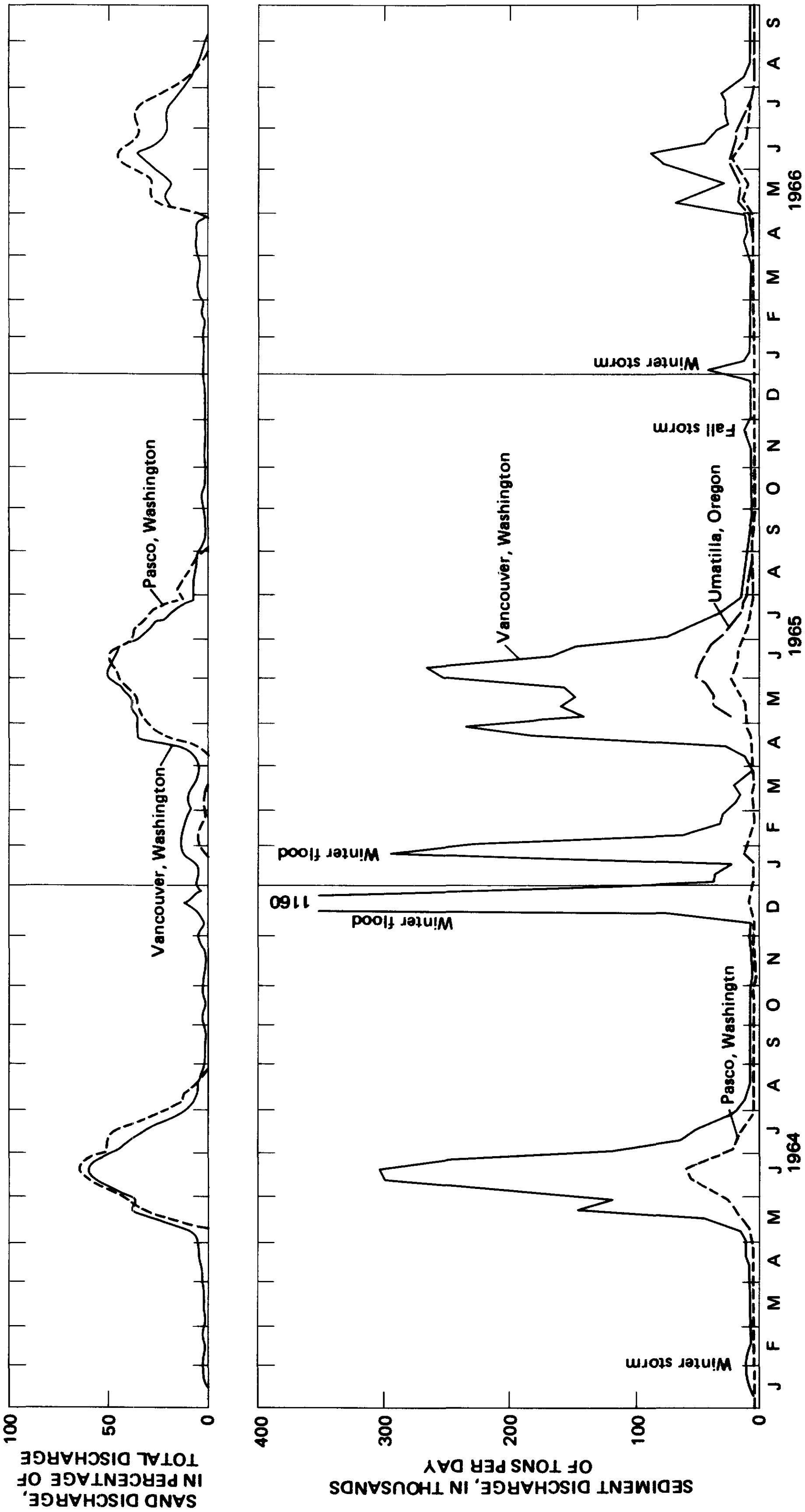


FIGURE 3.—Mean weekly sand discharges and total sediment discharges at Columbia River stations.

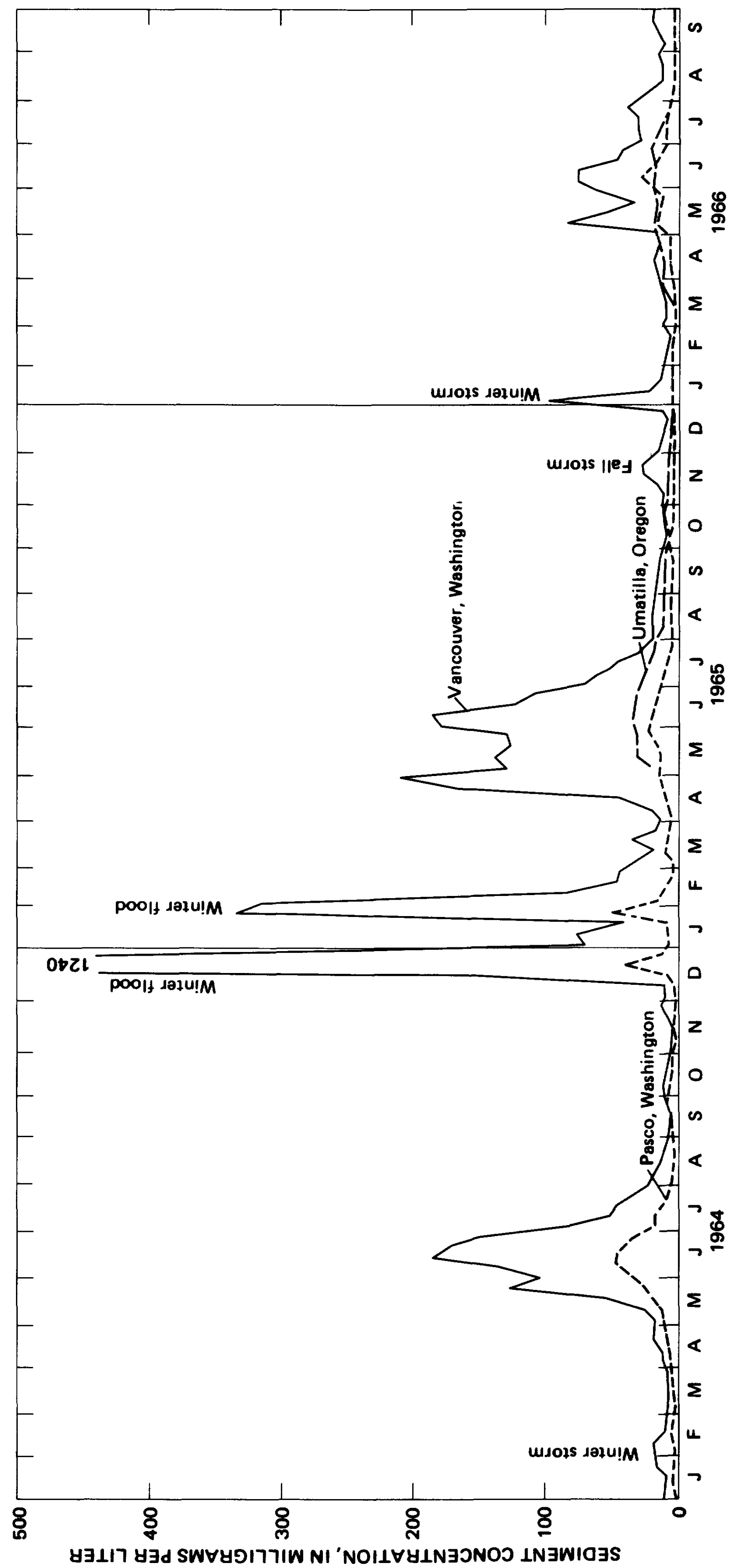


FIGURE 4.—Mean weekly suspended-sediment concentrations at Columbia River stations.

decreased from June to August. Fall and winter storms caused high concentrations and discharges of sediment for periods that varied from a few days—the usual period—to several weeks; the periods of high concentrations and discharges of sediment during the floods of December 1964 and January–February 1965 were comparatively long. Maximums in concentrations and discharges of sediment at Vancouver were relatively low during most falls and winters; they were extraordinarily high only during the 1964–65 winter floods (fig. 3). Suspended-sediment concentration was a good index of storm runoff because the storms usually caused an increase in concentration that was relatively more than the increase in water discharge. Storms caused increases in water discharge and (or) concentration and discharge of sediment each fall and winter at Vancouver but caused an increase only in concentration and discharge of sediment during one winter (1964–65) at Pasco.

The percentage of the sediment discharged at Pasco and Vancouver that was sand (particle size greater than 0.062 millimeter) depended on water discharge and the season. Velocity and turbulence of the flows during low water discharges were innsufficient to transport sand at Pasco and were sufficient to transport (on, or in near contact with, the streambed) only small quantities of sand at Vancouver. Data in figure 3 show that large quantities of sand were transported from April through August, the annual-flood period. Sand usually was less than 10 percent of the total sediment discharged during periods of runoff from fall and winter storms. Annual sand discharge generally was 25–35 percent of the annual total sediment discharge at the river stations.

The Snake River contributed most of the water inflow between Pasco and Vanncouver as is shown by the small differences between water discharges at Umatilla and Vancouver in figure 2. A large percentage of the sediment discharged during the annual-flood and winter-storm periods at Vancouver, however, originated downstream from Umatilla as is shown by the large differences between sediment discharges at Umatilla and Vancouver in figure 3. Sediment discharge for stations on some tributaries (U.S. Geol. Survey, 1964c, d; 1965a, b; 1966a, b) and reasonable estimates of sediment discharges for other tributaries indicated that inflow from the tributaries downstream of the Umatilla station was the main source of sediment discharged at Vancouver during the winter-storm periods but was a minor source during the annual-flood periods. Therefore, a large percentage of the sediment discharged at Vancouver during the April–August periods must have originated from the bed, banks, and flood plain of the Columbia River below Umatilla.

SOURCES OF RADIONUCLIDES

The water withdrawn from the Columbia River was treated before it was used to cool the reactors. Treatment, which included alum flocculation, settling, and filtration, removed part of the dissolved and solid materials from the river water (Richman, 1960). Sodium dichromate was added to the treated water to inhibit corrosion. Radionuclides were formed by exposure of dissolved and particulate materials in the cooling water to the neutron flux of a reactor. The probability of those materials in the cooling water that were incorporated in a thin film on fuel-element and process-tube surfaces being made radioactive is especially high, because the thin film may have adhered to the surfaces for relatively long times. Besides the materials contained in the cooling water, corrosion products from the water system and fuel-element surfaces of a reactor and impurities on and in the fuel-element surfaces were made radioactive and contributed part of the radionuclides found in the cooling-water effluent.

The treated Columbia River water absorbed fission-liberated heat while flowing through the process tubes and over the fuel-element surfaces of a reactor. The heated water was discharged into storage basins where it was retained for about one-half hour before being released to the river. About 99 percent of the cooling-water effluent was discharged directly from the storage basins into the river. The small quantity of cooling water that either leaked from the system or was discharged into open trenches in the vicinity of the reactors may have percolated to the underlying ground water and thence to the river; many of the radioions in this cooling water probably became fixed to the soil and aquifer particles. A reactor discharges cooling water at an essentially constant rate during operating periods and discharges cooling water at about 10 percent of this constant rate during shutdown periods.

During 1963, testing and operating was started of a recirculating water-cooled reactor that has been used for generation of electric power. This plant was designed to not contribute radionuclides directly to the river in its cooling-water effluent; however, corrosion products contained in the recirculating cooling water in a primary loop may be made radioactive by this power reactor. Water bled from the primary loop was discharged into rock storage cribs. Some radioactivity may have reached the Columbia River when the water stored in these cribs percolated through the soil and was subsequently transported to the river as ground water.

The historical record of the number of active reactors at the Hanford Works is: two, 1944; three, 1945–48; four, 1949; five, 1950–51; six, 1952–54; eight, 1955–62; and nine, 1963–64. Operation of three reactors was stopped during the study period—one each in December 1964, April 1965, and June 1965. All reactors were shut down serially over a 3-day period centered about July 8, 1966, and were subsequently restarted over a 3-day period centered about August 24, 1966.

The cooling-water effluents from the reactors contained more than 100 radionuclides (Nielsen, 1963). Because of short half lives and (or) low concentrations, many of these radionuclides were barely detectable beyond short distances downstream from the reactors. Chromium-51 is the most abundant radionuclide in the river. The approximate order of abundance for the seven other radionuclides studied in this report is zinc-65, scandium-46, iron-59, manganese-54, antimony-124, cobalt-58, and cobalt-60.

SAMPLING

Six-gallon samples of river water for radionuclide analysis were collected at biweekly intervals from January 1 to April 20, 1964, at Vancouver, and from January 1 to May 20, 1964, at Pasco. During the rest of the study period, 1-gallon samples obtained three times per week were composited biweekly into 6-gallon samples. This sampling frequency was temporarily increased (see data given in table 1) to define the variation in concentrations of radionuclides during and following the period in July and August 1966 when none of the reactors was operated.

To obtain the samples, weighted 1- or 6-gallon bottles were traversed vertically at rates such that water and suspended sediment were sampled as uniformly as possible throughout the total water depth. Samples were filtered, immediately after collection, through 0.30-micrometer filters to separate the particulate from the dissolved material. For this study, the 0.30 micrometer-size particle is defined as the division between particulate and dissolved radionuclides. Formaldehyde and concentrated nitric acid were added to the radionuclide samples to lessen the sorption of radionuclides by the glass bottles and to stop or retard biological activity. Both the solute and the filtered particulates from the samples were analyzed for concentrations, in picocuries per liter of water, of specific radionuclides.

River water for analysis of suspended-sediment concentration was sampled concurrently with radionuclide samples and at other times, as needed, to define relatively rapid variations in suspended-sediment concentration (U.S. Inter-Agency Committee on Water Resources, 1963). Suspended-sediment samples were obtained with a U.S. P–61 sampler, which may be used to sample while it is held stationary at a point or while it is traversed vertically. Samples for analysis of particle-size distribution of suspended sediment occasionally were obtained. Methods that are based on the fall rates of particles in distilled water were used to determine particle size of suspended sediment (U.S. Inter-Agency Committee on Water Resources, 1941, 1943, 1957a, b).

CONCENTRATIONS AND DISCHARGES OF RADIONUCLIDES

INFLUENCE OF PARENT MATERIALS

The concentrations and discharges of radionuclides in the Columbia River depend on the radionuclide quantities that were contained in the cooling-water effluents from the reactors. Just downstream from the reactors, the main factor affecting the concentrations of radionuclides was the dilution of the cooling-water effluents by the water in the river. The volume of the cooling-water effluents probably was nearly constant and was small compared to the water discharge of the river. Therefore, dilution effects may be computed from the known water discharges of the river. Assuming that decay and storage of transported radionuclides between the reactors and Pasco were negligible relative to the discharges of the radionuclides at Pasco, variations in radionuclide concentrations, which are adjusted for river discharge at Pasco, should reflect variations in radionuclide concentrations in the cooling-water effluents from the reactors. Normalized monthly concentrations (relative to their concentration for June) were used to show the observed and adjusted concentrations at Pasco of total (particulate plus dissolved) cobalt-60, zinc-65, and chromium-51 (fig. 5).

The observed normalized concentrations of chromium-51 at Pasco varied seasonally as though the reactors were discharging a nearly constant quantity of chromium-51 to the Columbia River. That is, concentrations were high and relatively constant during periods of low and relatively constant water discharges and were lowest during the period of highest water discharge (June). A nearly constant discharge of chromium-51 by the reactors is indicated by relatively small departures of the adjusted concentrations of chromium-51 from their mean value. The small seasonal differences in adjusted concentration—higher during April through July than during August through March—may be attributable to greater losses of transported chromium-51 to storage in bed sediments between the reactors and Pasco during low water discharges. Seasonal differences in the decay of dissolved chromium-51 during residence in the reactors–Pasco reach would be small as seasonal differences in travel time of water between the two locations are on the order of one-half day (Nelson, Perkins, and Haushild, 1966). The chromium-51 data then indicate a relatively constant operation of the reactors at uniform levels of plutonium production.

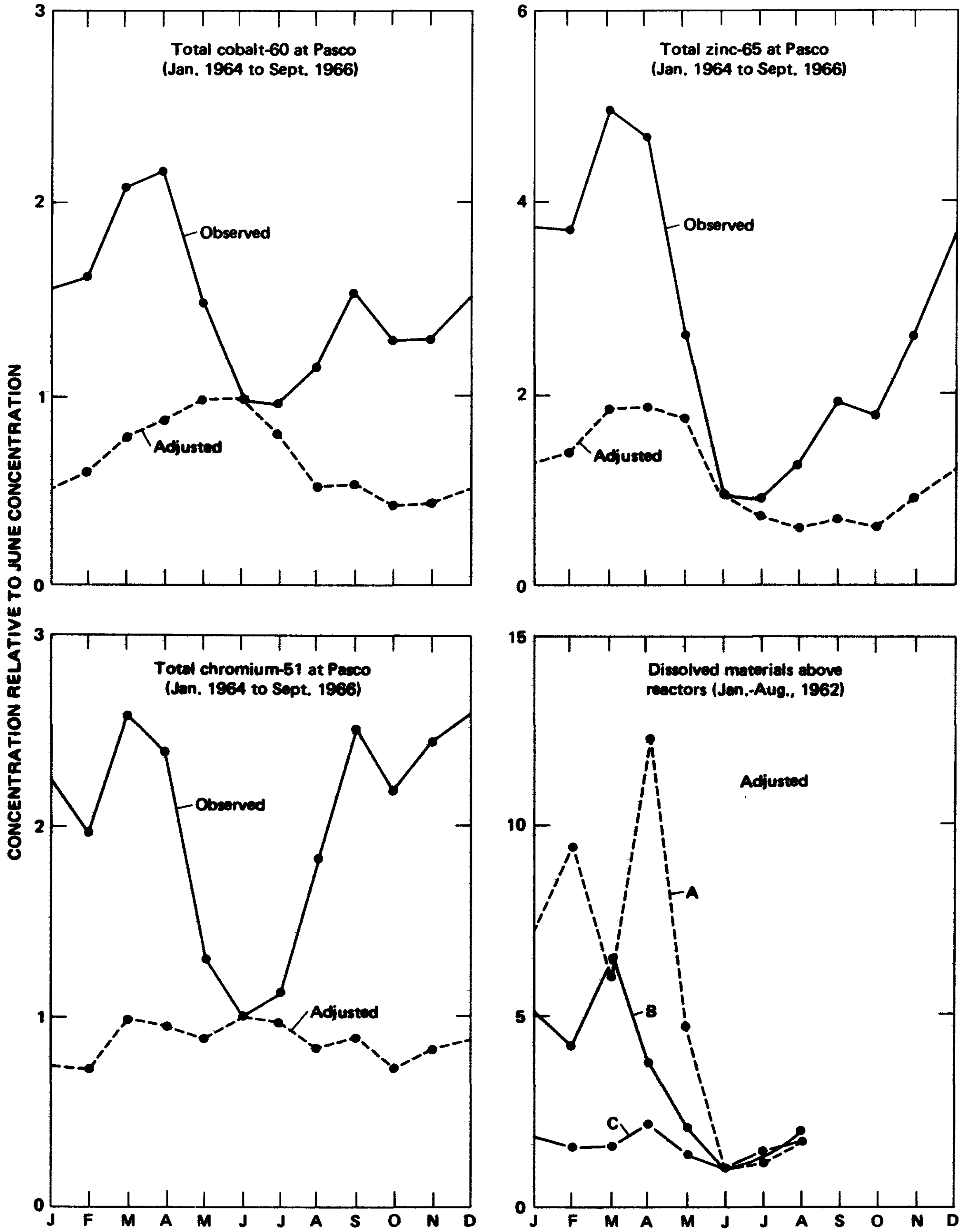


FIGURE 5.—Seasonal variations in normalized monthly concentrations of selected radionuclides in the Columbia River at Pasco, Wash., and variations in normalized monthly concentrations of dissolved materials in Columbia River just upstream from reactor area, Hanford Reservation, Wash. Adjusted curves show observed concentrations that were corrected for normalized monthly water discharges. Data for dissolved materials are based on monthly averages of data given by Silker, (1964, p. 541, table 1) for: A, arsenic, manganese, copper, and lanthanum; B, sodium and sulphur; and C, zinc and cobalt.

Constant operation of the reactors at uniform levels of production implies that the concentrations of radionuclides in the cooling-water effluents were proportional to the concentrations of parent materials in the treated cooling water. Although addition or partial removal of materials during treatment may have modified the concentrations of parent materials in the treated water from their concentrations in the untreated water, the seasonal-variation patterns in these concentrations probably were similar. Therefore, the adjusted concentrations of total cobalt-60 and total zinc-65 in figure 5 show the distinctive differences in the probable patterns of seasonal variations in concentrations of parent cobalt and zinc in the treated (and untreated) water. These data indicate that concentrations of parent zinc were maximum during March through May and minimum during August through October. Concentrations of parent cobalt were highest in June and lowest in October.

Some data on actual concentrations of parent materials in the Columbia River are available. Richman (1960) reported mean and extreme concentrations of manganese and iron in Columbia River water from data collected over a period of 6–11 years. Silker (1964) presented data on concentrations of dissolved (particles <0.45 micrometer) materials in Columbia River water from samples collected a short distance upstream from the reactors at approximately 2-week intervals from January 5 to August 17, 1962. Silker classified the temporal variations in concentrations of the dissolved materials into the following three categories: (A) concentrations of zinc and cobalt closely followed the variation in Columbia River flow and attained maximums during high river discharges in June; (B) concentrations of sodium, uranium, sulphur, and phosphorus tended to decrease as Columbia River flow increased; and (C) concentrations of copper, manganese, arsenic, and lanthanum were maximum in April. He also found that concentrations of iron varied erratically, and concentrations of scandium consistently were low.

Monthly averages of Silker's data were normalized (relative to their concentration for June) and were adjusted for the respective normalized monthly discharges of water in 1962. These data (fig. 5) show the estimated patterns of variation in average normalized concentrations of radionuclides at river sections just below the reactors that would have resulted from the variations observed during 1962 in concentrations of parent materials in the river above the reactors. The estimated patterns for all three of Silker's categories are similar: concentrations are at high levels in January and February, peak in March or April, lowest in June, and increase slightly during July and August. Also, these estimated patterns are very similar to the patterns observed in concentrations of total cobalt-60 and total zinc-65 at Pasco during January through August (fig. 5). Silker also stated that, characteristically, the seasonal fluctuations in the concentrations of many radionuclides in the cooling-water effluents increase in early spring (late March and April). Although Silker placed parent zinc and cobalt in the same category, the adjusted data in the upper two graphs of figure 5 indicate that the estimated concentrations of parent cobalt do peak in June (Silker's category A); whereas, the estimated concentrations of parent zinc peak in March and April (Silker's category C). Parent zinc may well be in category C instead of category A, for as Silker reported: "The changes of the concentration of zinc and the upper Columbia River flow rate were closely parallel. This is somewhat surprising***."

In the water of the Columbia River at the reactors, parent materials originate in the upstream drainage basins. Silker (1964) attributed the variations in concentrations for his three categories of materials in the Columbia River just above the reactors to variations in runoff characteristics (both in pattern of temporal variation and in volume contributed to the Columbia River) of two major drainages above the Hanford Reservation. One drainage is the Pend Oreille and Spokane River basins and the other is the Columbia River basin in Canada and the Kootenai River basin. Silker related the seasonal changes in concentration of elements in his category C to the variability in water discharge of the Spokane River. Seasonal changes in concentrations of elements in his other two categories (A and B) were ascribed to the relative quantity of water that each of the two major drainages contributed to the total flow of the Columbia River at Grand Coulee Dam. The variations in water discharge at stations on the Columbia River and two main tributaries during water years 1964 through 1966 are shown by the hydrographs in figure 6. Because of the year-to-year variability in water discharge at stations upstream from the reactors, concentrations of parent elements in the river and, consequently, concentrations of radionuclides may only have a generally similar pattern of seasonal variation from year to year. The actual maximum and minimum concentrations of radionuclides at Pasco did vary somewhat in magnitude and time of occurrence each year. However, the seasonal-variation patterns determined from observed concentrations for the 1964–66 period probably represent the general seasonal variations in concentrations of radionuclides at Pasco reasonably well.

SPECIFIC ACTIVITIES OF ZINC-65 AND CHROMIUM-51 AT VANCOUVER, WASH.

The specific activities (content of a particulate radionuclide in a unit weight of suspended sediment) of

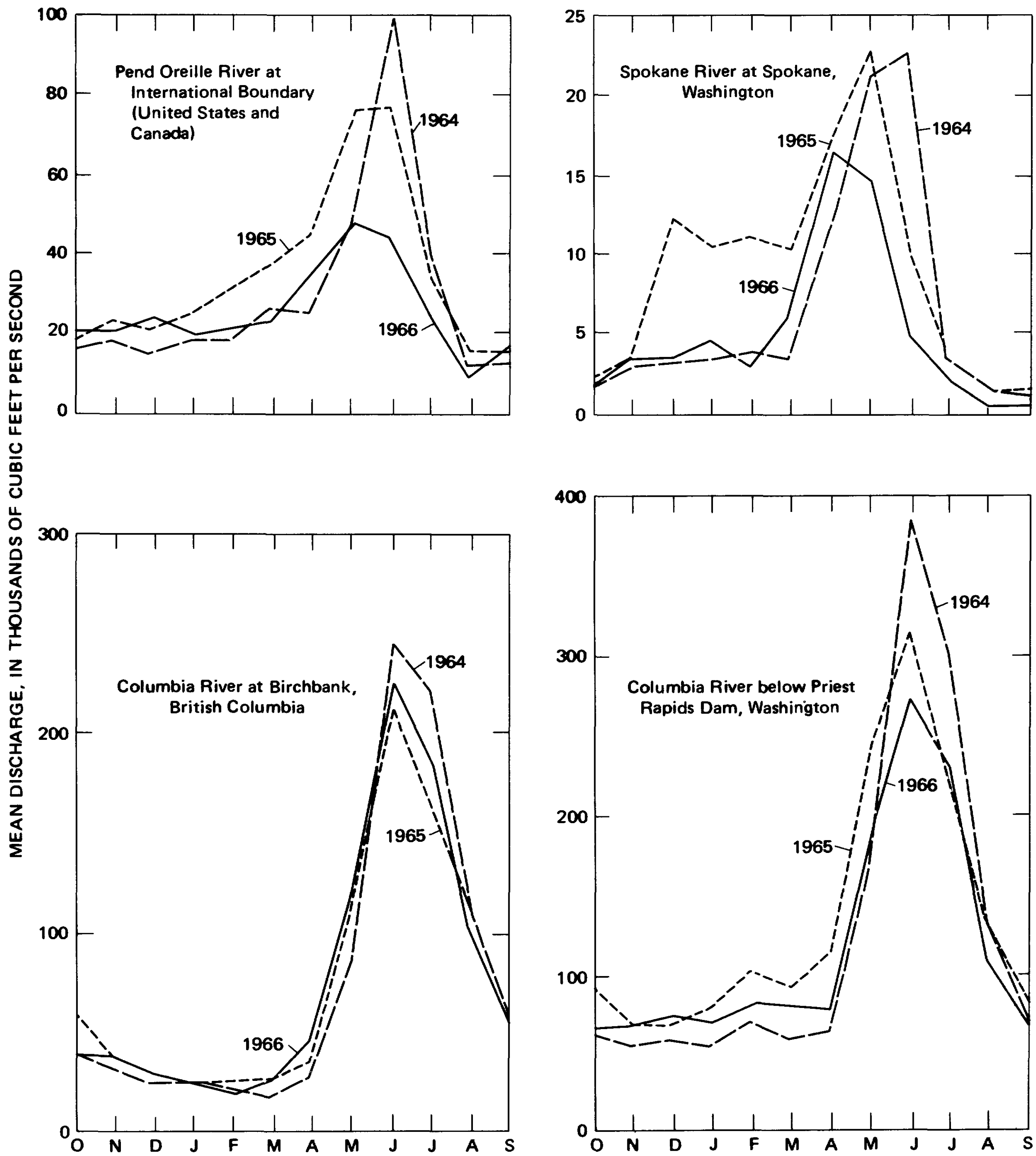


FIGURE 6.—Monthly water discharge for selected stations on the Columbia River and its tributaries.

zinc-65 and chromium-51 at Vancouver varied inversely with concentration of suspended sediment. Trend lines drawn through the data in figures 7 and 8 to indicate the approximate relations show that

$$C_p=\frac{K}{C_s}$$

where

C_p is the specific activity of a radionuclide, in picocuries per milligram of sediment;

C_s is the concentration of suspended sediment, in miligrams per liter of water; and

K is a coefficient of proportionality.

Time of year was introduced as a third variable (not shown in figs. 7 and 8) in a study of the relations between the specific activities of zinc-65 and chromium-51 and the concentration of suspended sediment. The results of this study indicated that time of year did not aid in explaining the variability in the specific activity

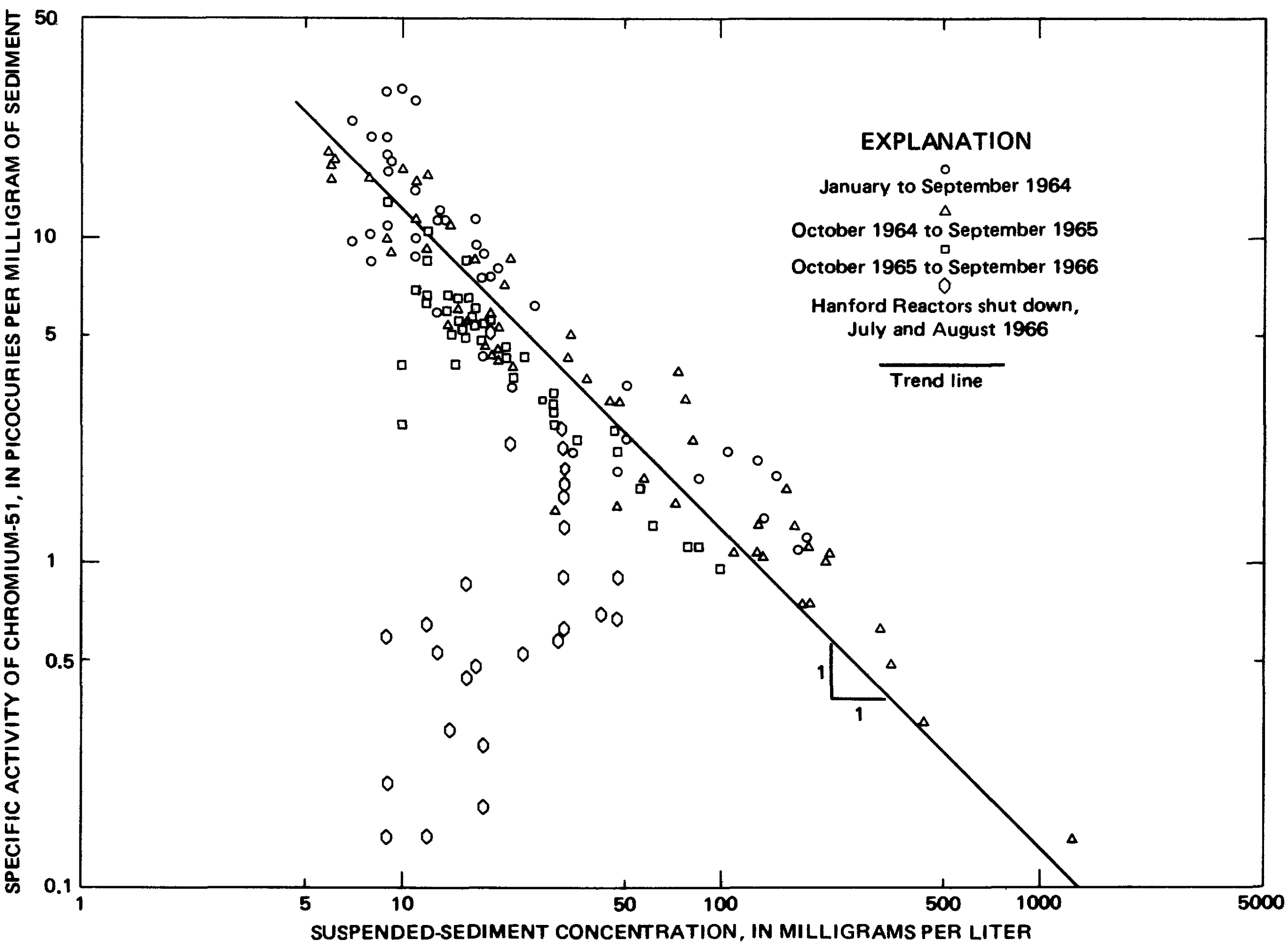


FIGURE 7.—Variation of specific activity of chromium-51 with suspended-sediment concentration of the Columbia River at Vancouver, Wash.

of chromium-51. However, specific activities of zinc-65 were generally higher during the periods from mid-March to early July and during the 1964–65 winter floods than specific activities during the periods from early July to mid-March. The separation of the zinc-65 data by time of year is shown in figure 8. The higher level of specific activity of zinc-65 during periods from mid-March through April at Vancouver may be caused partly by the high levels of concentration of zinc-65 at Pasco during these periods (fig. 5). During mid-March to April, any suspended sediment that was transported rather quickly from near Pasco downstream to Vancouver may contain high levels of zinc-65; also, more zinc-65 may be fixed to sediment in the river between Pasco and Vancouver than is fixed during other periods because of the higher level of dissolved zinc-65. The specific activity of zinc-65 at Vancouver may remain high from May to early July because much of the sediment transported by the stream is derived from the bed and banks of the river during this period of rises, peaks, and recessions in water and sediment discharges. This transported sediment may contain zinc-65 that was fixed during a previous period. Also, much of the zinc-65 fixed to suspended sediment in the upriver reaches of the river (from the reactors to Umatilla) probably is transported to Vancouver without deposition during the high-water periods. Transport of deposited radionuclides and a lesser traveltime of particulate radionuclides from upriver portions to Vancouver also may have contributed to the high level of specific activity of zinc-65 at Vancouver during the flood period in 1964–65.

The unique relation between specific activity of chromium-51 and concentration of suspended sediment at Vancouver—as contrasted with the relations for different time periods for zinc-65—is not fully explained. Deposition, transport, and traveltime of sediments should have affected transport of fixed zinc-65 and chromium-51 in the same manner. Differences in decay during temporary deposition of the radionuclides upstream from Vancouver may be a partial answer to the differences in the relations. The differences in the relations were more likely caused by the differences in

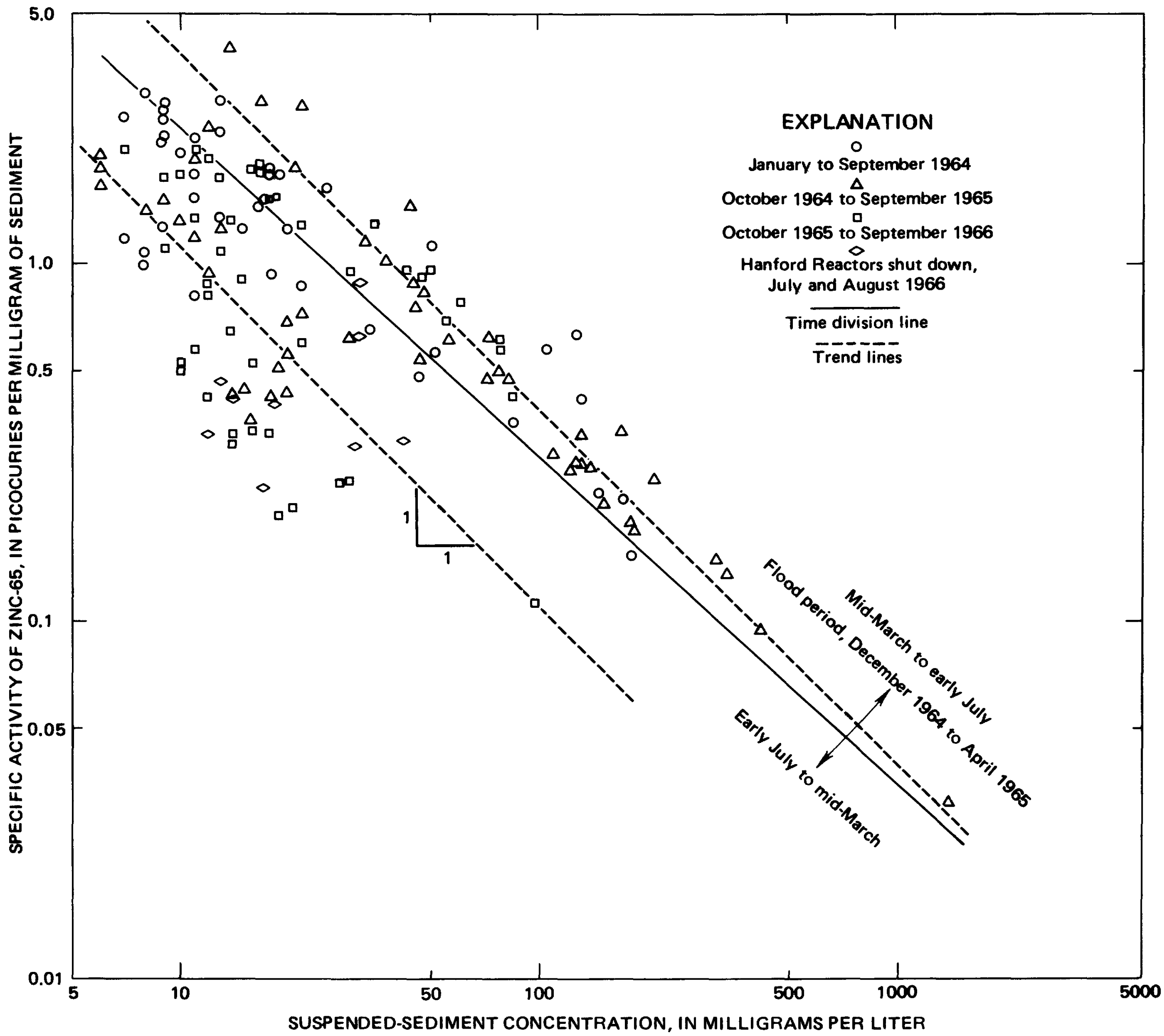


FIGURE 8.—Variation of specific activity of zinc-65 with suspended-sediment concentration of the Columbia River at Vancouver, Wash.

the physical-chemical characteristics of the generally anionic chromium-51 and the generally cationic zinc-65 and by differences in the reactions of zinc-65 and chromium-51 with Columbia River sediments.

The change in specific activities of zinc-65 or chromium-51 with changes in suspended-sediment concentration (slopes of trend lines in figs. 7 and 8) remained constant throughout the range in concentration of suspended sediment even though the particle size of the suspended sediment changed greatly. Suspended sediment at Vancouver was composed of fine particles at low concentrations and mixtures of fine and coarse particles at higher concentrations (Haushild and others, 1966). Sand (particle size greater than 0.0625 mm) content in suspended sediment ranged from 0 percent during low water discharges to as high as 50 percent during the peak water discharges of the annual floods (fig. 3). A large percentage of the suspended sediment during the 1964–65 winter floods was silt (particle size ranges from 0.004 to 0.0625 mm). Differences in particle-size distribution of the suspended sediment may have caused some of the variability in specific activities of zinc-65 or chromium-51 at particular concentrations of suspended sediment (Sayre and others, 1963). However, the general changes in specific activities of these radionuclides with changes in concentrations of suspended sediment were relatively independent of particle size of the sediment.

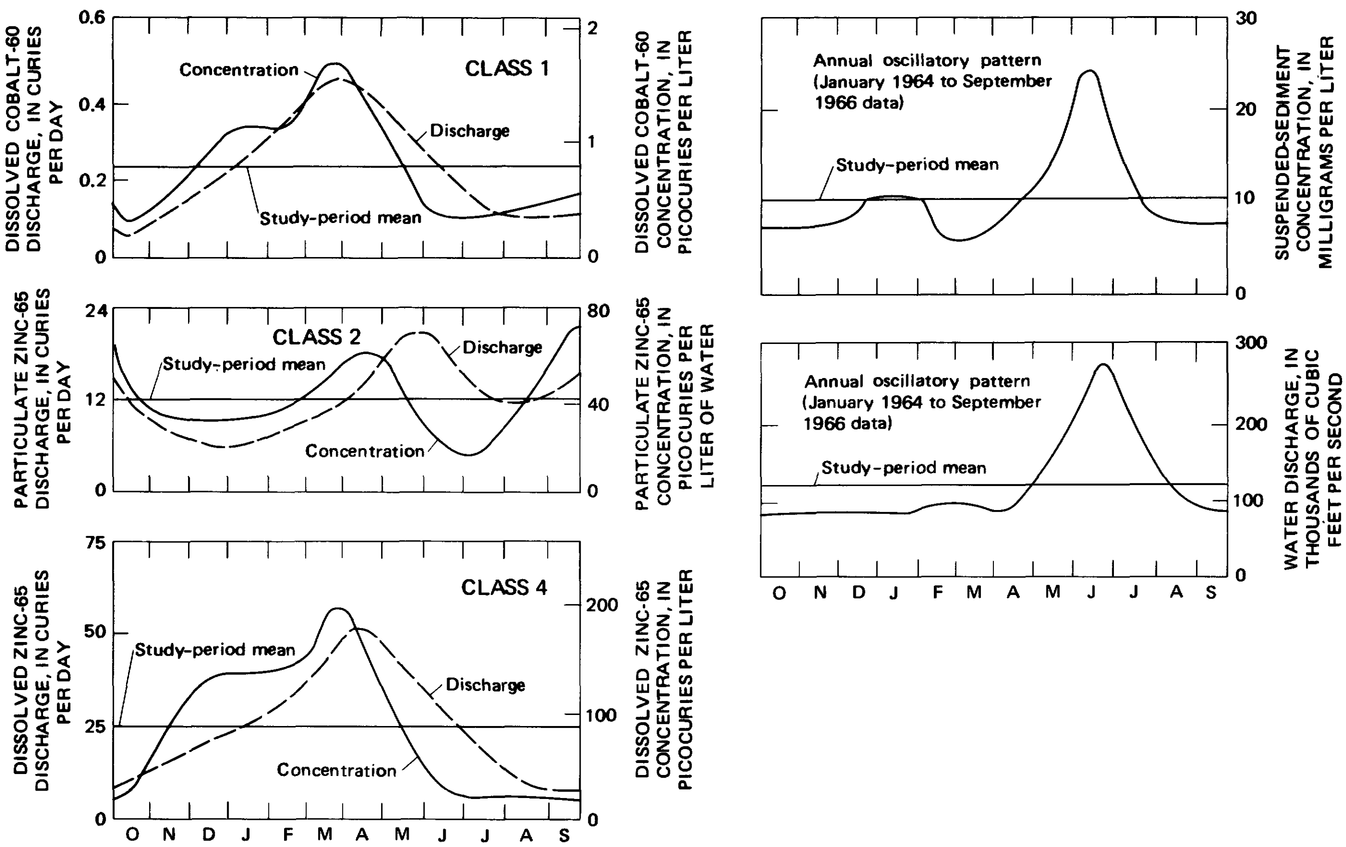


FIGURE 9.—Seasonal-variation patterns of water discharge and discharge and (or) concentration of suspended sediment and selected class-1, 2, and 4 radionuclides for the Columbia River at Pasco, Wash.

ANALYSIS OF CONTINUOUS TIME SERIES

Superposing the graphs of concentrations and discharges of a radionuclide for each year at Pasco or at Vancouver revealed a definite seasonal pattern of variation. Evidence of the seasonal variation in concentrations of dissolved and particulate radionuclides also can be seen from an inspection of the data in table 1. The seasonal patterns were determined by fitting curves through the median positions of the concentration and discharge data; the curves were fitted by using techniques described by Waugh (1943). Concentrations and discharges of radionuclides during the temporary shutdown of all reactors in July–August 1966 were excluded from this analysis. A plot of the deviations of individual observations from the seasonal curve show a decreasing trend with time for the distributions and concentrations of most radionuclides. The residual deviations from the seasonal discharges (corrected for trend) exhibit random variations for some radionuclide discharges and exhibit a relationship with water discharge for other radionuclides. The seasonal patterns and residual deviations in water discharges, in suspended-sediment concentrations, and in total sediment discharges from January 1964 to September 1966 were also determined for the Pasco and Vancouver stations.

TEMPORAL VARIATION

CLASSIFICATION OF RADIONUCLIDES

The seasonal variations in concentrations and discharges of particulate and dissolved radionuclides at Pasco and Vancouver were so similar for groups of radionuclides that they were used as the basis for classifying the radionuclides. The classification of dissolved and particulate radionuclides at Pasco and Vancouver is given in table 2. The unique patterns of seasonal

TABLE 2.—*Classification of dissolved and particulate radionuclides according to seasonal-variation patterns in their concentrations and discharges at Columbia River stations*

	Classification[1]			
	Pasco, Wash.		Vancouver, Wash.	
Radionuclide	Dissolved	Particulate	Dissolved	Particulate
Cobalt-58	1	4	3	4
Cobalt-60	1	2	2	5
Antimony-124	2	2	5	5
Zinc-65	4	2	5	5
Scandium-46	4	2	5	5
Manganese-54	4	2	4	5
Iron-59	4	3	2	5
Chromium-51	3	3	3	5

1 The patterns of seasonal variation for each class are shown in figures 9 and 10.

variation in concentration and discharge for each of the five classes of radionuclides are shown in figures 9 and 10. The seasonal-variation patterns—determined from

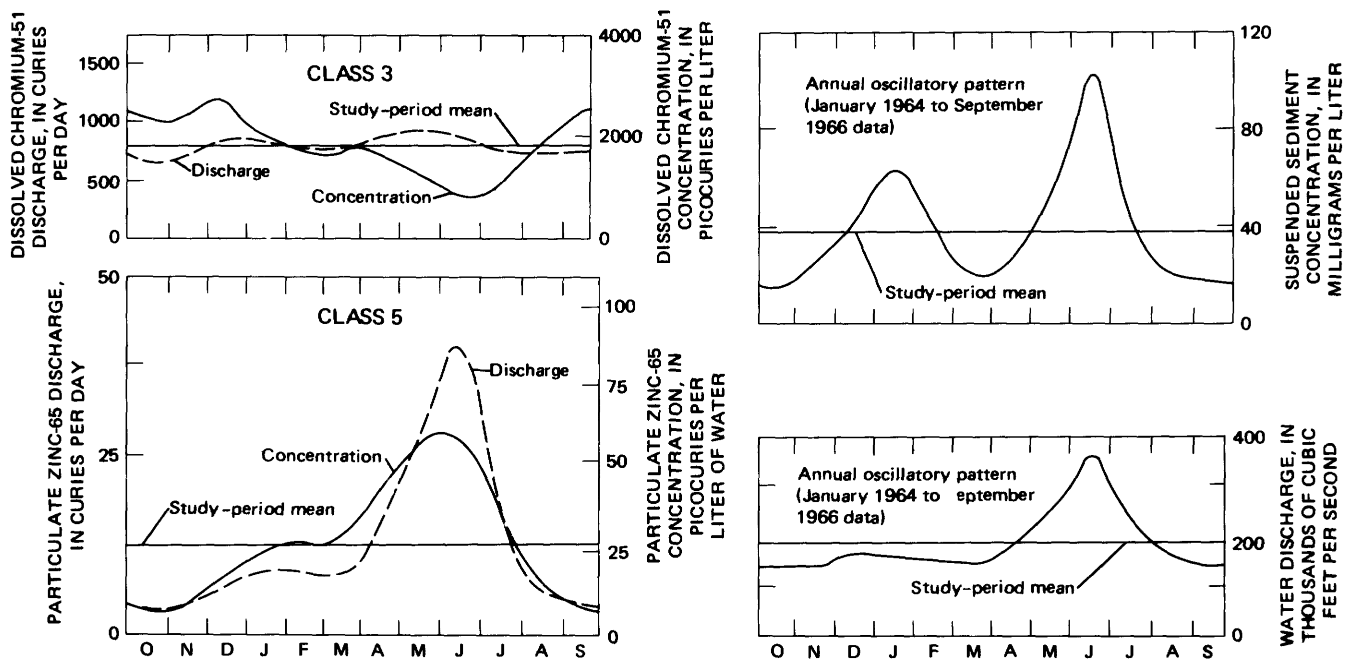


FIGURE 10.—Seasonal-variation patterns of water discharge and the discharge and (or) concentration of suspended sediment and selected class-3 and 5 radionuclides for the Columbia River at Vancouver, Wash.

study-period data—in water discharge and suspended-sediment concentration shown in figures 9 and 10 are indexes to the hydrodynamic and sedimentation characteristics of the Columbia River. They provide a comparison of the seasonal variation in their concentrations and (or) discharges with the variations in the concentration and discharge of each class of radionuclide.

SEASONAL VARIATION

Classes 1 and 4 are principally for dissolved radionuclides, and seasonal-variation patterns in their concentrations and discharges are nearly alike. The main difference is that concentrations of class-1 radionuclides were minimum in June and then increased slowly during July through November; whereas, concentrations of class-4 radionuclides remained low during July through October and increased rapidly during November and December. Concentrations of these classes were high during December–April, peaked in March, and decreased rapidly during the annual increase and peak in water discharge in May–June. Changes in discharges of class-1 and 4 radionuclides closely paralleled changes in their concentrations, except that the discharges continued to recede—because water discharge was still receding from its June peak—after the concentrations leveled out at their summer low values.

Concentrations of class-2 radionuclides have a dual-peak seasonal pattern with maximums in April and September and minimums in June–July and December. Because of the effect of the annual rise, peak, and recession of the water discharge in the Columbia River, the spring peak and subsequent summer minimum in discharge of class-2 radionuclides occurred later in the year (June and August–September) rather than coincident with the spring peak and its subsequent minimum in concentration (April and June–July). Also, the spring peak in discharge was greater than the fall peak; therefore, the relative magnitudes of peaks in discharge of class-2 radionuclides are the reverse of the relative magnitudes of their peaks in concentration.

The relative constancy of the discharge of class-3 radionuclides (fig. 10) is reflected in the approximately inverse variation of their concentration with water discharge. The reason for the constancy of discharge of chromium-51 was discussed previously. (See section on "Influence of Parent Materials.") The concentration of particulate iron in the treated cooling water probably was fairly constant. Richman (1960), in his discussion of water treatment for reactor cooling at the Hanford Reservation, reported that the turbidity concentrations in the treated cooling water generally were fairly constant (ranged from 0.003 to 0.005 mg/l) and that iron compounds constituted a substantial part of the suspended solids; therefore, it is not surprising that the concentration and discharge of particulate iron at Pasco followed the class-3 patterns of seasonal variation.

The seasonal-variation patterns for the discharges and concentrations of class-5 radionuclides (principally particulate radionuclides) closely agreed with the seasonal-variation pattern in water discharge at Vancouver.

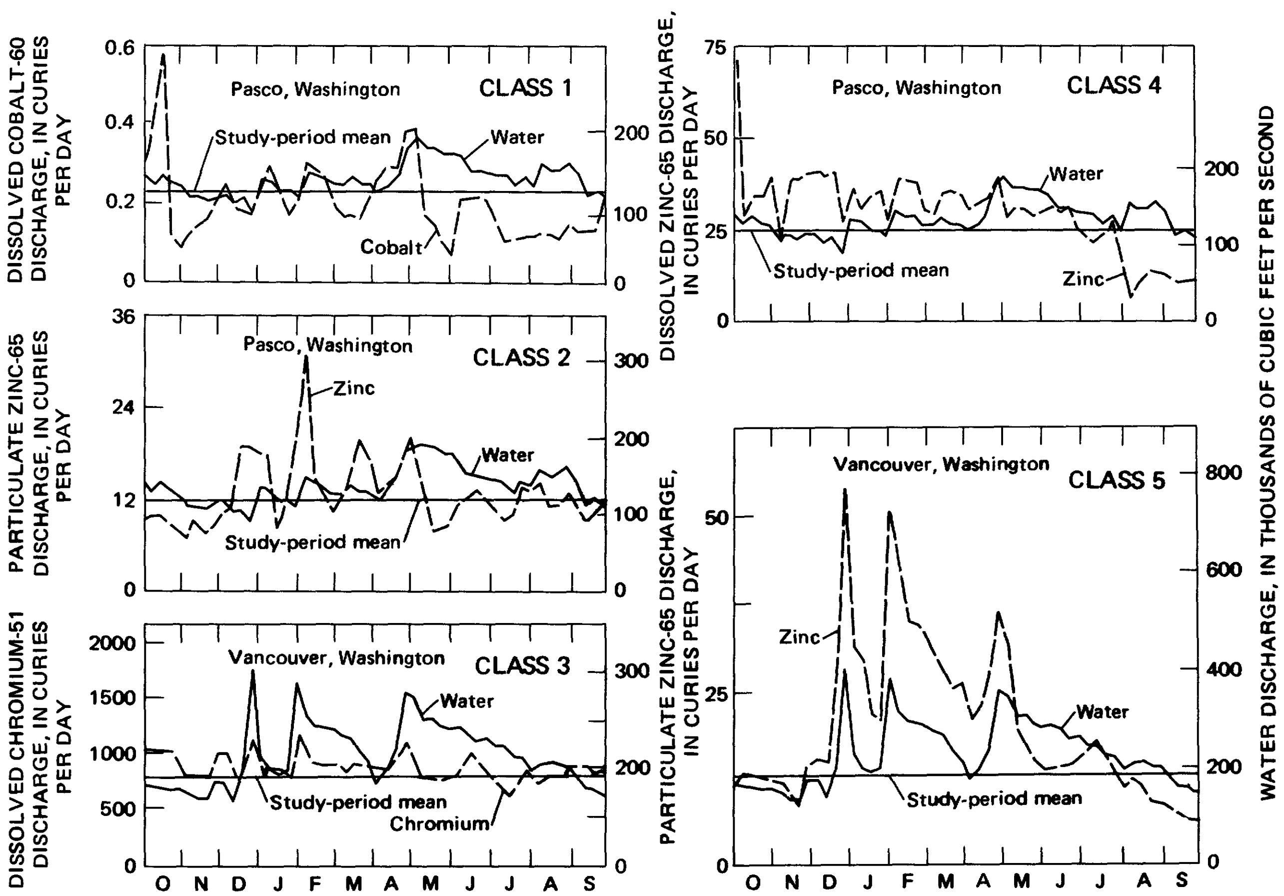


FIGURE 11.—Residual oscillations for the 1965 water year of water discharges and the discharges of selected class-1 to 5 radionuclides for the Columbia River at Pasco and Vancouver, Wash.

RESIDUAL OSCILLATIONS

Residual discharges are the departures of observed weekly discharges from the seasonal weekly discharges that were determined from the time-series analysis. The oscillations of the residual discharges (fig. 11) indicated a relative highness or lowness in observed discharges for a particular time of year and the duration of the periods when discharges were relatively high or low. The seasonal variations in radionuclide discharges were determined from an analysis of continuous time series of weekly discharges observed during a period of less than 3 years. Because of the short period of observation, rather high or low residual discharges and rather long periods of residual discharges remaining relatively high or low probably would be accepted as occurring by chance at some credible level of confidence. However, some of the apparently unusually high or low discharges and relatively long periods of such discharges remaining high or low for radionuclides in classes 1, 2, 3, and 4 may have resulted from unusually high or low concentrations, or from the persistence in concentrations to remain high or low, of the parent materials in Columbia River water at the reactors. Variations in treatment of Columbia River water for cooling the reactors and in the extent of cleaning of film and incrustations from process tubes and fuel-element surfaces of the reactor cooling system were other possible causes of "abnormal" discharges of radionuclides in classes 1–4. The dependency of the discharges of class-5 radionuclides on water discharge, which has been shown previously by the similarities in the seasonal-variation patterns of these discharges, was emphasized by the synchronism shown in figure 11 between oscillations of the residual discharges of particulate zinc-65 and the water at Vancouver. The data for the 1965 water year presented in figure 11 provide evidence that the variations in residual discharges for radionuclides in classes 1–4 generally were not related to the variations in residual water discharges, however, variations for class-3 radionuclides were weakly related.

TREND

The discharges of many dissolved and particulate radionuclides consistently decreased at a generally uniform rate during the period January 1964 to September 1966. Exceptions were discharges of dissolved antimony-124 and particulate zinc-65 at Pasco and Vancouver,

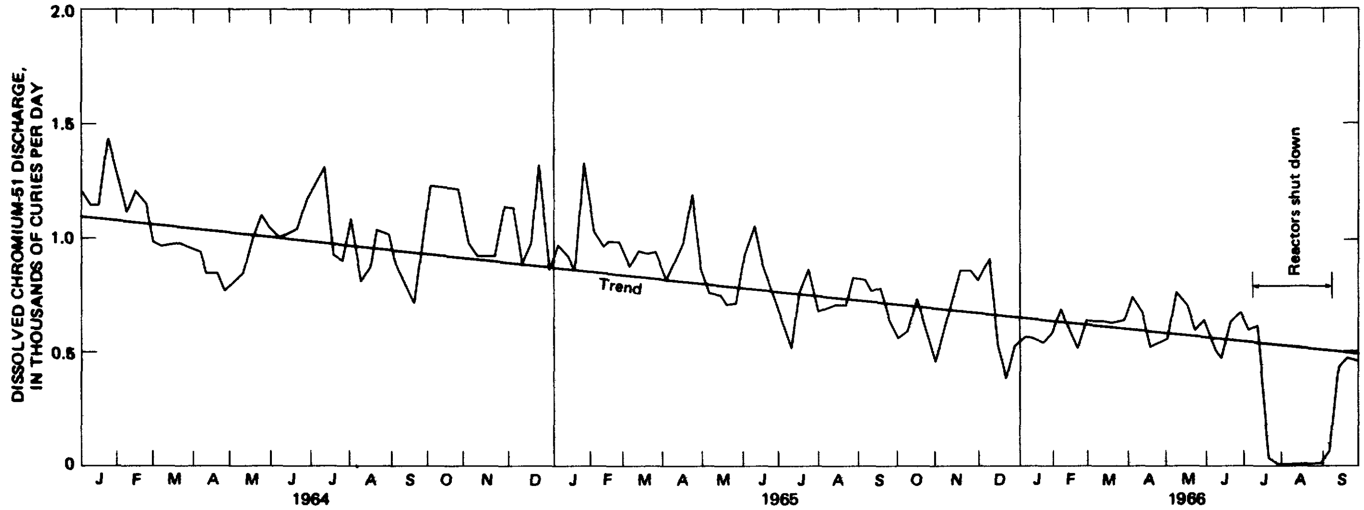


FIGURE 12.—The residual discharges of dissolved chromium-51 for the Columbia River at Vancouver, Wash. Notice the decreasing trend in discharges of radionuclides during the study period.

dissolved iron-59 at Pasco, and dissolved cobalt-58 at Vancouver; consistent decreases or increases in these discharges of radionuclides during the study period were not apparent. The number of operating reactors decreased from nine to six during the period from late December 1964 to early June 1965. The lesser number of operating reactors probably caused the decreasing trends noted in the discharges of many radionuclides from January 1965 to September 1966. Improvements and changes in operating procedures for the reactors may have caused the decreasing trend noted in the discharges of many dissolved and particulate radionuclides during 1964. Hall (1960) and Silker (1963) described programs for reducing radionuclide production rates by (1) increasing the efficiency of removal of materials from the water during treatment, and (2) reducing residence time of the dissolved and particulate materials in the reactors. The general decreasing trend during the study period in discharges of many dissolved and particulate radionuclides is exemplified by the graph shown in figure 12 of residual discharges of dissolved chromium-51 at Vancouver.

TOTAL DISCHARGES

The total discharge of a radionuclide at a river station is composed of the discharges of the radionuclide in the dissolved and particulate forms. Total discharges of radionuclides and the percentages that dissolved discharges were of the total discharges at Pasco, Umatilla, and Vancouver are given in tables 3–15.

Percentage dissolved (the percentage of the total discharge of a radionuclide that was discharged in the dissolved state) varied with type of radionuclide, with time (at a station), and in space (between the stations). The variations in percentages dissolved may be better evaluated from the summary given in table 16 than from the data given in tables 3–15.

Nelson (in Pearce and Green, 1966, p. 89–92) reported that the general chemical form of chromium-51 in the Columbia River is anionic; whereas, antimony-124 is either anionic or uncharged (ions are not retained in either cationic-exchange or anionic-exchange resin beds). Only small percentages of these radionuclides become fixed to sediments, and they occur mostly in the dissolved state in the Columbia River. Nelson reported that the other radionuclides in table 16 are dominantly cationic; they are transported more in the particulate form than in the dissolved state. A general ranking of selected radionuclides in descending order of percentage dissolved is antimony-124, chromium-51, cobalt-58, zinc-65, manganese-54, cobalt-60, scandium-46, and iron-59. The percentages dissolved for the last four radionuclides in the above ranking were so similar at Vancouver (table 16) that they can be ranked as a single group at this station.

The magnitudes of the seasonal variations in the percentages dissolved during the period May 1965 to June 1966 are the differences between the maximums and minimums shown in table 16. These differences—generally different for each radionuclide—ranged from less than 10 percent for chromium-51 and antimony-124 at all river stations to greater than 60 percent for zinc-65 at Pasco and Umatilla and manganese-54 at Pasco. There were definite periods of 3–4 months' extent when extremes in the percentage dissolved occurred for most radionuclides at each river station. The exceptions are: (1) antimony-124 and chromium-51, percentages dissolved were minimum during one 3–4 month period (see table 16) and fluctuated about an average maximum during the remainder of the year; (2) because of somewhat erratic fluctuations, the only period that could be determined was when the percentage dissolved for iron-59 at Pasco and Umatilla was minimum; and (3) percentage dissolved for manganese-54 was generally lowest from May to November (7 months) at Vancouver.

During the period May 1965 through June 1966, the extremes in percentages dissolved for a radionuclide generally occurred in accordance with the seasonal variations in its dissolved and particulate discharges. At Pasco, the percentages dissolved for zinc-65, scandium-46, cobalt-60, iron-59, and manganese-54 were maximum during the winter months when their dissolved discharges were increasing (classes 1 and 4) and their particulate discharges were either at minimum levels or low (class 2) or nearly constant (class 3). The occurrence of maximums in percentages dissolved, for the radionuclides at Pasco, apparently influenced the occurrence of maximums in their percentage dissolved at Vancouver even though the classifications of the dissolved and particulate forms of the radionuclides at Vancouver were different from those at Pasco. Maximums in percentage dissolved for the radionuclides generally occurred in the winter at all stations. The percentage of dissolved cobalt-58 at Pasco also was maximum during the winter; this fact indicated that the increase in its dissolved discharge (class 1) was greater than the increase in its particulate discharge (class 4). However, the maximum in percentage dissolved for cobalt-58 occurred at Vancouver in September–November when its particulate discharge (class 4) was at minimum levels relative to its dissolved discharge (class 3). The minimums in percentages dissolved for the radionuclides generally occurred when their particulate discharges were relatively high; this happened in late summer to early fall for class-2 particulate radionuclides at Pasco and during the high water discharge period, May–July, for class-5 particulate radionuclides at Vancouver. Percentages dissolved for iron-59 at Pasco was minimum from August to November when its dissolved discharge (class 4) was low relative to its particulate discharge (class 3).

During May 1965 to June 1966, changes between river stations of 5 percent or less in the percentage dissolved for the radionuclides may have been of lesser magnitude than the erors in their total discharges at the stations. Therefore, the changes in the percentages dissolved for chromium-51, antimony-124, iron-59, and scandium-46 in the downstream direction (table 16) may have been apparent changes instead of real changes. The decreases in the downstream direction in the percentages dissolved for the other radionuclides were indicative of a transfer of dissolved radionuclides to particulate radionuclides by fixation to sediments and other matter transported by the river. The percentages dissolved decreased by about 30 percent between Pasco and Vancouver for zinc-65, cobalt-60, and manganese-54, and about 11 percent for cobalt-58. For these radionuclides, the decrease in percentages dissolved between Pasco and Umatilla about equaled the decrease in percentages dissolved between Umatilla and Vancouver. (See table 16.) The equality of the decrease for these two unequal-length reaches of the Columbia River probably reflects the effects in McNary Reservoir of (1) the relatively low velocities of water on transport of radionuclides and (2) the availability of sediments from the Snake and Walla Walla Rivers on fixation, and subsequent deposition, of dissolved radionuclides by sediments.

DISPOSITION OF RADIONUCLIDE DISCHARGES MEASURED AT PASCO

The disposition of the radionuclides discharged at Pasco in the Pasco-Vancouver reach was evaluated by use of the continuity and the conservation-of-mass principles. An equation that relates these principles to radionuclide disposition states that the quantity of a radionuclide added to, or depleted from, storage, ΔS, in the Pasco-Vancouver reach during a time interval, Δt, equals the difference in discharge of the radionuclide at Pasco, I, and discharge of the radionuclide at Vancouver, O, during Δt. The discharges of the radionuclides at Pasco have to be corrected for decay during their residence time. Residence time is defined as the time the radionuclides spend in the Pasco-Vancouver reach during Δt.

$$I-O=\Delta S \tag{1}$$

Expressing equation 1 in relation to the input discharge at Pasco, I, gives

$$\frac{I}{I}-\frac{O}{I}=\frac{\Delta S}{I} \tag{2}$$

or, in percent,

$$100-\frac{(100)\,O}{I}=\frac{100(\Delta S)}{I} \tag{3}$$

Because of an uncertainty about actual residence times in the Pasco-Vancouver reach of radionuclides discharged at Pasco, the disposition of radionuclides discharged at Pasco is first evaluated without correcting the Pasco discharges for their decay in the reach during Δt. This evaluation results in an incremental storage $(+\Delta S)$ that will be too large or an incremental depletion $(-\Delta S)$ that will be too small. The effects of decay subsequently are qualitatively evaluated. (See following paragraphs.)

The average monthly total discharges of eight radionuclides during the period January 1964 to June 1966 at Pasco and Vancouver were used in equation 3 to

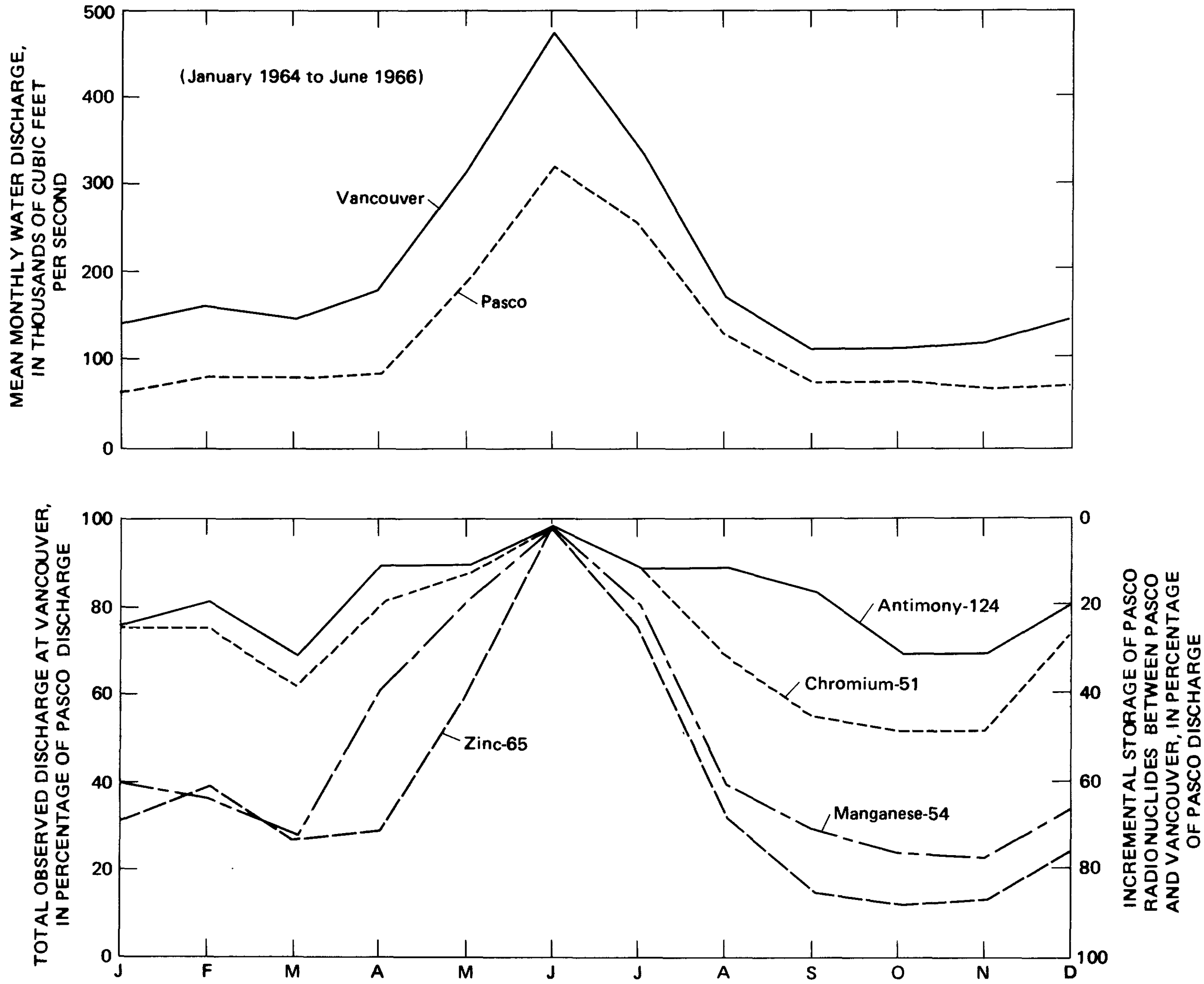


FIGURE 13.—Relations between the water discharge in the Columbia River and the transport, decay, and storage of radionuclides in the Pasco-Vancouver reach.

evaluate (1) the average monthly discharge of each radionuclide at Vancouver relative to its monthly discharge at Pasco, and (2) the quantity added to, or depleted from, storage of each radionuclide in the Pasco-Vancouver reach during each month relative to the monthly discharge of the radionuclide at Pasco. Plots of the results of these evaluations for selected radionuclides are shown in the lower graph of figure 13. In this figure, the graphs referred to the left-side ordinate represent the relative discharges of the radionuclides at Vancouver; the graphs referred to the right-side ordinate represent the incremental storage of the input radionuclides in the reach between the stations relative to the input (Pasco) discharges. Data from cobalt-60 closely agreed with the data shown for manganese-54 in figure 13. Data for iron-59, cobalt-58, and scandium-46 generally agreed with the zinc-65 data from December through August, except that the relative discharges at Vancouver of these radionuclides were less than the relative discharge for zinc-65 during the September-November period.

The transport, decay, and storage of radionuclides in the Pasco-Vancouver reach depends on the hydrodynamic and sedimentation characteristics of the Columbia River. Changes in the output discharges of radionuclides at Vancouver relative to the input discharges at Pasco closely followed the changes in water discharge of the Columbia River (compare lower graphs with upper graphs in fig. 13). Discharges of radionuclides at Vancouver were high, and incremental storages in the reach between Pasco and Vancouver were low during high water discharge in the Columbia River. During high water discharge periods, water velocities are high; previously deposited sediment is transported;

and deposition rates of transported sediment are low. Therefore, transported radionuclides spent less time and decayed less in the reach, deposition rates of transported radionuclides were lower, more of the previously deposited radionuclides were transported, and discharges of radionuclides at Vancouver were higher during periods of high water discharge than during periods of low water discharge.

The radionuclides discharged at Pasco spent variable amounts of time in the Pasco-Vancouver reach. If the time they spent, say T, during the time interval, Δt, is known, their decay, D, during T can be evaluated from

$$D=I\ (1-e^{-\lambda T}) \tag{4}$$

In equation 4, e is the natural logarithm base and λ is a decay coefficient, which equals 1n 2/half life, for a specific radionuclide. The time, T, could vary from the flow time of water between Pasco and Vancouver to longer than the time interval, Δt, used in evaluating equation 2. However, if T were longer than Δt, T equal to Δt should be used in equation 4, because the decay of the input radionuclides for their residence time in the reach during the time interval of evaluation is required. From a study of the flow times of the Columbia River by radioactive tracers, Nelson, Perkins, and Haushild (1966) estimated a flow time of water between Pasco and Vancouver of about 7 days during high water discharge and of about 14 days during low water discharge. Because monthly discharges of radionuclides at Pasco and Vancouver were used in evaluating radionuclide disposition in the Pasco-Vancouver reach, Δt, varies from 28 to 31 days and averages 30 days. The values of D relative to the input radionuclide discharge at Pasco equaled

$$\frac{D}{I}=(1-e^{-\lambda T}) \tag{5}$$

and are given in table 17 for T equal to 7, 14, and 30 days.

TABLE 17.—*Decay losses of selected radionuclides during periods of 7, 14, and 30 days*

Radionuclide	Half life (days)	Loss, in percent, for decay 7 days	14 days	30 days
Antimony-124	60	8	15	29
Chromium-51	28	16	30	53
Cobalt-58	71	7	12	25
Zinc-65	245	2	4	8
Manganese-54	314	1.5	3	6
Cobalt-60	1,920	.2	.5	1
Scandium-46	84	6	11	22
Iron-59	45	10	19	47

Comparison of the data in table 17 with the data in figure 13 provides general estimates of the relative role of decay in the reductions of discharges of Pasco radionuclides between Pasco and Vancouver. Most of the time, decay of the chromium-51 and antimony-124 discharged at Pasco during their transport through the Pasco-Vancouver reach probably was of the same magnitude as the difference between their discharges at Pasco and Vancouver. Only during the fall season did much of the input discharge of chromium-51 and antimony-124 at Pasco go into storage in the Pasco-Vancouver reach; little or none of the input discharge of these radionuclides was stored in the reach during winter, early spring, and late summer; and these radionuclides were removed from storage in the reach during the high water discharge periods in late spring and early summer. The proportion of the input discharges at Pasco of cobalt-58, zinc-65, maganese-54, cobalt-60, scandium-46, and iron-59 going into storage in the Pasco-Vancouver reach during most of the year was relatively high. Only during the high water discharges in June was removal of radionuclides from storage in the reach necessary to supply some of the discharges of these radionuclides at Vancouver.

SUMMARY AND CONCLUSIONS

Eight radionuclides in the Columbia River originated principally in the cooling-water effluent of the Hanford Reservation reactors; discharges averaged 9,190 curies per week at Pasco, Wash., and 6,630 curies per week at Vancouver, Wash., during the period January 1964 to September 1966. The approximate order of radionuclide abundance and the average percentage of their discharge (in the total radionuclide discharge at these river stations) were chromium-51 (96.4), zinc-65 (2.5), scandium-46 (0.5), iron-59 (0.2), antimony-124 (>0.1), manganese-54 (>0.1), cobalt-58 (<0.1), and cobalt-60 (<0.1).

The concentrations of dissolved and particulate radionuclides in the Columbia River at Pasco and Vancouver, Wash., varied seasonally in five separate patterns. These patterns were used as a basis for classifying the dissolved and particulate radionuclides. The seasonal variations in concentrations of radionuclides in classes 1, 2, and 4 were found to depend on the seasonal variations in concentrations of dissolved parent materials in the river at the reactors. The pattern of seasonal variation in concentrations of class-3 radionuclides exhibited the characteristics of dilution of a source of constant strength by the river discharge. The constancy in the supply of class-3 radionuclides resulted from either the addition of the parent material to the treated cooling water as a corrosion inhibitor (chromium-51 from sodium dichromate) or the parent material was the principal constituent (iron) of the fairly constant quantity of suspended solids in the treated cooling water. Changes in concentrations of class-5 radionuclides varied in synchronism with changes in water discharge. A correlation between the seasonal variations in the concentrations of some dissolved and particulate radionuclides and water discharge was only noted at Vancouver, which is about 270 miles downstream of the reactors. The seasonal variations in concentrations of class-5 radionuclides probably resulted from the inexactly known and nonpredictable interactions and (or) relations among decay, dispersion, fixation, dilution, and storage of radionuclides between the reactors and downstream locations. The seasonal variation of class-5 radionuclides indicated that variability in concentrations of most particulate radionuclides and a few dissolved radionuclides at stations located far downstream tend to lose their dependency on the strength and variability of the source and become dependent upon the variability in the discharge of water.

The seasonal variations in the concentrations of the dissolved and particulate radionuclides were evaluated according to their classification. Concentrations of class-1 radionuclides (dissolved cobalt-58 and cobalt-60 at Pasco) and class-4 radionuclides (dissolved zinc-65, scandium-46, and iron-59 at Pasco; dissolved manganese-54 at Pasco and Vancouver; and particulate cobalt-58 at Pasco and Vancouver) were high during December through April and peaked in March. Concentrations of class-1 and 4 radionuclides decreased rapidly during the annual increase in water discharge in May and June. Concentrations of class-1 radionuclides were minimum in June, and concentrations of class-4 radionuclides remained at low levels during June through October. Concentrations of class-2 radionuclides (particulate cobalt-60, antimony-124, zinc-65, scandium-46, manganese-54, and dissolved antimony-124 at Pasco, and dissolved cobalt-60 and iron-59 at Vancouver) had a dual-peak seasonal pattern with the maximums occurring in April and September and the minimums occurring in June-July and December. The concentrations of class-3 radionuclides (dissolved chromium-51 and particulate iron-59 and chromium-51 at Pasco, and dissolved cobalt-58 and chromium-51 at Vancouver) were at generally high levels during low-water discharge periods and at generally low levels during high-water discharge periods. The maximum concentrations of class-5 radionuclides(dissolved antimony-124, zinc-65, and scandium-46, and particulate cobalt-60, antimony-124, zinc-65, scandium-46, manganese-54, iron-59, and chromium-51 at Vancouver) coincided with the annual maximum in water discharge (June), and minimum concertations usually coincided with the minimum water discharges of September and October.

The specific activities of zinc-65 and chromium-51 at Vancouver varied inversely with concentration of suspended sediment in the river. Trend lines indicated that the relations between logarithms of the specific activities of these radionuclides and concentration of suspended sediment were probably linear and had a slope of -1. Some of the variability in specific activities of zinc-65 and chromium-51 at particular concentrations of the suspended sediment may have been caused by changes in particle size of the suspended sediment. However, the general relations between specific activities of these radionuclides and suspended-sediment concentration were not affected by the particle size of the suspended sediment. Seasonal variation in concentrations of dissolved and particulate zinc-65 in reaches of the river upstream of Vancouver and seasonal differences in deposition, transport, and travel time of sediments in the river were postulated as possible causes of a time-of-year dependency for the zinc-65 relation.

The seasonal variation in discharge of each dissolved or particulate radionuclide depended on the seasonal variations in its concentration and in the water discharge at the river stations. Concentration of the radionuclide naturally was the main controlling factor during the relatively constant and low-water discharge periods from September through April. The annual rise, peak, and recession of water discharge (May through August period) caused shifts in timing of peaks in discharges of radionuclides in classes 1, 2, and 4 relative to peaks in their concentrations, and also caused the dual peaks in discharges of class-2 radionuclides to have relative magnitudes opposite to the relative magnitudes of the dual peaks in their concentrations. Discharges of class-3 radionuclides were relatively constant. The pattern of seasonal discharges of class-5 radionuclides closely followed the pattern of seasonal discharge of water at Vancouver.

Discharges of dissolved antimony-124 and iron-59, and particulate zinc-65 at Pasco and discharges of dissolved antimony-124 and cobalt-58, and particulate zinc-65 at Vancouver did not show a definite increasing nor decreasing trend during the study period. The trend in the discharges of other dissolved and particulate radionuclides was to consistently decrease at a generally uniform rate. Improvements and changes in operating procedures for the reactors and the shutdown of three reactors during the study period caused the decreasing trends in radionuclide discharges. The total discharge of many radionuclides decreased by as much as 60 percent during the study period and consistently decreased slightly more at Vancouver than at Pasco.

The temporal and spatial variations in percentage dissolved (the percentage of dissolved discharge, in the total discharge of a radionuclide) depended greatly on the chemical form of the radionuclides in the river. The generally anionic chromium-51 and the anionic plus uncharged antimony-124 were transported mostly (averaged 93 and 96 percent, respectively) in the dissolved state; seasonal changes in percentages dissolved for these radionuclides were about 6 percent. The small changes between Pasco, Umatilla, and Vancouver in percentage dissolved for chromium-51 and antimony-124 may have been apparent rather than real, because the changes probably are less than the errors in their discharges at the stations. A ranking of the generally cationic radionuclides in descending order of percentage dissolved is cobalt-58, zinc-65, manganese-54, cobalt-60, scandium-46, and iron-59. The temporal variation in percentage dissolved was different for each of these generally cationic radionuclides. The differences between annual maximums and minimums in percentages dissolved ranged from about 10 percent for cobalt-60 at Vancouver to greater than 60 percent for zinc-65 at Pasco and Umatilla, and manganese-54 at Pasco. The maximums and minimums in percentages dissolved for most of the cationic radionuclides occurred during periods that related directly to the seasonal variations in their dissolved and particulate discharges. The percentage dissolved for iron-59 apparently remained about constant in the river between Pasco and Vancouver; some dissolved scandium-46 apparently became fixed to particulate matter during downstream transport. The percentages dissolved decreased between Pasco and Vancouver by about 30 percent for zinc-65, cobalt-60, and manganese-54, and by about 11 percent for cobalt-58. For these radionuclides, the decreases in percentage dissolved between Pasco and Umatilla about equaled the decreases between Umatilla and Vancouver. These equal decreases in percentages dissolved for unequal-length reaches of the river were attributed to the availability of sediments from the Snake and Walla Walla Rivers and the relatively low river velocities in McNary Reservoir.

When water and sediment discharges of the river were high, discharge of radionuclides at Vancouver was high, quantities of transported radionuclides going into storage between Pasco and Vancouver were low, and decay of the transported radionuclides in the Pasco-Vancouver reach was low. The factors causing these high discharges, low storages, and low decay of Columbia River radionuclides were the high water velocities, transport of previously deposited sediment, and low deposition rates of transported sediment during the periods of high water discharge. The effects of hydrodynamic and sedimentation characteristics of the river during low-water discharge periods on the disposition of Pasco radionuclides were almost the opposite of those during high-water discharge periods. Therefore, the discharges of radionuclides at Vancouver relative to their discharge at Pasco varied seasonally in close agreement with the seasonal variation in water discharge of the Columbia River. Incremental storage of a radionuclide in the Pasco-Vancouver reach was the excess of the difference between discharges of the radionuclide at Pasco and Vancouver over estimated decay of the radionuclide during its residency in the reach. A qualitative evaluation of the incremental storage of radionuclides discharged at Pasco indicated that only during the fall did much chromium-51 and antimony-124 go into storage in the Pasco-Vancouver reach. During the remainder of the year, differences between discharges of these radionuclides at Pasco and Vancouver were either about in equilibrium with, or less than, the estimated decay of the Pasco radionuclides during their travel between the stations. Depletion from storage of these radionuclides was necessary during much of the year to supply part of the discharge at Vancouver. Only during the high water discharges in June was depletion from storage necessary to supply part of the discharge at Vancouver of the generally cationic zinc-65, cobalt-58, cobalt-60, scandium-46, manganese-54, and iron-59.

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BASIC DATA

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]

[In picocuries per liter of water]

Date	Chromium-51 Solute	Chromium-51 Particulate	Zinc-65 Solute	Zinc-65 Particulate	Scandium-46 Solute	Scandium-46 Particulate	Antimony-124 Solute	Antimony-124 Particulate	Cobalt-58 Solute	Cobalt-58 Particulate	Cobalt-60 Solute	Cobalt-60 Particulate
PASCO, WASH.												
1964												
Jan. 13	10,900	631	211	17.0	10.3	22.2	6.76	0.40	1.63	1.18	1.66	0.46
Feb. 11	7,070	608	152	58.1	5.27	38.6	3.06	.69	1.02	1.96	1.14	2.00
Feb. 26	6,850	532	67.2	26.4	4.29	17.7	2.46	<.36	1.39	4.91	1.17	.53
Mar. 10	9,640	3,040[a]	211	108[a]	7.30	100[a]	4.26	1.27[a]	1.68	4.40[a]	1.92	2.67[a]
Mar. 24	8,650	617	205	56.8	9.10	41.5	5.05	.28	3.76	2.03	1.81	1.38
Apr. 7	14,400	838	240	64.0	8.78	59.0	7.97	.45	3.03	2.36	1.63	1.52
Apr. 21	7,700	946	177	59.0	5.72	45.9	6.62	.61	2.44	3.58	1.45	1.65
May 5	5,050	725	134	108	4.95	47.3	4.95	.63	2.09	2.35	1.19	2.52
May 22	2,640	214	75.2	51.8	1.80	20.3	3.21	2.21[a]	.53	1.46	.50	2.39
May 27	2,320	152	71.2	35.8	1.86	13.5	3.28	<.13	.43	.66	.50	1.49
June 5	1,450	119	44.0	29.1	1.39	9.14	2.45	.24	.18	1.34	.18	1.12
June 12	1,440	234	39.2	69.8	1.34	12.3	2.02	.19	.37	.79	.20	2.05
June 19	1,230	106	26.0	17.2	1.01	6.67	1.32	.23	.43	.45	.17	.91
June 26	1,280	150	31.5	15.2	1.19	7.07	1.67	<.13	.48	.51	.27	.75
July 3	1,460	91.0	34.7	10.1	1.53	6.26	1.61	<.21	.55	.29	.26	.32
July 9	1,500	1,090[a]	39.0	23.8	2.27	24.3[a]	1.61	.56	.72	1.30	.22	.65
July 16	1,110	85.1	29.2	11.6	1.58	7.43	1.74	<.12	.37	.66	.18	.44
July 24	1,380	102	28.8	12.4	1.65	7.84	1.34	.14	.58	1.14	.22	.38
July 31	2,400	191	41.6	18.5	1.89	12.3	1.90	<.10	.71	2.53	.24	.60
Aug. 7	2,980	236	45.0	30.6	2.27	16.1	2.95	.35	1.06	1.89	.32	.81
Aug. 14	4,500	259	41.9	37.2	2.72	15.8	2.72	.18	1.37	3.17	.36	1.07
Aug. 21	4,770	784	42.6	35.6	2.52	17.7	2.86	.23	1.59	3.89	.45	1.05
Aug. 28	5,360	233	39.8	27.3	2.00	14.3	2.67	.23	1.86	4.73	.32	1.17
Sept. 3	4,550	617	46.4	47.3	2.28	30.2	2.50	.45	1.93	7.43	.50	1.61
Sept. 11	6,980	443	42.5	54.0	2.75	24.3	3.56	.27	2.07	6.04	.55	1.63
Sept. 18	9,910	1,140	47.3	67.1	3.46	41.2	5.81	.31	2.17	4.64	.85	2.27
Sept. 25	8,060	482	75.7	63.5	3.36	25.7	4.64	.28	1.86	5.81	.54	2.00
Oct. 2	11,800	4,820[a]	148	113[a]	5.99	108[a]	6.76	1.66[a]	2.48	9.55[a]	.76	3.61[a]
Oct. 9	5,630	1,070	66.2	41.0	2.14	26.8	2.70	.56	.85	5.09	.30	1.46
Oct. 16	4,100	721	75.2	40.0	2.35	23.4	1.80	.30	1.58	8.15	.20	1.45
Oct. 23	5,090	428	90.1	34.3	3.05	21.3	2.79	.46	2.06	11.0	.34	1.75
Oct. 30	5,540	599	158	31.9	3.04	18.2	3.38	.18	2.89	12.5	.47	1.46
Nov. 6	6,980	536	129	26.6	3.32	17.4	3.76	.22	4.27	14.0	.55	1.26
Nov. 13	8,150	568	191	38.6	4.09	19.5	4.50	.30	7.34	20.1	.76	1.68
Nov. 20	8,740	505	192	26.6	4.64	17.9	4.73	.21	6.98	9.91	.92	1.11
Nov. 27	6,710	363	170	25.4	3.47	12.9	4.04	.09	5.99	8.56	.97	1.03
Dec. 4	9,320	486	206	25.9	3.83	16.8	4.05	.18	3.74	7.79	1.05	1.02
Dec. 11	7,790	1,380	223	34.7	4.95	28.9	5.45	.41	2.99	3.29	1.30	.96
Dec. 18	9,010	1,370	250	50.0	6.08	45.5	4.95	.74	3.06	2.94	1.41	1.12
Dec. 26	9,680	358	215	65.3	6.22	19.3	6.40	.25	2.68	.93	1.43	.56
1965												
Jan. 1	6,890	342	203	33.5	5.72	17.0	4.08	.08	1.91	1.47	1.41	.62
Jan. 8	5,140	1,920	147	45.9	5.41	60.4	3.20	1.57	1.86	1.30	1.08	1.31
Jan. 15	4,680	325	184	15.5	6.31	13.4	3.10	.09	2.40	.61	1.25	.39
Jan. 22	7,700	532	240	26.7	8.51	20.8	5.36	.20	2.86	.92	1.49	.45
Jan. 29	8,060	550	180	54.1	5.18	22.7	6.58	.27	4.82	1.31	1.49	.64
Feb. 5	7,690	1,600	210	94.6	6.94	68.2	7.57	1.17	2.75	1.71	1.35	.86
Feb. 12	3,270	393	207	41.7	4.95	19.2	6.53	.27	1.71	1.49	1.44	.90
Feb. 19	4,400	652	171	34.3	5.54	22.3	8.96	.77	1.61	.77	1.35	.81
Feb. 26	2,250	-------	215	35.6	5.41	23.9	8.06	<.05	1.44	1.04	1.35	-----
Mar. 5	3,060	487	191	33.5	5.59	25.4	7.03	.77	1.49	.41	1.53	.50
Mar. 12	4,930	356	250	47.7	6.04	17.9	10.5	.32	2.07	.63	1.76	.81
Mar. 23	6,030	534	314	76.6	6.89	29.9	14.6	.77	2.61	1.53	2.39	.59
Apr. 5	5,850	774	272	62.2	6.04	39.4	5.77	1.17	2.97	------	1.62	1.67
Apr. 17	3,760	462	223	62.6	4.55	29.8	10.3	.86	2.25	2.03	1.13	1.26
May 1	2,190	682	110	59.0	2.79	38.8	5.27	1.67	.95	1.53	.50	1.17
May 15	1,440	95.5	83.3	21.1	1.94	9.33	4.28	.22	1.04	1.39	.36	.52
May 29	1,660	73.4	54.3	19.6	1.78	7.44	4.05	.27	.68	1.06	.19	.43
June 12	1,760	213	48.7	26.7	1.79	10.9	2.68	.29	.61	.97	.29	.63
June 26	1,160	94.1	31.2	17.7	1.31	6.95	2.42	.22	.39	1.03	.29	.42
July 11	1,580	144	28.5	19.9	1.00	13.8	2.59	.92	.39	1.09	.09	.76
July 26	2,290	273	30.9	27.0	1.47	10.7	3.29	.38	.31	2.19	.11	.67
Aug. 8	2,220	261	4.65	41.0	.92	15.2	2.42	.69	.41	2.09	.14	1.08
Aug. 20	3,330	94.6	10.3	38.0	1.30	11.6	3.97	.41	.42	1.39	.16	1.02
Sept. 3	---------	-------	------	------	-----	-----	-----	-----	----	------	-----	-----
Sept. 17	5,600	420	9.34	57.6	1.23	17.2	4.60	.84	.60	1.00	.27	1.28
Oct. 1	7,160	1,100	9.95	87.1	1.62	26.9	4.47	.71	1.35	2.43	.68	1.95
Oct. 15	3,770	-------	12.6	------	2.44	-----	5.66	-----	.68	------	.23	-----
Oct. 29	6,480	-------	26.4	------	3.73	-----	7.79	-----	1.31	------	.48	-----
Nov. 12	4,850	-------	50.9	------	3.45	-----	5.66	-----	1.46	------	.41	-----
Nov. 29	5,550	-------	75.2	------	5.76	-----	6.55	-----	1.01	------	.49	-----

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Iron-59		Manganese-54		Barium-140		Zirconium-95-Niobium-95		Ruthenium-106		Cesium-137		Phosphorus-32	
Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
PASCO, WASH.--Continued													
3.10	14.0	6.13	1.52	------	------	1.68	2.58	3.02	-----	----	----	------	-----
1.14	14.6	4.39	5.09	------	------	1.03	2.99	3.40	-----	----	----	------	-----
4.59	10.2	4.30	4.30	------	------	4.91	5.59	4.00	-----	----	----	------	-----
1.45	49.1[a]	6.35	6.40[a]	------	------	1.87	20.7[a]	3.34	1.68[a]	----	----	------	-----
1.75	14.8	6.13	4.17	16.5	<0.23	2.53	6.35	2.33	1.43	----	----	------	-----
5.45	18.1	8.51	4.55	101	27.7	4.08	50.9	25.7	3.36	----	----	------	-----
1.57	35.3	5.23	3.82	29.1	3.14	2.44	11.3	2.08	1.38	----	----	------	-----
.87	14.5	2.92	6.35	23.1	1.06	1.48	90.5	3.27	.88	----	----	------	-----
.36	4.55	1.39	3.87	6.71	<1.16	.65	2.01	6.89	.85	----	----	------	-----
.33	1.09	1.14	2.99	7.52	2.70	.64	5.23	2.24	.75	----	----	------	-----
.58	2.75	.59	2.13	2.97	18.3	.32	14.0	2.29	.67	----	----	------	-----
.55	3.14	.64	3.05	3.08	.53	.43	5.90	.29	2.04	----	----	------	-----
1.22	3.02	.47	1.45	2.41	1.23	.24	2.06	2.75	.80	----	----	------	-----
.85	3.92	.83	1.37	2.27	<.95	.28	.70	2.27	.99	----	----	------	-----
.98	3.81	.81	.99	2.45	<1.36	.16	.27	3.30	.58	----	----	------	-----
1.12	18.4	1.00	1.24	1.62	<.73	.36	2.08	2.34	.67	----	----	------	-----
.54	3.07	.64	1.18	7.21	<.71	.34	1.09	2.90	.95	----	----	------	-----
.51	3.54	.51	1.17	2.55	.80	.28	.63	1.98	.49	----	----	------	-----
.46	5.00	.81	1.61	7.52	.90	.55	3.68	2.72	.75	----	----	------	-----
.58	6.40	1.00	2.05	9.82	<.36	.68	1.67	2.65	.55	----	----	------	-----
.80	4.48	.70	2.87	7.79	.64	.52	2.68	2.95	.35	----	----	------	-----
.45	13.5	.90	2.99	9.19	.34	.69	.96	3.46	<.55	----	----	------	-----
.69	5.68	.47	2.69	9.32	<.36	.52	.92	3.18	.58	----	----	------	-----
.71	13.2	.80	3.61	14.0	1.94	.80	4.14	2.29	<.65	----	----	------	-----
1.05	9.32	.89	4.77	11.3	.48	.53	2.80	2.48	<.27	----	----	------	-----
.52	20.0	1.08	5.45	14.3	1.23	.76	1.85	2.46	<.74	----	----	------	-----
.90	10.0	1.17	6.26	22.7	1.59	1.10	5.23	2.58	<.60	----	----	------	-----
.89	10.1[a]	2.30	11.5[a]	19.8	10.6[a]	1.46	24.8[a]	4.07	2.17[a]	----	----	------	-----
.52	18.1	.89	4.39	27.0	4.46	1.49	7.52	2.76	<.55	----	----	------	-----
.57	14.4	.89	3.80	18.5	4.24	1.21	12.3	2.78	<.48	----	----	------	-----
.40	9.73	1.07	3.70	20.6	2.31	1.39	7.75	2.57	<.55	----	----	------	-----
.51	9.95	1.41	3.41	17.0	.75	1.28	3.76	2.91	<.73	----	----	------	-----
.57	10.0	1.78	3.35	31.0	1.46	3.64	7.66	2.59	<.59	----	----	------	-----
.62	10.4	3.14	4.19	20.5	3.66	1.89	8.11	2.92	<.64	----	----	------	-----
.50	8.20	3.37	3.45	17.4	.25	1.31	3.12	2.76	<.58	----	----	------	-----
.56	6.26	3.46	3.01	6.49	.17	.92	5.59	2.45	<.26	----	----	------	-----
.77	4.86	3.95	3.14	13.9	.29	1.08	3.18	2.71	<.29	----	----	------	-----
.95	15.1	5.05	3.16	14.1	3.20	.54	5.63	2.73	<.51	----	----	------	-----
.80	21.8	5.99	2.77	14.5	14.8	.90	11.9	1.78	<.40	----	----	------	-----
.85	4.64	6.08	1.65	23.8	6.94	1.18	5.14	2.20	<.73	----	----	------	-----
.87	6.08	5.27	1.61	14.1	4.73	2.02	10.9	3.35	.70	----	----	------	-----
1.01	33.1	3.95	1.73	15.5	15.8	1.03	11.4	1.66	<.45	----	----	------	-----
1.15	5.68	4.32	.93	10.5	.47	1.08	2.05	2.04	<.63	----	----	------	-----
1.34	8.69	6.22	1.82	20.5	.26	1.25	2.80	----	<.60	----	----	------	-----
1.33	7.30	4.82	1.29	8.60	2.35	1.04	2.71	2.09	<.66	----	----	------	-----
1.94	30.5	4.28	2.07	-----	-----	1.17	2.57	1.17	<.03	----	----	------	-----
1.08	6.35	4.37	1.58	-----	-----	----	1.58	.77	<.02	----	----	------	-----
1.80	12.2	5.50	1.22	-----	-----	2.52	3.20	1.67	<.02	----	----	------	-----
1.44	9.32	4.32	1.40	-----	-----	.95	2.97	1.85	<.02	----	----	------	-----
2.79	11.4	5.36	1.44	-----	-----	1.22	9.46	1.62	.68	----	----	------	-----
4.14	8.78	6.98	1.94	9.86	<.05	1.08	14.9	1.67	.72	----	----	------	-----
3.11	12.3	9.01	2.03	13.6	4.41	1.40	2.03	1.85	<.03	----	----	------	-----
2.61	17.4	5.99	4.91	8.60	.50	2.21	6.53	4.91	.81	----	----	------	-----
.95	9.46	3.87	2.79	8.38	.45	1.17	5.18	1.31	<.03	----	----	------	-----
.90	15.4	2.30	2.43	3.87	4.58	.59	1.71	1.35	<.04	----	----	------	-----
.50	2.56	1.44	1.21	5.81	4.58	.63	3.36	.95	.08	----	----	------	-----
.57	2.39	1.25	1.35	3.14	.21	.18	.35	1.01	.81	----	----	------	-----
1.08	4.04	1.50	1.50	3.21	.34	.25	.45	1.25	<.02	----	----	34.6	-----
1.50	4.32	1.47	2.02	2.41	<.02	<.02	.24	1.30	.09	----	----	20.6	-----
.73	5.66	.57	2.02	2.64	.26	.16	1.99	.74	<.02	----	----	16.6	-----
.67	6.47	.79	2.45	4.17	.07	.31	.51	.87	<.02	----	----	17.8	-----
.41	5.70	.29	3.03	6.30	.19	.27	1.23	.90	<.02	----	----	10.1	-----
<.02	.95	.55	3.73	10.7	.18	.35	2.50	1.20	.09	0.70	0.59	23.9	-----
----	-----	----	----	-----	-----	----	-----	----	-----	----	----	------	-----
<.02	13.3	.54	1.15	14.6	<.02	.46	59.1	1.23	1.27	1.46	<.02	58.0	-----
.87	28.2	.62	10.6[a]	43.9	<.02	.31	8.71	1.95	1.35	2.23	1.75	128	-----
.76	-----	.69	-----	-----	-----	1.39	-----	1.46	-----	.57	----	37.30	35.3
.75	-----	1.36	-----	-----	-----	.69	-----	1.39	-----	1.09	----	24.50	28.9
1.27	-----	1.74	-----	-----	-----	.80	-----	1.38	-----	1.85	----	146	21.0
.84	-----	2.97	-----	-----	-----	.57	-----	1.86	-----	3.27	----	124	13.9

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Date	Chromium-51		Zinc-65		Scandium-46		Antimony-124		Cobalt-58		Cobalt-60	
	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
PASCO, WASH.--Continued												
1965												
Dec. 10	4,750	421	80.1	24.4	5.02	19.5	4.98	0.10	1.09	1.08	0.57	0.90
Dec. 27	4,930	199	114	13.1	6.17	9.57	5.62	.11	1.80	.83	.96	.57
1966												
Jan. 10	4,030	341	107	18.9	5.89	11.6	4.13	.14	1.71	.66	.87	.52
Jan. 24	5,700	188	128	18.3	8.75	12.8	6.14	<.02	2.13	.74	1.02	.52
Feb. 7	3,640	-------	123	------	7.55	-----	5.45	-----	2.24	------	.87	-----
Feb. 21	3,160	320	120	24.8	7.27	18.8	3.89	.05	2.61	.88	1.27	.62
Mar. 7	4,760	409	162	32.6	9.19	24.9	7.01	.48	1.77	.48	1.64	.50
Mar. 21	6,020	171	193	38.9	10.1	16.1	9.40	<.02	2.38	.67	1.59	.66
Apr. 4	5,920	216	168	96.0	9.20	24.3	9.82	.22	2.98	1.30	1.86	1.31
Apr. 18	3,220	-------	76.0	------	4.86	-----	5.36	-----	2.16	------	1.38	-----
May 2	1,710	219	58.6	89.7	3.24	22.9	5.54	.21	1.76	1.58	1.22	1.29
May 16	2,260	146	66.8	55.3	2.98	19.2	4.27	.14	.95	1.27	.52	1.31
May 30	1,190	58.6	38.1	41.1	3.73	11.4	7.53	.16	<.05	2.58	1.23	.76
June 13	873	67.1	23.4	24.5	1.81	11.7	2.51	.63	.50	.98	.14	.92
June 27	1,360	45.5	21.0	19.2	1.76	6.26	3.78	.45	.86	1.55	.18	.52
July 8	871	88.3	24.9	29.5	1.68	9.37	2.31	.17	.42	1.90	.15	1.56
July 8	737	141	32.2	33.3	2.27	14.0	5.30	.25	.36	1.96	.13	.62
July 9	77.9	22.1	11.3	14.4	.42	3.64	.12	.03	.14	.81	.08	.54
July 10	51.8	105	12.7	10.9	.57	2.78	.06	<.02	.14	.54	.05	.28
July 10	40.5	11.3	10.7	11.1	.69	2.83	.02	.02	.13	.58	.05	.34
July 11	27.9	12.6	9.28	8.33	.48	2.35	<.02	<.02	.10	.37	.03	.25
July 12	25.7	7.66	10.4	7.30	.62	2.09	.02	<.02	.08	.38	.05	.20
July 13	17.1	6.76	5.54	5.59	.31	1.64	.17	<.02	<.05	.35	.05	.21
July 15	22.5	5.41	5.50	4.64	.19	1.21	.05	.03	.08	.22	<.02	.22
July 18	10.4	4.05	4.14	3.06	.21	.94	<.02	<.02	.03	.18	<.02	.14
July 21	9.91	6.31	3.92	3.51	.19	1.43	.04	<.02	.06	.20	<.02	.16
July 26	11.3	--------	2.84	3.33	.25	.07	.38	<.02	.07	.18	.02	.15
July 27	49.5[a]	--------	1.04	2.30	.09	.41	.17	<.02	.05	<.05	.02	.11
July 29	3.15	--------	2.48	2.07	.08	.50	.03	<.02	.05	<.05	<.02	.11
Aug. 1-3-5	12.6	3.15	1.26	3.60	.14	.97	.08	.03	.03	.28	.04	.20
Aug. 9-11-12	7.66	16.7	1.08	6.62	.16	1.36	.08	.06	.04	.52	<.02	.25
Aug. 15-17-19	3.60	--------	.54	4.01	.12	1.07	.05	<.02	.18	.83	.04	.34
Aug. 22	4.95	--------	2.30	1.98	.14	1.08	.09	<.02	.14	<.05	.10	.16
Aug. 24	22.1	--------	1.22	2.25	.21	.57	<.02	<.02	.11	<.05	.06	.03
Aug. 25	326	100	2.48	22.0	.18	8.52	.39	.29	.16	.44	.09	.52
Aug. 26	1,010	95.9	8.11	37.6	1.10	11.8	3.32	.18	.73	2.18	.18	1.08
Aug. 29	4,090	182	14.0	61.0	1.49	14.7	8.05	.35	.86	1.99	.20	1.59
Sept. 1	4,510	230	27.7	53.2	1.27	17.0	8.95	.49	.95	1.55	.28	1.35
Sept. 12	4,780	342	20.7	78.2	1.64	43.8	6.02	.78	.41	2.30	.17	1.42
UMATILLA, OREG.												
1965												
May 15	684	68.0	30.2	19.4	0.60	5.32	2.17	0.11	0.45	0.87	0.14	0.35
May 29	589	56.8	14.0	19.9	.39	3.97	1.43	.14	.28	.29	.12	.30
June 13	530	88.7	12.4	17.7	.30	4.07	1.32	.12	.23	.29	.15	.29
June 27	---------	100	------	20.1	-----	4.61	-----	.14	-----	.55	-----	.38
July 12	---------	-------	------	------	-----	-----	-----	------	-----	-----	-----	-----
July 22	1,650	107	3.68	26.4	.42	5.25	2.83	.07	.51	.59	.12	.37
Aug. 9	1,730	104	1.26	23.8	.33	5.74	2.58	.13	.28	.68	.08	.48
Aug. 20	2,310	140	2.40	20.0	.32	4.28	3.08	.13	.34	.61	.14	.48
Sept. 3	3,230	-------	3.45	------	.29	-----	4.23	------	.31	-----	.10	-----
Sept. 17	3,460	151	2.11	15.4	.30	3.18	4.08	.09	.28	.36	.06	.40
Oct. 1	2,590	-------	.74	------	.29	-----	3.64	------	.27	-----	.10	-----
Oct. 15	2,650	168	1.80	15.2	.39	3.82	4.36	.03	.33	.48	.08	.42
Oct. 29	2,530	184	2.16	12.5	.61	6.41	3.48	<.02	.25	.39	.04	.51
Nov. 12	3,230	-------	4.59	------	.99	-----	4.60	------	.26	-----	.04	-----
Nov. 26	2,390	120	9.23	12.0	1.12	6.09	2.81	<.02	.25	.40	<.02	.42
Dec. 9	---------	66.2	------	9.5	-----	4.16	-----	<.02	-----	.18	-----	.27
Dec. 27	2,360	109	35.0	11.7	2.15	4.95	3.03	.04	.59	.55	.27	.35
1966												
Jan. 10	2,660	185	30.5	13.9	2.13	4.60	2.95	<.02	.45	.43	.25	.32
Jan. 24	2,300	86.0	33.6	15.9	2.34	5.64	2.74	<.02	.55	.54	.19	.31
Feb. 7	3,150	146	56.4	14.5	3.69	8.15	4.10	<.02	1.16	.51	.49	.32
Feb. 21	1,870	109	53.5	13.2	3.31	6.26	2.44	.05	.88	.47	.52	.28
Mar. 7	2,900	108	50.8	27.3	2.50	7.23	4.65	.09	.66	.72	.35	.73
Mar. 21	2,490	114	37.2	39.6	2.17	7.25	4.09	.02	.41	.58	.28	.58

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Iron-59		Manganese-54		Barium-140		Zirconium-95-Niobium-95		Ruthenium-106		Cesium-137		Phosphorus-32	
Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
PASCO, WASH.--Continued													
1.01	8.79	2.58	3.63	-----	-----	<0.02	6.07	1.79	0.55	2.86	<0.05	190	13.2
1.81	5.22	3.75	1.58	-----	-----	<.02	.59	1.71	.23	3.59	.29	132	9.46
.04	5.86	3.19	1.70	-----	-----	<.02	3.63	1.46	<.05	3.61	<.05	96.4	15.1
2.87	<.05	5.22	1.38	-----	-----	<.02	1.03	2.27	.06	4.20	.36	121	14.9
<.05	-----	4.10	-----	-----	-----	<.02	-----	1.97	----	6.32	----	------	-----
2.26	8.85	4.62	1.78	-----	-----	<.02	2.68	1.64	.60	4.86	<.05	79.5	-----
1.35	11.6	6.08	1.95	-----	-----	<.02	2.29	2.61	.23	5.44	<.05	------	-----
2.70	6.01	7.85	2.37	-----	-----	<.02	.84	2.30	.86	5.66	1.25	174	33.6
1.93	5.71	7.45	3.37	-----	-----	<.02	16.0	2.68	<.05	5.32	<.05	------	-----
.32	-----	3.76	----	-----	-----	<.02	-----	1.09	----	2.59	----	88.7	-----
1.08	7.77	3.33	3.43	-----	-----	<.02	.66	1.31	.95	2.21	3.24	23.4	27.0
4.03	4.00	1.99	3.48	-----	-----	<.02	44.8	.93	.18	2.01	<.05	36.5	17.4
1.40	2.95	1.32	1.53	-----	-----	.85	<.02	18.8[a]	<.05	.80	<.05	40.5	-----
.13	3.05	.46	1.39	-----	-----	<.02	<.02	.55	1.55	.75	<.05	12.3	-----
.78	1.79	.83	.72	-----	-----	<.02	.12	.99	1.88	.85	<.05	26.8	-----
<.05	.37	.68	1.74	-----	-----	<.02	<.02	.80	.07	.91	1.12	------	-----
1.10	.67	.60	1.63	-----	-----	.25	<.02	1.06	.24	1.40	1.03	------	-----
.10	<.05	.27	.77	-----	-----	<.02	<.02	.16	.16	.63	.54	------	-----
.02	<.05	.09	.57	-----	-----	<.02	<.02	.20	<.05	.56	.33	------	-----
.14	<.05	.12	.45	-----	-----	<.02	<.02	.35	.05	.52	.34	------	-----
.05	.17	.06	.53	-----	-----	<.02	<.02	.39	.07	.47	.26	------	-----
<.05	<.05	.23	.42	-----	-----	.02	<.02	.28	<.05	.70	.23	------	-----
<.05	<.05	.05	.36	-----	-----	<.02	<.02	1.71	<.05	<.05	.18	------	-----
.09	<.05	.05	.37	-----	-----	<.02	<.02	.24	.11	.30	.20	------	-----
.15	.06	.18	.28	-----	-----	.06	.10	.16	.15	.48	<.05	------	-----
<.02	<.05	.17	.36	-----	-----	.05	.12	.23	<.05	.42	.27	------	-----
<.05	<.05	.10	.30	-----	-----	.12	<.02	.30	.09	.33	<.05	------	-----
1.04	<.05	.04	.29	-----	-----	<.02	<.02	.18	<.05	<.05	<.05	------	-----
<.05	<.05	<.02	.23	-----	-----	.16	<.02	.29	.89	<.05	<.05	------	-----
<.05	<.05	.08	.38	-----	-----	<.02	<.02	.41	.12	.24	.12	------	-----
.13	1.00	.04	1.18	-----	-----	.09	14.5	.05	9.14[a]	<.05	1.64	------	-----
.11	<.05	<.02	.44	-----	-----	<.02	<.02	.11	<.05	<.05	<.05	------	-----
.68	<.05	.14	.42	-----	-----	.04	<.02	.09	<.05	.19	<.05	------	-----
.15	<.05	.07	.21	-----	-----	<.02	<.02	.29	<.05	.24	<.05	------	-----
.02	<0.05	.14	.89	-----	-----	.12	.64	.05	.23	.34	.59	------	-----
1.02	1.16	.13	2.18	-----	-----	<.02	3.25	.31	.29	.44	.69	------	-----
2.83	<.05	.14	4.14	-----	-----	<.02	.90	.64	.45	.48	1.59	------	-----
2.17	.93	.45	4.23	-----	-----	<.02	.29	.57	.57	.75	1.34	------	-----
.98	8.67	.24	5.13	-----	-----	<.02	1.54	1.03	<.05	.77	<.05	------	-----
UMATILLA, OREG.--Continued													
0.27	1.40	0.76	0.50	1.44	1.39	0.07	1.73	0.93	0.36	----	----	13.3	-----
.52	1.31	.69	.66	1.50	.82	.06	.70	1.01	.15	----	----	------	-----
.17	1.41	.63	.52	.48	.26	<.02	.39	.99	.33	----	----	10.8	-----
----	2.84	----	.96	-----	.09	-----	.65	-----	.60	----	----	------	-----
----	-----	----	----	-----	-----	-----	-----	-----	----	----	----	------	-----
.10	2.08	.32	1.45	2.26	.14	<.02	.75	.51	.30	----	----	------	3.24
<.02	.06	.23	2.12	5.65	<.02	.09	<.02	.95	.35	0.32	1.67	5.75	-----
<.02	<.02	.22	2.29	5.02	.69	.47	3.42	1.05	.43	.42	.07	10.8	-----
.26	-----	.63	----	6.88	----	.41	-----	1.09	----	.91	----	7.81	-----
.33	2.99	.14	1.96	8.09	<.02	<.02	1.14	.92	.26	.21	.30	15.8	-----
.60	-----	.02	----	10.1	----	.03	-----	.87	----	.07	----	19.2	-----
<.05	3.47	.09	2.33	-----	----	.06	.45	1.14	.17	.24	.53	13.3	27.6
.08	3.71	.05	2.11	-----	----	.08	.86	.90	.30	.25	.28	26.5	15.4
.19	-----	.27	----	-----	----	.20	-----	1.05	----	.36	----	29.1	12.6
.05	2.44	.27	1.49	-----	----	.35	1.07	.77	.26	.55	.23	47.8	3.92
----	1.57	----	1.08	-----	----	-----	.41	-----	.30	----	.23	97.3	3.82
.06	2.86	1.26	1.23	-----	----	<.02	.24	1.11	.16	1.39	.32	46.5	2.70
.06	.67	1.10	1.17	-----	----	<.02	.73	.96	.20	1.31	.34	43.2	1.49
.20	2.20	.89	1.20	-----	----	<.02	.34	1.01	.09	1.23	.53	64.1	4.64
.27	2.05	1.83	1.02	-----	----	<.02	.45	1.30	.30	2.40	<.05	------	-----
.65	5.44	1.73	.95	-----	----	.63	1.58	.63	.32	----	.64	46.1	-----
.51	2.12	1.51	2.23	-----	----	<.02	.39	1.13	.36	2.06	.94	------	-----
.17	1.21	1.39	2.45	-----	----	<.02	.21	1.04	.56	1.50	1.64	76.5	8.87

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Date	Chromium-51		Zinc-65		Scandium-46		Antimony-124		Cobalt-58		Cobalt-60	
	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
						UMATILLA, OREG.--Continued						
1966												
Apr. 4	2,140	93.7	24.9	37.5	2.42	6.44	4.41	0.07	0.53	0.69	0.20	0.65
Apr. 18	2,050	111	10.0	37.5	1.38	7.76	4.10	.80[a]	.17	1.21	.28	.99
May 2	1,780	77.9	11.4	34.7	1.94	6.37	4.08	<.02	.39	.57	.19	.75
May 16	1,420	106	12.9	36.3	.75	9.30	3.30	.09	.24	.79	.08	.85
May 30	984	62.2	6.04	42.1	2.10	8.16	6.98	.27	<.05	1.05	.99	.86
June 13	576	72.1	4.32	36.6	.90	10.7	1.63	-----	.13	<.05	.15	1.07
June 27	1,100	119	2.48	40.6	.83	17.4	2.84	.67	.15	1.44	.18	1.18
July 8	801	87.8	2.70	36.7	.55	7.41	1.94	.06	.23	.82	.16	.82
July 11	609	68.9	2.70	35.5	.44	9.10	1.20	.05	.27	.67	.21	.70
July 11	264	39.2	1.98	30.0	.25	4.88	.44	.05	.14	.42	.17	.50
July 12	93.7	45.5	2.52	34.4	.19	6.41	.17	.07	.19	.46	.18	.77
July 12	66.2	79.7	2.52	23.8	.20	7.07	.17	.05	.25	.46	.27	.62
July 13	32.0	55.0	1.62	33.2	.18	5.98	.13	.04	.23	.45	.14	.78
July 14	17.1	36.9	1.35	22.4	.12	4.45	.05	.01	.14	.49	.06	.55
July 15	14.9	47.7	1.22	24.2	.14	4.60	.05	.20	.12	.36	.11	.67
July 18	10.4	33.8	1.35	25.5	.09	9.65	.04	.45	.06	.32	.08	.67
July 21	8.56	14.4	1.71	15.5	.07	2.50	.03	<.02	.04	.31	.03	.38
July 25	7.21	3.15	.90	16.3	.08	2.94	<.02	.03	.04	.10	.05	.40
July 27	10.4	--------	.72	15.2	.07	2.49	<.02	<.02	.11	<.05	.04	.36
July 29	<2	18.0	.86	15.6	.06	4.07	.13	<.02	<.05	<.05	<.02	.34
Aug. 1-3-5	6.31	13.5	.36	9.10	.05	1.58	<.02	<.02	.02	.23	.04	.26
Aug. 8-10-12	9.46	23.4	.54	13.8	.09	1.92	.02	<.02	.08	.23	.05	.44
Aug. 15-17-19	6.76	6.76	.45	7.79	.05	.79	<.02	<.02	.18	.18	.05	.37
Aug. 27	1,720	91.0	1.35	14.8	.36	2.93	5.87	.04	.25	.34	.10	.39
Aug. 28	1,210	91.4	3.11	16.1	.38	2.91	4.43	.06	.32	.36	.12	.36
Aug. 29	1,900	95.9	2.66	19.8	.53	3.52	5.67	.06	.42	.45	.10	.36
Aug. 31	2,790	86.9	2.39	20.4	.53	3.72	5.38	.02	.29	.45	.11	.36
Sept. 3	2,860	82.9	2.52	19.1	.55	3.32	6.13	.03	.09	.34	.13	.41
Sept. 5-7-9	3,020	291	2.61	19.6	.34	2.70	5.23	<.02	<.05	.27	.09	.49
Sept.12-14-16	2,510	234	1.71	16.6	.24	2.97	4.08	<.02	.31	.42	.09	.49
Sept. 25	2,670	138	3.69	19.2	.30	3.46	5.25	.06	.27	.45	.05	.61
						VANCOUVER, WASH.						
1964												
Jan. 13	5,000	209	12.5	23.5	0.86	8.29	1.77	<0.38	<0.18	1.25	0.12	0.66
Feb. 10	3,720	111	12.3	28.5	.76	5.45	1.89	<.27	<.14	<.31	.07	.46
Feb. 24	3,950	184	12.0	20.5	.77	5.77	1.85	<.39	<.13	<.38	.09	.33
Mar. 9	2,820	156	7.75	16.1	.57	3.51	1.36	<.34	.19	<.23	.09	.29
Mar. 23	3,320	139	2.94	25.7	.80	5.00	2.03	<.08	<.13	.19	.11	.42
Apr. 6	3,270	151	6.89	27.3	.97	6.49	1.82	<.10	.20	.39	.09	.46
Apr. 20	2,610	144	7.43	34.1	1.19	6.98	2.11	<.09	<.07	.35	.07	.60
Apr. 24	2,270	123	3.92	32.2	.86	6.35	2.08	<.03	<.06	.31	.07	.55
May 1	2,330	146	4.39	30.7	1.34	7.43	2.54	<.14	.14	.65	.07	.64
May 8	2,180	153	2.83	40.0	1.05	8.92	2.30	.07	.08	.82	.09	.96
May 15	1,780	156	4.73	54.1	1.19	10.5	2.47	.15	<.08	.69	.13	1.36
May 22	1,300	252	4.27	82.4	.64	14.2	1.64	.14	.06	.99	.05	2.14
May 29	1,320	230	3.84	62.2	.65	13.6	1.67	.10	.06	.83	.04	2.21
June 5	946	165	5.54	61.3	.51	11.3	1.54	.16	.08	.77	.05	1.86
June 12	802	214	2.71	26.9	.46	7.75	1.54	<.14	<.06	1.07	.03	1.51
June 19	716	160	1.97	38.8	.38	7.25	1.09	<.13	.10	.72	.06	1.09
June 26	856	280	2.22	35.2	.37	10.6	1.35	.27	<.05	.67	.04	.94
July 1	905	147	2.40	30.6	.39	7.88	1.23	.19	<.06	.60	.04	.81
July 9	1,160	127	1.25	31.0	.45	6.62	1.45	<.10	<.06	.99	.03	.79
July 16	869	87.4	1.74	23.0	.39	5.81	1.18	<.10	.06	.58	.02	.57
July 23	977	70.3	1.38	23.1	.36	4.77	1.16	<.09	.11	.74	.04	.58
July 30	1,790	74.8	.95	19.6	.30	4.49	1.09	<.09	.06	.75	.05	.46
Aug. 12	1,610	60.8	1.53	15.6	.38	3.25	1.66	<.11	<.08	.61	.07	.27
Aug. 19	2,640	84.7	1.52	18.8	.44	3.65	2.41	<.09	<.07	.56	.12	.36
Aug. 26	2,720	97.3	2.59	13.0	.36	3.48	2.14	<.09	.26	.52	.13	.23
Sept. 2	2,640	77.0	1.90	8.29	.31	1.92	2.32	<.09	.28	.50	.14	.23
Sept. 9	2,790	79.7	1.68	7.75	.21	1.88	1.92	<.11	.29	.49	.10	.17
Sept. 16	2,100	43.1	1.62	8.83	.35	2.68	1.67	.07	.31	.66	.10	.31
Sept. 23	3,260	101	1.55	9.37	.36	2.55	2.44	<.10	.33	.56	.13	.26
Sept. 30	3,680	108	1.58	8.83	.35	1.90	2.80	<.05	.26	.42	.11	.27
Oct. 7	3,680	120	2.13	13.7	.50	2.94	2.89	<.03	.18	.36	.14	.31
Oct. 14	3,220	183	1.61	13.0	.42	4.19	2.34	<.04	.14	.46	.06	.36
Oct. 21	3,110	135	4.64	13.3	.42	3.38	1.82	<.03	.35	.63	.11	.36
Oct. 28	2,230	95.9	2.49	9.46	.36	3.05	1.42	<.03	.28	.58	.08	.26

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Iron-59		Manganese-54		Barium-140		Zirconium-95-Niobium-95		Ruthenium-106		Cesium-137		Phosphorus-32	
Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
						UMATILLA, OREG.--Continued							
0.18	0.29	0.96	2.36	-----	-----	0.03	0.05	0.75	0.43	0.98	1.33	------	-----
.23	2.86	.49	2.29	-----	-----	.20	<.02	<.05	.17	<.05	1.36	43.5	-----
.30	1.70	.45	2.54	-----	-----	.05	<.02	.76	.50	.55	1.23	25.6	-----
1.05	2.91	.79	1.97	-----	-----	<.02	.04	.83	.60	.71	1.44	34.2	-----
1.27	1.57	1.01	1.80	-----	-----	.82	<.02	14.6[a]	<.05	.72	<.05	25.5	-----
.23	3.20	.69	1.32	-----	-----	.09	<.02	.23	<.05	<.05	<.05	5.27	18.3
.32	3.77	.42	1.84	-----	-----	.11	.41	.55	3.36[a]	<.05	.16	19.6	24.4
.14	<.02	.70	2.11	-----	-----	.36	.65	.39	.50	.27	1.27	------	12.7
.05	1.19	.78	1.75	-----	-----	.12	.46	.32	.46	.28	1.56	------	26.0
<.05	1.01	.68	1.59	-----	-----	<.02	1.31	.18	.48	.31	1.13	------	-----
<.05	<.05	.72	1.66	-----	-----	.06	.03	.12	.36	.46	1.50	------	-----
.07	.78	.77	1.47	-----	-----	.07	.52	.14	.12	.42	<.05	------	-----
<.05	.12	.47	1.43	-----	-----	<.02	.58	.13	.36	.17	.98	------	-----
.37	<.05	.21	1.29	-----	-----	<.02	<.02	.15	.31	.16	.67	------	-----
.15	.35	.24	1.38	-----	-----	.03	.14	.14	.28	.14	.67	------	-----
.04	1.91	.37	1.15	-----	-----	.13	.39	.14	<.05	.27	<.05	------	-----
<.05	<.05	.16	1.12	-----	-----	.06	.50	.18	.42	.30	.54	------	-----
.13	.46	.17	1.12	-----	-----	.09	.31	.17	.17	<.05	<.05	------	-----
<.05	<.05	<.02	1.04	-----	-----	.08	<.02	.23	.96	.11	<.05	------	-----
<.02	1.32	.05	.96	-----	-----	.24	.74	.18	1.26	<.05	<.05	------	-----
.13	.26	.05	.77	-----	-----	.05	.25	.23	.07	.12	.20	------	-----
.16	<.05	.07	1.17	-----	-----	<.02	<.02	.04	.08	.16	.38	------	-----
.18	1.24	<.02	1.07	-----	-----	<.02	<.02	<.05	.23	.13	.75	------	-----
.11	.62	.07	1.44	-----	-----	.13	<.02	.51	.07	.10	.41	------	-----
.25	<.05	.14	1.52	-----	-----	.03	.18	.48	.15	.23	.50	------	-----
.05	.45	.07	1.55	-----	-----	.11	<.02	.38	.18	.17	.50	------	-----
<.05	.68	.09	1.51	-----	-----	.09	.08	.26	.17	.12	.61	------	-----
<.05	.95	.06	1.49	-----	-----	.15	<.02	<.05	.20	<.05	.51	------	-----
<.05	<.02	.05	2.37	-----	-----	.16	.99	.59	.09	<.05	.75	------	-----
<.05	.49	<.02	1.81	-----	-----	<.02	<.02	.45	.14	.12	.39	------	-----
<.05	<.05	<.02	2.27	-----	-----	<.02	.04	.41	.20	.09	.45	------	-----
						VANCOUVER, WASH.--Continued							
1.86	4.82	0.22	1.52	-----	-----	0.87	1.77	3.32	2.07	-----	-----	------	-----
1.23	2.42	.28	1.40	-----	-----	.62	.37	2.34	.45	-----	-----	------	-----
1.88	4.59	.35	1.20	-----	-----	.65	.61	2.16	.51	-----	-----	------	-----
1.09	4.36	.27	1.08	-----	-----	1.12	6.26[a]	2.59	.73	-----	-----	------	-----
.31	1.55	.14	1.36	3.18	<0.15	.53	.82	2.00	<.32	-----	-----	------	-----
.70	1.87	.21	1.49	4.86	.65	.44	1.36	2.20	1.00	-----	-----	------	-----
.39	1.68	.22	2.30	3.06	<.25	.46	1.33	3.56	1.02	-----	-----	------	-----
.31	1.57	.17	2.10	1.97	.21	.36	1.08	2.72	1.00	-----	-----	------	-----
.74	2.01	.26	1.77	2.69	.61	.64	2.10	3.55	1.91	-----	-----	------	-----
.45	1.68	.18	2.50	2.50	.78	.46	1.99	2.79	.99	-----	-----	------	-----
.17	2.18	.27	3.40	2.53	.63	.44	1.57	2.86	3.85	-----	-----	------	-----
.19	3.34	.22	3.93	1.43	.59	.25	1.98	2.76	1.66	-----	-----	------	-----
.36	3.59	.16	2.86	1.14	.50	.25	1.81	2.98	.96	-----	-----	------	-----
.16	2.37	.17	2.75	.98	.58	.23	1.77	2.95	1.18	-----	-----	------	-----
.33	3.51	.11	2.01	.53	<1.61	.23	.45	3.10	.77	-----	-----	------	-----
.09	3.14	.07	1.90	.46	.76	.05	2.45	2.76	1.36	-----	-----	------	-----
.24	5.81	.08	1.75	.37	<.71	.12	.92	2.55	1.16	-----	-----	------	-----
.35	3.94	.12	1.57	.86	<1.03	.19	.71	2.50	1.47	-----	-----	------	-----
.40	2.69	.12	1.37	.99	<.71	.22	.80	2.18	.73	-----	-----	------	-----
.34	2.42	.11	1.24	.76	<.57	.12	.77	2.21	.93	-----	-----	------	-----
.40	1.74	.12	1.18	1.14	<.46	.21	1.26	2.10	.64	-----	-----	------	-----
.28	1.62	.10	.82	.95	<.43	.14	.47	2.14	.77	-----	-----	------	-----
.18	1.38	.11	.75	2.22	<.40	.23	.56	2.30	.45	-----	-----	------	-----
.23	1.14	.09	.99	2.31	<.28	.26	.42	2.24	.28	-----	-----	------	-----
.20	1.27	.09	.94	1.87	.43	.16	.59	2.18	.53	-----	-----	------	-----
.05	.87	.10	.79	2.19	.29	.09	.26	2.07	.54	-----	-----	------	-----
.23	1.17	<.05	.81	1.87	<.56	.05	.28	2.16	.41	-----	-----	------	-----
.13	.58	.12	.76	3.06	.09	.22	.25	2.01	.15	-----	-----	------	-----
.30	.89	.05	.98	2.69	<.51	.16	.32	2.26	.30	-----	-----	------	-----
.30	.73	.07	.95	2.01	.34	.18	.27	2.39	.25	-----	-----	------	-----
.32	1.08	.17	1.18	4.32	.34	.23	.51	2.13	.38	-----	-----	------	-----
.12	2.56	.07	1.29	2.33	.18	.16	.72	1.78	.23	-----	-----	------	-----
.16	1.34	.11	1.22	2.98	.27	.13	.58	1.82	.30	-----	-----	------	-----
.43	1.18	.14	.91	2.06	.23	.22	.43	1.88	.18	-----	-----	------	-----

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Date	Chromium-51		Zinc-65		Scandium-46		Antimony-124		Cobalt-58		Cobalt-60	
	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
VANCOUVER, WASH.--Continued												
1964												
Nov. 4	2,450	95.0	4.20	10.2	0.45	3.06	1.80	0.03	0.17	0.82	0.05	0.27
Nov. 11	2,450	96.8	6.94	12.3	.56	2.99	1.95	<.03	.29	1.32	.06	.33
Nov. 18	3,020	107	6.53	11.9	.58	2.86	2.16	<.03	.27	1.35	.04	.35
Nov. 25	3,230	103	11.4	14.5	.77	2.91	2.38	<.03	.32	1.85	.05	.31
Dec. 2	3,210	118	20.0	19.4	.95	3.96	2.18	<.03	.32	2.09	.09	.37
Dec. 9	3,680	122	25.8	23.7	1.00	4.43	2.61	<.03	.38	2.75	.04	.49
Dec. 16	3,490	223	18.5	32.4	.72	4.31	2.15	<.03	.14	1.47	.08	.31
Dec. 23	2,310	265	17.4	34.0	.87	4.26	2.05	.10	.15	1.12	.05	.41
Dec. 29	1,270	86.9	2.73	38.6	.36	3.00	.87	.07	.20	.42	.02	.33
1965												
Jan. 6	2,350	151	7.07	39.2	.78	4.86	1.73	.03	<.06	.69	.03	.45
Jan. 13	2,790	343	10.3	49.5	.86	12.3	1.64	.24	.12	.95	.05	.63
Jan. 20	2,370	153	13.2	30.5	.94	5.81	1.90	.05	<.06	.87	.04	.43
Jan. 27	1,950	121	11.8	38.5	.92	5.99	1.66	<.04	.19	.82	.05	.47
Feb. 3	1,750	178	2.12	51.4	.45	6.08	1.49	.14	.14	.54	.02	.45
Feb. 10	1,620	-------	6.35	------	.90	11.7	2.20	.18	.14	.32	.05	.54
Feb. 17	1,600	188	14.2	37.1	.99	8.47	3.11	.18	.14	.86	.05	.54
Feb. 25	1,760	104	21.5	43.1	1.26	7.39	3.74	.09	.09	.72	.09	.59
Mar. 3	1,770	112	20.3	39.8	1.22	7.30	3.92	.14	.18	.59	.09	.45
Mar. 10	1,410	150	24.1	37.0	.95	9.82	2.97	.23	.14	.59	.09	.50
Mar. 20	2,000	133	21.2	39.5	1.22	6.76	4.91	.09	.09	.59	.09	.59
Apr. 3	2,490	143	30.0	57.2	1.31	8.51	6.71	.09	.09	.90	.09	.77
Apr. 17	1,980	218	15.7	65.3	.72	11.5	5.09	.27	.05	1.22	.05	.95
May 1	1,050	203	5.16	53.3	.59	8.78	3.58	.23	.03	1.00	.06	.66
May 15	876	144	4.75	37.8	.51	5.76	2.73	.12	.06	.88	.04	.58
May 28	797	131	3.84	35.1	.44	5.95	2.46	.20	<.02	.82	.03	.50
June 11	927	139	2.89	34.0	.27	4.91	1.91	.14	.07	.62	<.02	.58
June 26	698	112	2.77	33.0	.27	5.94	1.50	.08	.06	.77	.02	.63
July 12	545	99.1	1.63	35.6	.19	6.16	1.63	.18	.04	.81	<.02	.70
July 23	1,230	87.4	1.30	20.3	.20	3.20	2.22	.09	.08	.54	<.02	.42
Aug. 6	1,420	96.8	.91	13.6	.22	2.92	2.64	.08	.21	.30	<.02	.28
Aug. 20	1,570	76.6	1.10	9.56	.12	1.95	2.01	.05	.17	.36	.07	.23
Sept. 3	2,090	-------	.91	------	.14	-----	3.27	-----	.20	-----	<0.02	-----
Sept. 17	2,560	82.4	2.62	5.88	.18	0.95	4.12	0.03	.33	0.14	.04	0.15
Oct. 1	1,900	69.4	.50	6.26	.12	.91	2.96	.03	.14	.06	<.02	.16
Oct. 15	2,280	25.2	.63	5.05	.16	.72	1.81	<.02	.23	.05	.07	.18
Oct. 29	1,300	63.5	.95	4.23	.22	1.39	2.57	<.02	.18	.15	.03	.16
Nov. 12	1,920	81.5	1.04	5.59	.36	1.90	3.34	.03	.15	.10	.03	.21
Nov. 26	2,780	86.5	1.98	7.34	.44	2.39	3.30	.07	.12	.16	<.02	.22
Dec. 10	3,660	143	5.36	8.78	.76	3.49	3.37	.07	.16	.22	<.02	.18
Dec. 27	1,600	105	7.43	9.73	.73	3.49	2.10	<.02	.03	.16	<.02	.20
1966												
Jan. 10	1,810	-------	8.20	------	.75	-----	2.45	-----	.14	-----	<.02	-----
Jan. 24	1,760	72.1	13.1	13.8	.89	3.24	1.97	<.02	.13	.33	.06	.17
Feb. 7	2,250	77.0	22.3	15.0	1.69	4.16	3.32	<.02	.35	.34	.08	.27
Feb. 21	1,660	101	20.0	15.4	1.47	4.17	2.81	.03	.32	.44	.10	.29
Mar. 7	1,820	81.5	16.1	17.8	1.05	4.53	2.82	.07	.18	.35	.07	.37
Mar. 21	1,600	74.3	13.1	24.1	.97	4.08	3.12	.04	.18	.32	.02	.40
Apr. 4	1,910	96.4	14.3	33.2	1.45	6.07	4.02	.05	.17	.43	.05	.46
Apr. 18	1,570	93.2	8.38	27.0	1.49	4.68	3.97	.05	.16	.49	.05	.50
May 2	1,670	93.2	3.69	31.2	.80	5.49	3.30	.04	.36	.73	.10	.65
May 16	1,170	89.6	4.14	38.6	1.01	6.18	3.10	.05	.12	.65	<.02	.74
May 30	1,020	74.8	3.06	47.8	1.56	8.91	6.71	.27	<.05	.60	1.05[a]	.95
June 13	555	85.1	3.06	47.9	.59	8.89	2.11	.68	<.05	1.36	.04	1.19
June 27	1,000	102	1.58	41.4	.53	13.1	2.60	.63	<.05	2.96[a]	.05	1.11
July 8	755	82.9	1.80	28.3	.39	5.60	2.16	.05	.11	.83	.02	.76
July 14	683	73.9	1.53	28.9	.22	5.14	1.58	<.02	.08	.89	.02	.62
July 14	651	72.5	2.79	28.9	.23	5.20	1.34	.03	.14	.71	.05	.64
July 15	247	55.4	2.03	24.3	.15	4.05	.47	<.02	.14	.50	.05	.63
July 15	146	56.3	1.76	25.1	.16	4.11	.31	.03	.07	.42	.05	.62
July 16	46.4	52.3	1.58	22.7	.09	4.64	.11	<.02	.05	.32	.03	.61
July 17	22.5	57.7	1.13	21.9	.07	5.02	.07	.05	.04	.47	<.02	.48
July 19	13.1	19.8	1.44	17.7	.09	2.87	.02	.03	.05	.32	.03	.48
July 22	11.3	28.8	1.44	15.5	.07	2.27	<.02	.04	.04	.21	.05	.43
July 26	7.21	28.4	1.22	12.7	.05	2.14	<.02	<.02	.03	.23	.03	.33
July 29	7.66	-------	.99	10.3	.05	1.55	.07	<.02	.03	<.05	.04	.26

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Iron-59		Manganese-54		Barium-140		Zirconium-95-Niobium-95		Ruthenium-106		Cesium-137		Phosphorus-32	
Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
VANCOUVER, WASH.--Continued													
0.27	1.20	0.15	0.82	1.65	0.11	0.35	0.62	1.49	0.21	-----	-----	------	-----
.14	1.02	.11	.95	3.53	.13	.22	.57	1.64	.18	-----	-----	------	-----
.16	.93	<.05	.98	7.07	.28	.95	1.55	1.69	.15	-----	-----	------	-----
.32	1.08	.15	.91	4.14	.29	.46	.63	1.43	.28	-----	-----	------	-----
.35	1.23	.28	1.06	3.14	.27	.44	.64	1.73	.20	-----	-----	------	-----
.43	1.53	.18	1.24	3.57	.20	.46	.82	1.55	<.18	-----	-----	------	-----
.23	1.48	.20	1.44	2.09	.20	.30	.82	1.62	.50	-----	-----	------	-----
.14	1.57	.22	1.22	1.14	.77	.24	.24	1.89	1.47	-----	-----	------	-----
.05	1.21	<.04	1.52	.25	.29	<.05	.68	.90	2.10	-----	-----	------	-----
.23	1.30	.15	1.64	1.36	1.67	.16	1.67	1.91	.57	-----	-----	------	-----
.29	5.27	.24	1.27	1.60	1.43	.28	1.00	1.65	.33	-----	-----	------	-----
.29	1.74	.26	1.08	2.37	.67	.20	.98	1.63	.30	-----	-----	------	-----
.19	1.50	.23	1.34	1.63	1.05	.20	2.70	1.50	.36	-----	-----	------	-----
.95	3.87	.05	1.76	-----	-----	.14	.68	1.13	1.17	-----	-----	------	-----
.23	217[a]	.09	-----	-----	-----	.05	33.8[a]	1.53	164[a]	-----	-----	------	-----
.54	2.70	.41	.90	-----	-----	.14	.50	.99	.45	-----	-----	------	-----
.45	1.89	.18	.99	-----	.45	.63	.63	1.62	.32	-----	-----	------	-----
.45	2.57	.36	1.08	.99	-----	.23	1.17	1.35	.63	-----	-----	------	-----
.54	3.15	.45	.86	1.17	1.53	.09	1.17	1.49	.36	-----	-----	------	-----
1.04	2.79	.54	1.49	-----	.41	.41	1.98	1.40	.32	-----	-----	------	-----
.72	2.66	.41	2.30	2.25	.77	.32	.68	1.17	.27	-----	-----	------	-----
.32	3.24	.18	2.57	1.98	.72	.18	1.26	1.04	.27	-----	-----	------	-----
.23	2.77	.25	1.61	.55	.74	.14	1.20	1.12	.65	-----	-----	------	-----
.26	1.51	.13	1.36	.50	.32	.13	16.9[a]	.80	1.10	-----	-----	26.0	-----
.23	1.87	.14	1.26	.63	.53	.16	.76	.93	.33	-----	-----	12.1	-----
<.02	1.86	.13	1.39	<.2	.23	<.02	.35	.99	.37	0.25	-----	12.8	-----
.72	3.32	.11	1.70	.35	.61	.07	.48	.97	.47	-----	-----	5.46	-----
.36	3.33	.08	1.95	.40	.24	.05	.40	.85	.27	-----	-----	.68	-----
<.02	<.2	<.02	1.08	1.23	.02	<.02	<.02	.96	.28	.23	0.56	1.45	-----
.10	.72	.04	1.15	3.27	.49	<.02	.30	.80	.22	.20	.34	<.02	-----
.58	<.02	.09	.94	2.21	.23	<.02	1.26	.99	.14	.31	.11	4.50	-----
<0.02	-----	.03	-----	2.83	-----	<0.02	-----	.76	-----	.24	-----	4.59	-----
.42	.56	.44	.85	1.87	<0.02	.34	.20	1.11	.12	.56	.25	4.06	-----
<.02	.80	<.02	.97	2.98	<.02	<.02	.26	.98	.21	.07	.27	9.44	-----
.51	.77	<.02	.97	-----	-----	<.02	.19	1.00	.15	.68	.23	24.4	8.10
<.05	.51	<.02	.73	-----	-----	<.02	.18	.95	.20	.14	.07	11.9	7.38
.25	.89	.08	.97	-----	-----	<.02	.35	.77	.20	.18	.27	38.6	6.11
.07	1.40	.13	.96	-----	-----	.18	1.54	.89	.32	.21	.10	38.1	1.97
.05	2.41	.32	.95	-----	-----	.47	2.29	.87	.24	.38	.10	33.1	2.07
.26	1.68	.18	.80	-----	-----	.09	.27	.58	.11	.36	.26	39.0	1.02
<.05	-----	.23	-----	-----	-----	.09	-----	.70	-----	.50	-----	24.1	-----
.46	1.74	.29	.86	-----	-----	<.02	.60	.79	.17	.54	.40	24.3	1.34
.18	1.10	.41	1.07	-----	-----	.05	.13	.70	.12	.93	.42	------	-----
<.05	1.32	.38	.84	-----	-----	.04	.17	.64	.20	.91	.56	34.1	-----
.47	1.82	.44	1.18	-----	-----	.09	.32	.59	.21	.64	.64	------	-----
.18	1.25	.27	1.21	-----	-----	<.02	<.02	.68	.26	.59	.86	31.8	5.73
.40	.06	.35	1.71	-----	-----	<.02	.16	.92	.36	.57	1.18	------	-----
.38	1.09	.23	1.78	-----	-----	.15	<.02	.58	.44	.31	1.00	19.2	11.5
.43	1.17	.03	2.17	-----	-----	<.02	<.02	.63	.49	.28	1.12	7.28	15.2
.14	1.09	.07	2.32	-----	-----	.07	.24	.38	.37	.22	1.53	14.3	7.04
1.20	1.58	.59	2.28	-----	-----	.84	-----	13.3[a]	-----	.67	-----	17.9	24.7
.24	4.07	.11	2.05	-----	-----	.07	.59	.28	3.76[a]	-----	.24	4.86	-----
.16	-----	.07	1.55	-----	-----	.09	<.02	.55	<.05	-----	-----	3.68	-----
.27	.44	.11	1.88	-----	-----	.12	.23	.32	.28	.25	1.05	------	-----
.09	.94	<.02	1.44	-----	-----	<.02	<.02	.19	.32	.15	.87	------	-----
.16	.27	.09	1.46	-----	-----	<.02	<.02	.31	.35	.17	.87	------	-----
<.02	.66	.07	1.31	-----	-----	<.02	<.02	.18	.22	.18	.71	------	-----
.17	.33	.06	1.32	-----	-----	<.02	<.02	.10	.34	.16	.77	------	-----
<.05	1.47	<.02	1.36	-----	-----	<.02	<.02	<.05	.23	.11	.71	------	-----
<.05	1.31	.04	1.19	-----	-----	.05	.12	.05	.24	<.05	.61	------	-----
.13	.38	.14	1.24	-----	-----	.08	.07	.07	.30	.27	.88	------	-----
<.05	<.02	.10	.92	-----	-----	.03	<.02	.14	.26	.15	.45	------	-----
<.05	.10	.14	.79	-----	-----	.07	.08	.17	.10	.25	.37	------	-----
.30	<.05	.11	.60	-----	-----	<.02	2.94[a]	.23	1.50	.14	<.05	------	-----

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Date	Chromium-51 Solute	Chromium-51 Particulate	Zinc-65 Solute	Zinc-65 Particulate	Scandium-46 Solute	Scandium-46 Particulate	Antimony-124 Solute	Antimony-124 Particulate	Cobalt-58 Solute	Cobalt-58 Particulate	Cobalt-60 Solute	Cobalt-60 Particulate
VANCOUVER, WASH.--Continued												
1966												
Aug. 1-3-5	6.31	14.9	1.17	9.32	0.04	1.56	0.04	<0.02	<0.05	0.12	0.03	0.26
Aug. 8-10-12	3.15	12.6	.63	6.94	.02	1.01	<.02	<.02	.07	.09	.04	.19
Aug. 15-17-19	36.0[a]	4.05	.68	5.86	<.02	.82	.05	<.02	<.05	.09	.04	.14
Aug. 29	6.31	7.66	.50	4.10	.03	.50	<.02	<.02	.08	.11	.05	.15
Sept. 2	7.66	--------	.81	3.15	.05	.45	<.02	<.02	<.05	.02	.05	.09
Sept. 4	7.21	3.60	.32	3.69	.23	.45	<.02	<.02	<.05	.19	.03	.14
Sept. 6	89.2	5.41	.45	3.83	.45	.40	.30	<.02	.10	.09	.05	.17
Sept. 9	812	14.9	.59	5.09	.99	.77	2.96	.09	.04	.03	.04	.16
Sept.12-14-16	1740	131	.59	5.90	1.44	.73	4.21	<.02	.38	.15	.08	.27
Sept.19-20-23	1740	58.6	.90	3.78	1.44	.50	4.06	<.02	.19	<.02	.07	.14

[1] Compositing periods vary from fractional parts of a day to two weeks.
[a] Questionable concentrations.

TABLE 1.—*Concentrations of solute (dissolved) and particulate radionuclides in composited water samples from the Columbia River*[1]—Continued

[In picocuries per liter of water]

Iron-59		Manganese-54		Barium-140		Zirconium-95-Niobium-95		Ruthenium-106		Cesium-137		Phosphorus-32	
Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate	Solute	Particulate
VANCOUVER, WASH.--Continued													
<0.05	<0.05	0.07	0.70	-----	-----	<0.02	0.10	0.27	0.17	<0.05	0.24	------	-----
.30	.45	.08	.62	-----	-----	<.02	<.02	.07	.08	.10	.22	------	-----
<.05	<.05	.05	.67	-----	-----	<.02	.09	.20	.08	<.05	.29	------	-----
.14	.25	<.02	.54	-----	-----	<.02	<.02	.08	.18	<.09	<.05	------	-----
<.05	<.05	.21	.29	-----	-----	<.02	.05	.22	<.05	.08	<.07	------	-----
<.05	.09	<.02	.48	-----	-----	<.02	<.02	.22	.07	<.05	.06	------	-----
<.05	.26	<.02	.63	-----	-----	<.02	.14	.09	<.05	.08	.15	------	-----
<.05	<.05	.04	.49	-----	-----	.07	.04	.12	<.05	<.05	<.05	------	-----
<.05	.14	<.02	.61	-----	-----	<.02	.03	.13	.05	<.05	.08	------	-----
<.05	1.06	<.02	.21	-----	-----	.03	.23	.36	<.05	.02	<.05	------	-----

TABLE 3.—*Quantity and percentage dissolved of chromium-51 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	51,000	...	43,000	47,000	...	35,000	29,000	22,000	19,000	94	...	95	89	...	92	95	95	96
February	44,000	...	35,000	39,000	...	32,000	23,000	21,000	18,000	93	...	96	86	...	91	92	95	96
March	51,000	...	30,000	41,000	...	30,000	36,000	25,000	20,000	94	...	95	91	...	93	95	96	96
April	49,000	...	30,000	41,000	...	36,000	23,000	22,000	22,000	92	...	95	87	...	90	94	95	95
May	44,000	...	40,000	36,000	18,000	33,000	27,000	28,000	26,000	91	...	89	87	91	85	93	94	93
June	44,000	...	45,000	38,000	23,000	35,000	23,000	22,000	22,000	90	...	80	91	87	87	95	90	90
July	34,000	...	33,000	34,000	29,000	22,000	4,900	6,800	9,000	93	...	91	91	91	90	88	86	87
August	43,000	...	29,000	32,000	28,000	23,000	4,600	4,200	300	92	...	97	94	95	95	93	93	62
September	46,000	...	24,000	36,000	27,000	21,000	29,000	20,000	10,000	92	...	97	92	96	97	93	93	96
October	48,000	...	31,000	34,000	22,000	15,000	...	...	...	90	...	96	85	94	97	...	...	...
November	46,000	...	24,000	33,000	22,000	18,000	...	...	...	94	...	96	91	95	96	...	...	...
December	55,000	...	40,000	32,000	20,000	25,000	...	...	...	91	...	94	94	96	96	...	...	...
Total	555,000	...	404,000	443,000	189,000	325,000	200,000	171,000	146,000	...	...	...	...	...	...	...	...	...
Mean daily	1,500	...	1,100	1,200	790	890	730	630	540	...	...	...	...	...	...	...	...	...
Average	...	...	...	...	...	...	...	...	...	92	...	93	90	93	92	93	93	90

TABLE 4.—*Quantity and percentage dissolved of zinc-65 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	1,100	...	310	1,500	...	720	780	410	240	85	...	35	84	...	18	86	70	47
February	910	...	300	1,800	...	940	880	550	320	77	...	33	80	...	21	84	78	57
March	1,200	...	260	2,500	...	950	1,400	690	420	79	...	23	82	...	36	80	54	38
April	1,200	...	420	2,400	...	1,400	1,100	540	480	74	...	14	78	...	20	51	29	23
May	1,900	...	1,400	2,100	1,100	1,400	1,600	960	900	60	...	6	72	55	10	50	21	8
June	1,800	...	1,800	1,600	1,000	1,400	1,000	1,000	1,200	58	...	7	64	39	8	48	9	5
July	1,100	...	810	880	630	720	390	540	490	67	...	6	56	19	5	48	7	7
August	730	...	230	500	290	180	130	130	89	58	...	9	19	9	8	23	6	10
September	640	...	87	410	150	77	560	140	40	50	...	16	14	13	19	22	12	14
October	980	...	140	380	130	51	...	...	...	72	...	18	22	10	11	...	...	...
November	1,100	...	180	470	140	61	...	...	...	84	...	40	64	32	18	...	...	...
December	1,500	...	680	700	300	130	...	...	...	84	...	33	83	71	39	...	...	...
Total	14,200	...	6,620	15,200	3,740	8,030	7,840	4,960	4,180	...	...	...	...	...	...	...	...	...
Mean daily	39	...	18	42	16	22	29	18	15	...	...	...	...	...	...	...	...	...
Average	...	...	...	...	...	...	...	...	...	71	...	20	60	31	18	55	32	23

TABLE 5.—*Quantity and percentage dissolved of scandium-46 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	190	...	66	240	...	110	110	65	43	23	...	15	18	...	10	37	30	21
February	180	...	56	270	...	160	150	83	51	17	...	12	15	...	10	30	32	26
March	220	...	53	250	...	130	190	88	62	18	...	13	19	...	13	31	25	19
April	270	...	81	350	...	200	180	92	81	12	...	14	12	...	7	19	21	20
May	340	...	280	350	130	220	290	190	160	9	...	7	11	10	7	16	14	11
June	300	...	410	240	160	210	240	340	280	12	...	4	15	7	5	17	7	5
July	210	...	190	230	110	120	76	110	90	19	...	6	9	7	4	15	5	5
August	180	...	52	150	65	36	32	20	12	13	...	9	8	6	7	9	7	3
September	180	...	22	120	31	12	250	23	5	9	...	12	7	8	12	4	9	17
October	190	...	35	140	38	9	...	...	...	12	...	12	10	9	10	...	...	...
November	120	...	31	140	54	20	...	...	...	18	...	17	17	13	15	...	...	...
December	190	...	68	130	53	36	...	...	...	16	...	16	27	27	17	...	...	...
Total	2,570	...	1,340	2,610	641	1.260	1,520	1,010	784	...	...	...	...	...	...	...	...	...
Mean daily	7.0	...	3.7	7.2	2.7	3.4	5.6	3.7	2.9	...	...	...	...	...	...	...	...	...
Average	...	...	...	...	...	...	...	...	...	15	...	11	14	11	10	20	17	14

TABLE 6.—*Quantity and percentage dissolved of antimony-124 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	16	...	12	32	...	25	30	25	24	92	...	84	90	...	95	99	99	99
February	21	...	18	60	...	48	29	27	27	87	...	84	92	...	95	98	99	99
March	26	...	18	90	...	68	54	40	35	93	...	89	94	...	97	97	99	98
April	34	...	23	81	...	95	42	48	47	92	...	96	88	...	96	97	91	99
May	63	...	47	94	50	94	82	96	92	73	...	94	87	94	94	97	97	97
June	59	...	66	70	55	73	83	80	88	91	...	89	92	92	94	88	85	83
July	42	...	39	59	52	47	15	16	23	86	...	91	81	96	94	92	90	97
August	29	...	25	40	38	35	10	11	1	92	...	95	86	96	98	92	98	64
September	25	...	19	32	34	33	40	34	25	93	...	96	86	97	99	89	99	99
October	26	...	21	34	31	20	...	...	...	89	...	99	93	99	99	...	...	...
November	25	...	17	36	29	27	...	...	...	95	...	99	97	99	99	...	...	...
December	31	...	28	34	24	25	...	...	...	93	...	97	98	99	98	...	...	...
Total	397	...	333	662	313	590	385	377	362	...	...	...	...	...	...	...	...	...
Mean daily	1.1	...	0.9	1.8	1.3	1.6	1.4	1.4	1.3	...	...	...	...	...	...	...	...	...
Average	...	...	...	...	...	...	...	...	...	90	...	93	90	97	97	94	95	93

TABLE 7.—*Quantity and percentage dissolved of cobalt-58 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	8	....	6	22	....	13	15	9	4	50	....	16	67	....	13	73	54	35
February	13	....	5	24	....	13	18	12	6	51	....	25	64	....	18	75	65	45
March	21	....	4	25	....	11	19	11	6	62	....	38	67	....	15	76	45	34
April	26	....	5	36	....	21	23	13	9	49	....	23	54	....	4	62	27	28
May	30	....	20	41	26	29	40	21	16	36	....	8	40	37	5	36	19	17
June	32	....	37	36	22	28	41	39	48	34	....	8	35	42	8	32	8	2
July	35	....	23	32	22	18	15	12	13	36	....	9	19	42	8	18	23	12
August	44	....	10	22	12	7	8	4	2	29	....	16	20	34	35	23	37	37
September	45	....	7	12	5	4	16	4	2	25	....	35	34	45	59	17	36	73
October	72	....	7	18	6	2	....	....	....	19	....	31	31	40	72	....	....	....
November	110	....	14	16	5	2	....	....	....	31	....	16	43	39	53	....	....	....
December	40	....	23	15	7	3	....	....	....	46	....	14	58	57	35	....	....	....
Total	476	....	161	299	105	151	195	125	106	....	....	....	....	....	....	....	....	....
Mean daily	1.3	....	0.4	0.8	0.4	0.4	0.7	0.4	0.4	....	....	....	....	....	....	....	....	....
Average	....	....	....	....	....	....	....	....	....	39	....	20	44	42	27	46	35	31

TABLE 8.—*Quantity and percentage dissolved of cobalt-60 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	6	....	4	14	....	7	8	5	2	61	....	15	62	....	9	64	44	19
February	13	....	4	15	....	9	10	7	3	52	....	17	67	....	7	67	58	23
March	14	....	4	17	....	9	15	9	5	61	....	20	69	....	13	70	32	10
April	15	....	7	27	....	16	17	11	7	46	....	13	58	....	9	53	22	11
May	36	....	37	21	12	20	29	25	17	23	....	4	37	29	6	44	33	5
June	50	....	58	21	16	22	23	33	30	13	....	3	29	30	4	25	20	3
July	18	....	20	15	11	14	10	14	13	27	....	4	14	24	4	11	14	5
August	15	....	8	12	7	4	4	4	3	33	....	11	13	19	14	14	14	16
September	10	....	3	10	4	2	9	4	2	25	....	32	19	17	15	11	14	27
October	17	....	4	10	4	2	....	....	....	23	....	27	22	14	21	....	....	....
November	11	....	3	8	4	2	....	....	....	25	....	18	30	7	12	....	....	....
December	12	....	6	9	4	2	....	....	....	50	....	14	50	32	10	....	....	....
Total	217	....	158	179	62	109	125	112	82	....	....	....	....	....	....	....	....	....
Mean daily	0.6	....	0.4	0.5	0.2	0.3	0.4	0.4	0.3	....	....	....	....	....	....	....	....	....
Average	....	....	....	....	....	....	....	....	....	37	....	15	39	22	10	40	28	13

TABLE 9.—*Quantity and percentage dissolved of iron-59 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	44	....	30	98	....	41	26	14	19	15	....	29	8	....	11	29	8	13
February	73	....	45	110	....	59	50	33	13	8	....	29	10	....	14	15	12	11
March	76	....	35	110	....	53	64	17	17	9	....	22	22	....	21	20	17	20
April	130	....	23	130	....	61	46	21	14	4	....	22	10	....	11	13	11	34
May	350	....	68	120	43	68	97	64	30	2	....	10	9	21	11	39	31	14
June	110	....	170	120	73	99	62	87	83	20	....	5	23	11	11	17	11	6
July	88	....	87	110	53	72	5	9	12	20	....	12	12	6	9	48	24	30
August	76	....	20	64	5	13	7	8	4	8	....	14	8	38	31	51	18	44
September	75	....	9	83	21	6	52	2	4	6	....	19	5	13	31	12	18	8
October	170	....	16	110	28	8	....	....	....	2	....	15	4	6	26	....	....	....
November	53	....	11	66	24	10	....	....	....	6	....	18	9	4	13	....	....	....
December	72	....	24	52	18	19	....	....	....	7	....	13	15	3	6	....	....	....
Total	1,320	....	538	1,170	265	509	409	255	196	....	....	....	....	....	....	....	....	....
Mean daily	3.3	....	1.5	3.2	1.1	1.4	1.5	0.9	0.7	....	....	....	....	....	....	....	....	....
Average	....	....	....	....	....	....	....	....	....	9	....	17	11	13	16	27	17	20

TABLE 10.—*Quantity and percentage dissolved of manganese-54 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	22	....	9	42	....	23	33	19	11	67	....	14	76	....	12	73	48	24
February	49	....	14	45	....	25	37	23	12	52	....	19	75	....	14	73	60	29
March	57	....	13	71	....	27	59	34	18	55	....	15	78	....	25	75	37	21
April	50	....	22	66	....	45	49	31	25	57	....	10	56	....	10	58	21	11
May	74	....	75	60	32	48	68	56	48	30	....	6	49	57	10	41	29	3
June	88	....	93	76	44	59	40	54	51	21	....	5	44	46	8	36	29	5
July	47	....	41	51	35	38	18	37	31	36	....	8	25	24	4	26	21	7
August	32	....	13	38	29	15	10	12	8	25	....	10	12	11	5	7	5	9
September	34	....	8	22	17	10	30	14	3	17	....	8	15	15	20	5	2	8
October	38	....	12	38	18	8	....	....	....	23	....	9	12	4	2	....	....	....
November	36	....	9	34	15	8	....	....	....	45	....	12	34	12	9	....	....	....
December	45	....	22	36	16	10	....	....	....	67	....	11	53	39	21	....	....	....
Total	572	....	331	579	206	316	344	280	207	....	....	....	....	....	....	....	....	....
Mean daily	1.6	....	0.9	1.6	0.8	0.9	1.3	1.0	0.8	....	....	....	....	....	....	....	....	....
Average	....	....	....	....	....	....	....	....	....	41	....	11	44	26	12	44	28	13

TABLE 11.—*Quantity and percentage dissolved of barium-140 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	......	......	......	120	......	34	......	......	......	......	......	......	74	......	59	......	......	......
February	......	......	......	4	......	5	......	......	......	......	......	......	78	......	55	......	......	......
March	58	......	9	70	......	20	......	......	......	83	......	92	97	......	51	......	......	......
April	290	......	38	81	......	42	......	......	......	83	......	89	82	......	68	......	......	......
May	160	......	54	120	66	32	......	......	......	87	......	75	69	55	53	......	......	......
June	210	......	64	71	39	28	......	......	......	40	......	39	94	74	45	......	......	......
July	100	......	46	59	44	23	......	......	......	80	......	58	95	94	78	......	......	......
August	92	......	30	91	72	41	......	......	......	94	......	83	98	91	90	......	......	......
September	97	......	23	110	71	23	......	......	......	91	......	87	100	89	97	......	......	......
October	180	......	29	......	......	......	......	......	......	83	......	92	......	......	......	......	......	......
November	110	......	35	......	......	......	......	......	......	93	......	95	......	......	......	......	......	......
December	130	......	31	......	......	......	......	......	......	72	......	80	......	......	......	......	......	......
Total	1,430	......	359	726	292	248	......	......	......	......	......	......	......	......	......	......	......	......
Mean daily	4.0	......	1.0	2.6	1.2	0.9	......	......	......	......	......	......	......	......	......	......	......	......
Average	......	......	......	......	......	......	......	......	......	81	......	79	87	81	66	......	......	......

TABLE 12.—*Quantity and percentage dissolved of zirconium-95–niobium-95 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	40	......	20	47	......	23	13	4	5	37	......	42	18	......	12	1	4	12
February	39	......	12	31	......	29	13	10	2	40	......	52	34	......	13	1	24	20
March	44	......	14	61	......	26	24	3	2	33	......	49	16	......	17	1	13	24
April	53	......	19	55	......	24	35	1	2	25	......	26	22	......	15	......	79	55
May	67	......	49	44	36	260	320	7	12	16	......	16	20	5	2	1	91	57
June	150	......	66	12	20	19	4	9	13	6	......	10	30	7	12	68	54	33
July	33	......	29	25	16	7	2	12	8	20	......	18	14	6	12	55	27	21
August	26	......	9	52	23	11	33	2	3	23	......	28	6	15	3	1	32	9
September	24	......	4	250	9	6	9	2	1	19	......	33	1	16	28	2	21	20
October	66	......	7	49	5	2	......	......	......	15	......	26	10	9	10	......	......	......
November	43	......	11	43	9	7	......	......	......	24	......	37	9	20	10	......	......	......
December	46	......	13	24	4	14	......	......	......	13	......	30	2	14	17	......	......	......
Total	631	......	253	693	122	428	453	50	48	......	......	......	......	......	......	......	......	......
Mean daily	1.7	......	0.7	1.9	0.5	1.2	1.6	0.2	0.2	......	......	......	......	......	......	......	......	......
Average	......	......	......	......	......	......	......	......	......	23	......	31	15	12	13	14	38	28

TABLE 13.—*Quantity and percentage dissolved of ruthenium-106 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	8	......	24	18	......	32	11	10	9	100	......	67	79	......	71	95	86	83
February	19	......	27	11	......	34	14	10	7	100	......	78	94	......	67	80	75	80
March	22	......	26	18	......	26	19	14	10	70	......	79	85	......	79	83	68	73
April	21	......	41	23	......	27	12	15	14	56	......	73	90	......	74	78	29	62
May	73	......	110	25	31	52	110	120	110	85	......	61	78	77	55	97	94	92
June	100	......	170	32	45	51	89	85	100	69	......	71	88	70	71	66	64	51
July	76	......	92	15	22	28	11	13	11	80	......	70	97	61	75	81	38	41
August	35	......	36	12	17	15	23	4	4	85	......	81	90	71	83	9	46	47
September	18	......	21	14	11	10	6	4	2	82	......	87	56	73	88	91	75	82
October	25	......	21	14	10	10	......	......	......	84	......	88	62	83	85	......	......	......
November	18	......	15	12	9	9	......	......	......	83	......	89	71	77	78	......	......	......
December	17	......	38	13	10	8	......	......	......	83	......	58	81	81	79	......	......	......
Total	432	......	621	207	155	302	295	275	267	......	......	......	......	......	......	......	......	......
Mean daily	1.2	......	1.8	0.6	0.6	0.8	1.1	1.0	1.0	......	......	......	......	......	......	......	......	......
Average	......	......	......	......	......	......	......	......	......	98	......	75	81	74	75	76	64	68

TABLE 14.—*Quantity and percentage dissolved of cesium-137 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January	......	......	......	......	......	......	25	15	9	......	......	......	......	......	......	95	78	60
February	......	......	......	......	......	......	33	21	12	......	......	......	......	......	......	98	84	63
March	......	......	......	......	......	......	38	27	16	......	......	......	......	......	......	91	55	43
April	......	......	......	......	......	......	26	18	18	......	......	......	......	......	......	76	25	26
May	......	......	......	......	......	......	31	32	32	......	......	......	......	......	......	75	43	25
June	......	......	......	......	......	......	17	5	22	......	......	......	......	......	......	95	60	37
July	......	......	......	......	......	4	17	18	20	......	......	......	......	......	30	55	23	21
August	......	......	......	12	8	7	7	6	3	......	......	......	61	51	51	22	22	25
September	......	......	......	11	4	5	5	4	1	......	......	......	76	46	62	82	15	39
October	......	......	......	10	5	5	......	......	......	......	......	......	61	31	65	......	......	......
November	......	......	......	13	5	3	......	......	......	......	......	......	93	61	51	......	......	......
December	......	......	......	21	11	5	......	......	......	......	......	......	96	80	68	......	......	......
Total	......	......	......	67	33	29	199	146	133	......	......	......	......	......	......	......	......	......
Mean daily	......	......	......	0.9	0.5	0.4	0.7	0.5	0.5	......	......	......	......	......	......	......	......	......
Average	......	......	......	......	......	......	......	......	......	......	......	......	77	54	55	77	45	38

TABLE 15.—*Quantity and percentage dissolved of phosphorus-32 monthly discharges for Columbia River stations*

[Station abbreviations: Pasco, Pasco, Wash.; Umat., Umatilla, Oreg.; Vanc., Vancouver, Wash.]

	Total discharge in curies									Dissolved discharge in percent of total discharge								
	1964			1965			1966			1964			1965			1966		
Month	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.	Pasco	Umat.	Vanc.
January							700	470	270							88	94	95
February							630	460	290							80	89	94
March							990	700	400							81	88	84
April							610	650	360							72	71	60
May					240	380	760	970	590							67	61	50
June				440	340	370	580	740	390							73	43	39
July				290	110	35												
August				200	98	35												
September				370	110	46												
October				510	320	200							63	44	73			
November				750	340	320							85	78	87			
December				1,000	600	330							93	95	96			
Total				3,560	2,160	1,720	4,270	3,990	2,300									
Mean daily				39	23	19	24	22	13									

TABLE 16.—*Ratios of discharges of dissolved radionuclides to total discharges of radionuclides at Columbia River stations based on data for the period May 1965 through June 1966*

		Ratio of discharge in dissolved state to total discharge				
		Extremes, 3–4 month averages[2]				
		Maximum		Minimum		
Radionuclide	Columbia River station[1]	Months	Percent	Months	Percent	Annual average[3] (percent)
Chromium-51	Pasco		94	May–July	90	91
	Umatilla		96	do	90	94
	Vancouver		96	do	87	94
Zinc-65	Pasco	Dec.–Feb.	84	Aug.–Oct.	18	56
	Umatilla	do	48	do	13	37
	Vancouver	do	48	May–Aug.	7	23
Scandium-46	Pasco	Jan.–Mar.	33	July–Sept.	8	19
	Umatilla	Dec.–Feb.	30	June–Aug.	7	17
	Vancouver	Jan.–Mar.	22	May.–Aug.	6	14
Antimony-124	Pasco		98	July–Sept.	84	94
	Umatilla		99	May–July	94	97
	Vancouver		99	do	94	98
Cobalt-58	Pasco	Jan.–Mar.	75	July–Oct.	26	47
	Umatilla	Dec.–Feb.	59	Apr.–June	18	42
	Vancouver	Sept.–Nov.	61	May–July	6	36
Cobalt-60	Pasco	Jan.–Mar.	67	July–Sept.	15	40
	Umatilla	do	45	Sept.–Nov.	13	28
	Vancouver	do	17	May–July	5	12
Iron-59	Pasco		32	Aug.–Nov.	6	16
	Umatilla		30	Oct.–Jan.	5	13
	Vancouver		30		6	18
Manganese-54	Pasco	Jan.–Mar.	74	Aug.–Oct.	13	43
	Umatilla	Dec.–Feb.	49	do	10	29
	Vancouver	Dec.–Mar.	15		6	13

[1] Pasco and Vancouver, Wash., and Umatilla, Oreg.

[2] A consecutive 3–4 month period of maximum or minimum ratios was not evident in data for some radionuclides.

[3] Average for period June 1965 through May 1966.

TABLE 18.—*Concentrations of dissolved and particulate*

[Concentrations: D, dissolved; P, particulate;

Date	Chromium-51		Zinc-65		Scandium-46		Antimony-124		Cobalt-58		Cobalt-60	
	D	P	D	P	D	P	D	P	D	P	D	P
Pasco, Wash.												
1963												
Oct. 7	10,300	631	103	59.5	5.36	34.9	....	....	....	....	....	....
Oct. 21	21,100	586	150	51.8	6.22	31.0	....	....	....	....	....	....
Nov. 5	14,100	1,440	177	111	13.0	63.1	....	....	....	....	....	....
Nov. 18	14,100	1,100	157	57.7	6.53	40.7	....	....	....	....	....	....
Dec. 2	17,800	910	228	68.5	9.77	42.0	....	....	....	....	....	....
Dec. 16	10,700	339	167	22.7	10.5	22.5	....	....	....	....	....	....
Dec. 30	13,400	775	222	47.7	11.4	43.2	....	....	....	....	....	....
Hood River, Oreg.												
1963												
Oct. 8	3,920	92.8	2.81	8.92	1.19	2.07	....	....	....	....	....	....
Oct. 22	3,400	94.6	2.62	11.4	1.15	2.12	....	....	....	....	....	....
Nov. 5	6,710	179	17.3	18.6	2.31	3.93	....	....	....	....	....	....
Nov. 19	4,390	374	5.68	26.8	1.69	15.8	....	....	....	....	....	....
Dec. 3	4,910	183	10.5	24.7	1.97	6.76	....	....	....	....	....	....
Dec. 17	3,860	201	16.6	24.1	1.75	8.83	....	....	....	....	....	....
Dec. 30	5,180	111	18.7	30.3	1.70	6.35	....	....	....	....	....	....
1964												
Jan. 14	6,350	200	18.8	30.0	.88	9.28	3.15	<0.36	0.20	1.41	0.10	0.74
Feb. 11	5,500	230	17.7	58.6	1.18	15.3	2.80	<.42	<.15	.90	.09	1.04
Feb. 25	5,680	310	28.1	24.7	1.97	8.15	1.87	<.38	.14	<.39	.16	.37
Mar. 10	4,200	182	17.5	20.8	1.07	4.25	2.37	<.36	.07	.48	.18	.39
Mar. 24	4,180	159	9.01	32.4	2.14	8.65	3.02	<.09	.24	1.00	.14	.56
Apr. 7	11,100	393	10.5	48.2	2.12	11.4	5.95	.10	.28	1.15	.10	.83
Apr. 21	4,300	190	6.44	55.4	1.74	10.1	3.25	.12	.14	.76	.12	.87
May 12	1,700	144	3.14	55.0	1.06	11.4	2.03	.08	.13	.95	.14	1.38
June 11	946	150	5.54	46.8	.51	10.4	1.54	.30	.08	.73	.05	1.28
July 21	1,160	67.6	2.94	24.0	.44	5.27	1.42	<.09	<.06	.97	.05	.61
Aug. 17	2,800	91.0	2.22	25.0	.53	4.73	2.25	<.09	.22	.77	.13	.47
Sep. 22	3,060	107	.73	11.2	.39	3.12	2.06	<.10	.33	.43	.11	.23
Vancouver, Wash.												
1963												
Oct. 7	2,280	70.3	2.32	6.71	1.01	0.99	....	....	....	....	....	....
Oct. 21	4,030	86.5	6.44	7.93	2.74	1.04	....	....	....	....	....	....
Nov. 4	5,230	122	3.52	8.65	2.14	1.55	....	....	....	....	....	....
Nov. 18	4,200	81.5	3.36	8.60	1.16	2.23	....	....	....	....	....	....
Dec. 2	5,000	223	4.82	21.2	1.49	5.32	....	....	....	....	....	....
Dec. 16	6,080	230	12.1	20.5	1.62	7.75	....	....	....	....	....	....
Dec. 31	5,000	107	12.1	16.4	2.07	3.72	....	....	....	....	....	....

radionuclides in water samples from the Columbia River
in picocuries per liter of water]

Date	Iron-59		Manganese-54		Barium-140		Zirconium-95–Niobium-95		Ruthenium-103–Rhodium-103		Ruthenium-106		Cerium-141	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Pasco, Wash.														
1963														
Oct. 7	....	....	....	....	....	....	4.32	6.26	10.0	2.03	....	....	15.5	4.14
Oct. 21	....	....	....	....	....	....	3.82	10.0	16.4	2.12	....	....	....	5.05
Nov. 5	....	....	....	....	....	....	20.2	16.4	62.6	5.77	....	....	2.87	6.08
Nov. 18	....	....	....	....	....	....	3.91	5.09	11.4	2.32	....	....	5.54	3.75
Dec. 2	....	....	....	....	....	....	7.07	7.48	19.4	5.41	....	....	....	6.98
Dec. 16	....	....	....	....	....	....	8.24	2.99	16.1	.94	....	....	2.95	2.85
Dec. 30	....	....	....	....	....	....	7.84	13.5	13.3	9.32	....	....	....	9.55
Hood River, Oreg.														
1963														
Oct. 8	....	....	....	....	....	....	0.73	1.31	5.27	0.59	....	....	0.71	0.23
Oct. 22	....	....	....	....	....	....	.85	1.09	5.50	.65	....	....	.71	.77
Nov. 5	....	....	....	....	....	....	.87	1.66	6.40	.95	....	....	....	1.33
Nov. 19	....	....	....	....	....	....	.93	2.51	5.86	1.79	....	....	1.12	2.39
Dec. 3	....	....	....	....	....	....	1.09	1.92	5.18	.67	....	....	.98	.79
Dec. 17	....	....	....	....	....	....	1.19	3.73	10.5	2.03	....	....	....	2.09
Dec. 30	....	....	....	....	....	....	1.18	1.88	8.78	8.29	....	....	....	17.9
1964														
Jan. 14	1.16	4.00	0.18	2.18	....	....	.67	11.3	....	....	2.81	0.55	....	....
Feb. 11	.79	9.01	.26	2.53	....	....	.63	2.43	....	....	2.56	.42	....	....
Feb. 25	1.50	7.79	.32	1.69	....	.....	.84	.96	....	....	2.34	.46	....	....
Mar. 10	.58	4.77	.37	1.66	7.43	....	1.11	1.60	....	....	2.47	.24	....	....
Mar. 24	2.30	3.09	.18	2.02	9.73	<0.33	2.51	3.20	....	....	2.10	.47	....	....
Apr. 7	.89	2.03	.30	2.89	21.6	2.51	.71	2.33	....	....	3.75	.70	....	....
Apr. 21	.62	2.09	.23	3.09	4.27	.67	.55	1.30	....	....	3.04	.89	....	....
May 12	.35	1.97	.19	3.27	4.82	1.54	.38	2.22	....	....	36.9	.79	....	....
June 11	.16	3.42	.17	1.85	.98	<1.06	.23	.77	....	....	2.94	1.68	....	....
July 21	.37	1.65	.10	1.33	1.90	<.30	.21	.47	....	....	2.17	.56	....	....
Aug. 17	.36	1.57	.14	1.18	3.65	<.24	.28	.52	....	....	2.77	.28	....	....
Sep.22	.21	1.35	.03	.95	2.93	<.51	.13	.95	....	....	1.56	.40	....	....
Vancouver, Wash.														
1963														
Oct. 7	....	....	....	....	....	....	0.43	1.22	5.18	0.54	....	....	2.15	....
Oct. 21	....	....	....	....	....	....	1.05	.89	5.27	.54	....	....	2.91	1.14
Nov. 4	....	....	....	....	....	....	1.21	1.29	6.13	.66	....	....	....	1.18
Nov. 18	....	....	....	....	....	....	1.13	.97	5.27	.44	....	....	2.64	.78
Dec. 2	....	....	....	....	....	....	.92	1.56	4.68	.76	....	....	5.86	1.27
Dec. 16	....	....	....	....	....	....	1.31	2.02	12.3	.67	....	....	....	1.52
Dec. 31	....	....	....	....	....	....	1.47	1.51	9.05	.73	....	....	....	1.83

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